MODEL TRAINING COURSE

on

Protected Cultivation, Post-Harvest Technology, Value Addition and Supply Chain Management in Potato

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Potato in India

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Potato (*Solanum tuberosum* L.) is one of the most important food crops after wheat, maize and rice, contributing to food and nutritional security in the world. This tuber crop of the family solanaceae has about 200 wild species. It originated in the high Andean hills of South America, from where it was first introduced into Europe towards the end of 16th century through Spanish conquerors. There the potato developed as a temperate crop and was later distributed throughout the world largely as a consequence of the colonial expansion of European countries. It was introduced to India by early 17th century probably through British missionaries or Portuguese traders.

Potato: The Crop and the Food

Potato is an annual, herbaceous, dicotyledonous and vegetatively propagated plant. It can also be propagated through botanical seed known as True Potato Seed (TPS). The potato tuber is a modified stem developed underground on a specialized structure called stolon. It contains all the characteristics of a normal stem like dormant bud (eye) and scaly leaf (eyebrow). Potato tuber is a bulky commodity which responds strongly to its prevailing environment thus needs proper storage. Potato is a highly nutritious, easily digestible, wholesome food containing carbohydrates, proteins, minerals, vitamins and high quality dietary fibre. A potato tuber contains 80 per cent water and 20 per cent dry matter consisting of 14 per cent starch, 2 per cent sugar, 2 per cent protein, 1 per cent minerals, 0.6 per cent fibre, 0.1 per cent fat, and vitamins B and C in adequate amount. Thus, potato provides more nutrition than cereals and vegetables. Keeping in view the shrinking cultivable land and burgeoning population in India, potato is a better alternative to deal with the situation.

Potato in India

In Europe the potato crop is grown in summer having long photoperiod of up to 14 hours and the crop duration of 140-180 days. The potato in Indian plains is, however, grown in completely contrasting situations. Nearly 85 per cent of the crop is grown during winters having short photoperiod (with about 10-11 hours sunshine) and the crop duration is also limited to 90-100 days because of short and mild winter. The mornings usually have fog, which further reduces the sunshine hours posing severe constraints on photosynthetic activity. Besides, the post-harvest period consists of long hot summer, which creates storage problems.

All these problems called for suitable varieties and technologies for growing potatoes under the sub-tropical conditions of India. This necessitated to initiate indigenous potato research and development programmes, and accordingly the Central Potato Research Institute (CPRI) came up in 1949 at Patna. The headquarters was later on shifted to Shimla in order to facilitate hybridization and maintenance of seed health. In 1971 the All India Coordinated Research Project (AICRP) on potato was initiated under the aegis of the Indian Council of Agricultural Research (ICAR) at the CPRI with an objective to coordinate potato research and development in the country across diverse agro-ecological regions. The success story of over five decades of potato research in India is phenomenal. Compared to the area, production and productivity in 1949-50, the increase over this period is 550 per cent, 1745 per cent and 178 per cent, respectively (Table 1). India now ranks fourth in potato area (1.48 million ha) and third in production (28.47 million tonnes) in the world with an average yield of 183,3q/ha.

Table 1: Area, Production & Yield of Potato in India

Year	*Area (million ha)*	*Production (million tones)*	*Productivity (q/ha)*
1949-50	0.239	1.54	65.9
1959-60	0.362	2.73	75.5
1969-70	0.496	3.91	78.9
1979-80	0.685	8.33	121.5
1989-90	0.940	14.77	157.1
1999-00	1.340	24.71	184.4
2003-04	1.270	23.12	182.0
2005-06	1.400	23.90	170.6
2006-07	1.482	22.09	149.0
2007-08	1.553	28.47	183.3
2008-09	1.810	28.58	157.8
2009-10	1.840	36.58	199.2
2010-11	1.860	42.34	227.2
2011-12	1.910	41.48	217.5
2012-13	1.992	45.34	227.8
2013-14	1.973	41.55	211.0
2014-15	2.075	48.01	231.0
2015-16	2.117	43.41	205.0
2016-17	2.164	46.54	215.0

It was only because of indigenously developed technologies that potato in India has shown spectacular growth in area, production and productivity during the last five decades. The major achievements of potato research in India are as under:

Varietal Improvement

So far 61 potato varieties have been bred for different agro-climatic regions of the country with 28 varieties alone for north Indian plains. Varieties have also been developed for north Indian hills and other special problem areas viz. Sikkim, north Bengal hills and south Indian hills. Most of these varieties possess resistance/tolerance to major pest and diseases. These are Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Himsona, Kufri Frysona, Kufri Jyoti, Kufri Chandramukhi, Kufri Lauvkar and Kufri Surya. All these varieties fall in three maturity groups, i.e. early (70-80 days), medium (90-100 days) and late (110-120 days). The potato varieties developed by CPRI are grown not only in India but also in several neighbouring countries. The variety Kufri Chandramukhi is grown in Afghanistan, Kufri Jyoti in Nepal and Bhutan, and Kufri Sindhuri in Bangladesh and Nepal. Besides, five Indian hybrids are also commercially grown in Sri Lanka, Madagascar, Mexico and Philippines.

Seed Plot Technique

This technique was developed in 1970s to enable healthy seed potato production in the sub-tropical Indian plains under low aphid period. This technique aided by bio-technological approaches for virus elimination, micro-propagation and effective viral diagnostics has sustained the National Potato Seed Production Programme by producing about 2600 tonnes of breeder's seed annually. This breeder's seed is further multiplied to about 4,32,000 tonnes of certified seed by the State Departments of Agriculture/ Horticulture. Thus, the country saves about 484 million US dollars because most Asian countries like Pakistan, Bangladesh and even China continue to import seed potatoes from Europe.

The decentralization of potato breeding from hills to plains in India through the seed plot technique enabled the development of varieties suited to different agro-climatic regions of the country. The area under seed potato production also increased by 12 times and enabled the availability of seed potato throughout the country in proper physiological state.

Tissue Culture

Efforts are being made to improve seed health standards and reduce the time required for production of breeder's seed by employing *in vitro* techniques of meristem culture and micro-propagation. Presently, about 5 per cent of Breeder's seed production programme is fed annually by microtubers produced through tissue culture. It is proposed to produce 100 per cent of breeder's seed through tissue culture propagated material in the years to come.

Agro-techniques

The development of package of practices for potato production in different agro-climatic zones has helped in improving potato productivity in these zones. The potato crop is input intensive and requires optimum cultural practices for achieving higher productivity. Optimum cultural practices depend on delineated phenological phases of crop growth and development viz. pre-emergence, emergence to tuber initiation, tuber initiation to tuber bulking and tuber bulking to termination of bulking.

The cultural practices are adjusted in the Indian plains in a way so that tuber initiation and development coincide with the period when night temperature is less than 20ºC and day temperature is below 30ºC. The phenological phase of tuber initiation to tuber bulking is mainly conditioned by nutrition and moisture. For this purpose, fertilizer and irrigation requirement in different agro-climatic zones have been worked out through multi-locational trials under AICRP (Potato). Termination of tuber bulking coincides with onset of foliage senescence. By manipulating the nutrition and moisture, the foliage senescence is delayed for ensuring continuation of linear tuber bulking phase resulting in higher yield.

Several profitable potato-based inter-cropping and crop rotations have also been identified for different regions of the country. Potato can be profitably intercropped with wheat, mustard and sugarcane. These cropping systems have helped in the maintenance of soil fertility and have improved the fertilizer economy, crop yield and gross returns. Besides, potato cultivation has also been mechanized in selected regions through the fabrication and development of cost-effective tools and implements.

Plant Protection

Effective management practices have been devised for the major potato diseases and insect-pests in India. Late blight is the most notorious disease of potato which occurs almost every year in the hills and plains. Besides chemical control measures, several late blight resistant varieties have been developed. Potato varieties have also been bred which possess resistance to wart and cyst nematodes. Cultural and biological control measures have also been developed to control the diseases and insect-pests. The development of late blight forecasting systems for hills and plains has enabled the early warning mechanism for the appearance of late blight disease.

Storage

In European countries, the potato crop is grown in summer and the main storage season is the cold winter. However, in India, 85 per cent of potato is produced in winter and stored during long hot summer. This requires storage of potatoes in cold stores at 2-4^{0}C, which involves substantial cost. It also leads to accumulation of reducing sugar in the potato tubers resulting in sweetening of potatoes. However, there are a number of traditional low-cost and non-refrigerated storage structures (essentially based on evaporative or passive evaporative cooling) in use in India with varying degrees of success. These traditional structures have been studied, validated and popularized for particular regions. In non-refrigerated storages, use of sprout suppressants has also been popularized to prevent excessive weight loss and shrinkage due to sprouting. The CIPC (isopropyl-N-chlorophenyl carbamate) is the most effective sprout inhibitor when applied @ 25 mg a.i. per kg tubers.

Processing and Value Addition

In addition to raw consumption, potatoes can be processed into several products like chips, French fries, cubes, granules and canned products. The primary determinants for potato processing include high dry matter and low reducing sugar content. A dry matter content of more than 20 per cent is desirable for chips, French fries and dehydrated products. Similarly, a reducing sugar content in tubers up to 100 mg/100g fresh weight is considered acceptable for processing. Nine varieties viz. Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Jyoti, Kufri Chandramukhi, Kufri Lauvkar, Kufri Surya and Kufri Himsona, Kufri Frysona have been developed for processing purposes. In India, potato processing in organised sector started about a decade ago, and the recent proliferation of this sector mainly results from the development of three indigenous potato processing varieties, viz. Kufri Chipsona-1 and Kufri Chipsona-3 by CPRI. These two varieties are now being used by the industries for processing into chips and French fries.

Computer Applications

Simulation modelling is now widely used in various disciplines to work out tactical decisions. CPRI has developed INFOCROP-POTATO model to simulate the potato growth and development, to determine the best growing period, to optimise management practices under different agro-ecological regions, and to forecast the accurate yield estimates. An expert system (Potato Pest Manager) has also been developed for decision support with respect to identification and management of diseases and insect-pests.

Transfer of Technology

Research achievements alone are not adequate to gauge the success of an agricultural system. The research information needs to be assessed and refined under various bio-physical and socio-economic situations through adaptive research before it is labelled as a technology. In this regard, the multi-locational trials under AICRP (Potato) and the TOT projects undertaken by CPRI such as Operational Research Project (ORP), Lab-to-Land Programme (LLP), Tribal Area Development (TAD) programme and Institution-Village Linkage Programme (IVLP) proved landmark in getting feedback from the field and development of appropriate technologies.

Transfer of technology to the end users is a complex task which consists of a number of components and dimensions. One of the important components is proper linkage between technology generating system and the client system. In this regard, innovative approaches like need assessment, participatory planning and implementation, and direct scientist-farmer interface facilitated faster dissemination of technologies and consequent adoption by the farmers/clients. The CPRI has build up linkages with farmers through demonstrations, trainings, Kisan Melas, potato school on All India Radio, supply of literatures and other extension activities. Besides, studies have been conducted to measure the socio-economic impact and constraints in transfer of potato technology.

Potato Export

Although India contributes 7.55% to the total world potato production, its 0.7% share in world's potato export is quite insignificant. Indian potatoes are truly free from the prohibited disease like wart, black scruf, and pests like tuber moth and nematodes, which are the barometer for phytosanitary standards. India has also the natural advantage of exporting fresh table potatoes during January to June when supply from European countries dwindles. It can also supply fresh potatoes round the year because India has diverse agro-climates and potato is grown throughout the year in one or the other part of the country. Potato has a good future in India under the changed scenario of global economy. Globalisation has resulted in many developing countries becoming much more integrated into the international potato trade. With the phasing out of quantitative restrictions on agricultural commodities, the imports and exports of potato would be based on the differences in price and production cost between the importing and exporting countries involved. Due to low production cost in the country as a result of the availability of cheap labour, India will have competitive advantage in the international potato trade.

Potato in the New Millennium

With the improvement in the living standard of people in India, the dietary habits will shift from cereals to vegetables. Under such a situation it is estimated that India will have to produce 49 million tonnes of potato by 2020. This target could be achieved only by improving the productivity level. The productivity of potato in India is quite low (183.3q/ha) as compared to that of Belgium (490q/ha), New zealand (450q/ha), UK (397q/ha) and USA (383q/ha). This is due to shorter crop duration in India. There is a wide ranging variations in the agro-ecological setting of different parts of the country, which results in wide variations in the productivity levels of different states (Table 2). Therefore, all our efforts may be put in to develop location-specific and problem-specific varieties and technologies.

Table 2: Major potato producing states in India during 2016-17

States	Area (,000 Hectares)	Production (' 000 Tonnes)	Productivity (q/ha)
Gujarat	112.40	3549.38	31.58
Haryana	36.29	964.80	26.58
West Bengal	422.50	11052.60	26.16
Punjab	96.57	2518.95	26.08
Telangana	4.27	110.88	25.96
Maharashtra	22.80	540.61	23.71
Uttar Pradesh	611.15	13916.00	22.77
Madhya Pradesh	156.20	3134.46	20.07
Bihar	320.47	6089.90	19.00
Jammu & Kashmir	6.91	127.24	18.42

Source: Directorate of Economics & Statistics, Govt. of India.

Most of the people in India have either no knowledge or wrong notions about the nutritive value of potato. With low fat (0.1 per cent) and calorie contents, it does not cause obesity. Due to misconception the potato consumption, the per capita consumption of potato in India is only about 16 kg/year. On the other hand, the per capita consumption in Europe is 121 kg/year and as high as 136 kg/year in Poland. Hence, there is ample scope for improving the consumption of potatoes in India. For this purpose, a publicity compaign like eggs and milk needs to be launched through mass media such as television, radio and newspapers highlighting its nutritional value. Moreover, the possibility of using surplus potatoes as animal feed also needs to be explored.

The surplus potatoes in a season are stored in cold stores at 2-4ºC in the country. This makes stored potatoes just unfit for processing and loses preference for table purposes due to accumulation of sugar content. To avoid sweetening potato are required to be stored at 10-12ºC. Only seed potatoes should be cold stored at 2-4ºC. This would release atleast 60 per cent of cold storage space that can be converted to store potatoes for processing and table purposes at 10-12ºC with CIPC treatment leading to considerable savings on energy and storage costs.

Processing is a fast growing sector in the potato world economy. Due to increased urbanization, rise in per capita income and expanding tourism, the demand for processed potato products in India and international market has risen at a fast pace. However, in India, processing of potatoes constitutes less than 2 per cent of the total annual production as compared to 60 per cent in USA, 47 per cent in the Netherlands and 22 per cent in China. Hence, there is great scope to expand the potato processing industries in India and also to diversify the processing to produce flour, cubes, granules, flakes and starch.Under the changed global scenario, the potato production and utilisation pattern is changing very fast. These changes harbour many opportunities which could be tapped through effective extension system. The use of modern information and communication technologies (ICT) to create awareness is highly pertinent in the contemporary times. This would enable us to reach directly to the end users by eliminating the intermediate channels which create distortion of information. Efforts are also needed to devise market-based extension strategies in order to promote entrepreneurship among potato growers with regard to potato production and marketing.

Introduction of different potato varieties and their development

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One of the most important factors governing productivity of a crop is the 'variety'. Thus breeding of improved cultivars is of paramount importance. Variety development, however, is a continuous process as new biotic and abiotic stresses continue to arise and the variety previously resistant or tolerant to such stresses may become susceptible due to the evolving of new strains/races of the pathogens or insects and also due to emerging abiotic factors. Performance of a variety depends on the agro-climatic conditions under which it is grown and also the purpose for which it has to be used. Thus the CPRI has been developing potato varieties suitable for cultivation under varying agro climactic zones of the country and also for different purposes i.e. table and processing.

Ecological zones and varietal requirements:

India has diverse soil types and agro-climatic conditions. Successful potato cultivation requires night temperatures of 15-20oC with sunny days. Indian sub-tropical plains offer optimum conditions for potato cultivation, where 85-90 per cent of potatoes are grown during short winter days from October to Feb. The hills account for less than 5 per cent of the total potato production where the crop is grown during long summer days from April to September/October. The plateau regions of South-eastern, central and peninsular India constitutes about 6 per cent area where potato is grown mainly as rainfed or irrigated winter crop. On the basis of the diverse soil, climate and other agronomic features, the potato growing areas in India can be divided into eight zones (Table-1). These zones lay in two major potato growing areas i.e. north Indian hills and north Indian plains, while southern and north Bengal and Sikkim hills and plateaus are three special problem areas. The varietal requirements of these regions are given in Table 1

Table 1. Potato growing zones in India and their varietal requirements

Zone	Varietal requirements
North-western hills	Long day adapted , highly resistant to late blight
Central hills	Long day adapted, highly resistant to late blight and bacterial wilt
North-eastern hills	Long day adapted, highly resistant to late blight and bacterial wilt.
North-western plains	Short day adapted, early bulking, heat tolerance and moderate resistant to late blight, slow rate of degeneration. Tolerance to frost is an added advantage.
West-central plains	Short-day adapted, early bulking, moderate resistant to late blight and slow rate of degeneration. Tolerance to frost is an added advantage.
North-eastern plains	Short day adapted, early bulking, moderate resistant to late blight and slow rate of degeneration. Red skin tubers are preferred in some areas.
North Bengal hills and Sikkim	Medium maturity, resistance to late blight and immunity to wart. Red skin potatoes are preferred.

Plateau region	Early bulking, ability to tuberize under high temperatures, resistance to bacterial wilt, mites & potato tuber moth and slow rate of degeneration.
Southern hills	Long day adapted, early bulking, resistant to late blight and cyst nematode.

Quality attributes of potato for table and processing purposes: Marketability of potato produce is a function of its quality. Appearance, colour, size, shape and defects decide the quality for fresh potato. Total solids or dry matter is highly correlated with texture. On the basis of dry matter and texture, potatoes can be used for different purposes. A mealy texture is associated with high solids and a waxy texture with low solids. Mealy textured varieties are usually considered best for baking or French fries. Varieties with waxy texture are more often used for boiling or as salad. In India, mostly white, yellow or red skinned varieties with shallow or medium eyes are the choice of the consumers. Interest now seems to be shifting towards yellow fleshed varieties. More yellow flesh color is indicative of the higher level of vitamin A. Yellow fleshed varieties have a richer flavour than traditional white fleshed varieties and exhibit less darkening after cooking than some red skinned varieties. Specific characteristics of potato varieties for different purposes are listed in Table 2.

The varieties should be widely adaptable, resistant to major diseases and pests, possess good keeping quality and can be used either for table or processing or both. Varieties should produce attractive, medium sized, shallow eyed, white, yellow or red skinned tubers, less physical injuries with good keeping and nutritional quality. For processing purposes varieties should possess high dry matter, low reducing sugars and less tuber defects for producing quality processed potato products. Low glycoalkaloids content and ability to withstand cold induced sweetening are added advantages.

Table 2. Requirement of potato varieties for different purposes

Characters	Use requirements			
	Table potatoes		Processing	
	Boiled	Baking	French fries	Chips
Tuber shape	Long-oval/round	Long-oval/round	Long-oval (>3 inch)	Round (2.5-3.3 inch)
Skin color	White/yellow/ Red	White/yellow /red	White/ yellow	White/ yellow
Eye depth	Shallow/ medium	Shallow/ medium	Shallow	Shallow
Flesh color	White/yellow	White/ yellow	White/yellow	White/yellow
Texture	Waxy	Mealy	Mealy	Mealy
Uniformity	High	High	High	High
Defects	Minimum	Minimum	Minimum	Minimum
Dry matter (%)	18-20	>20	>20	>20
Reducing sugars*	-	-	<200mg	<100mg
Phenols	Less	Less	Less	Less
Glycoalkaloids *	< 15mg	< 15mg	< 15mg	< 15mg
Keeping quality	Good	Good	Good	Good
Damage resistance	High	High	High	High

*mg/100g fresh tuber weight

Potato Improvement:

Basics: Cultivated tuber-bearing potato is a clonally propagated crop and maintained over generations through tuber seeds. The plant is tetraploid (2n=4x=48) with a complex tetrasomic inheritance combined with high degree of heterozygosity. Pure line breeding is not practiced in potato owing to heterozygosity and high degree of pollen sterility. Selfing of fertile clones results in inbreeding depression. Conventional potato breeding within the ploidy levels involves hybridization between superior clones followed by selection. The vegetative mode of propagation offers distinct advantages. It leads to the perpetuation of a specific gene-combination with precision over generations, thus allowing the breeders to select and maintain, with ease, outstanding segregants in breeding programme and obtain indefinite number of genetically identical individuals. Various hybridization methods like distant crossing, some time followed by back-crossing, bi-parental cross, multiple cross and poly-cross are usually utilized in potato breeding. Besides the above traditional approaches, non-conventional methods are also used in potato breeding and germplasm improvement programmes taking advantages of diversity in reproductive biology like synaptic mutants, unilateral sexual polyploidization, haploidy, stylar barriers, endosperm barriers, endosperm balance number (EBN) etc. Many a times, dihaploids are evolved for production of homozygous lines or for pre-breeding at diploid level for transferring desired traits through transgression.

Early attempts: From its initial status of a garden vegetable in Western India in early 17th century, potato cultivation spread to diverse eco-zones in India over the next two and a half centuries. Early potato introductions in India were S. tuberosum ssp. andigena. There was enormous confusion regarding the identity and nomenclature of these introductions as these were known by different local names in diverse dialects. As a result, during the initial periods of potato research in India, efforts were directed towards identification of such local "desi varieties". Based on the studies on various morphological features, duplicate samples were eliminated, and subsequently a few samples were got identified with the help of Potato Synonym Committee, National Institute of Agricultural Botany, England. These efforts led to the identification and characterization of 16 non-European varieties, which came to be known as desi or indigenous samples or varieties. These indigenous samples represent survivors of earlier introductions and chance selections in the Indian agro-climates. A list of these indigenous varieties with their salient attributes is presented in Table 3.

Table 3: Indigenous potato varieties/samples in India

Varieties/samples	Salient features
Agra Red, Chamba Red, Coonoor White, Coonoor Red, Darjeeling Red Round, Desi, Dhantauri, Gola Type A, Gola Type B, Gola Type C, Phulwa, Phulwa Purple Splashed, Sathoo, Red Long Kidney, Shan and Silbilati	Heat and drought tolerant, therefore cultivated predominantly in the Indian plains; tolerant to degenerative viruses; due to physiological advantages can be stored in country stores during hot Indian summers

Source: Pushkarnath (1969). Potato in India-Varieties, Indian Council of Agricultural Research, New Delhi, 493, pp.

Among these, Phulwa, Darjeeling Red Round and Gola, were found to be the most popular ones. These types though no more the mainstream varieties under cultivation now in our country, yet they enjoy consumer preference in small pockets atleast in Eastern India. Besides the indigenous, 38 17 European varieties were identified from whatever were under cultivation in India before independence. These are referred to as exotic varieties. Not all exotic varieties, however, were commercially important. Only 16 of these had some commercial value (Table 4).

These exotic European varieties were naturally long-day adapted and, therefore, their cultivation was restricted to the hills of the Indian sub-continent.

Table 4: Exotic potato varieties in India

Varieties	Salient features
Ally, Arran Counsal, Ben Cruachan, Craig's Defiance, Dunbar Cavalier, Great Scot, Italian White Round, Late Carman, Magnum Bonum, Majestic, Northern Star, President, Raeburn's Gregor Cups, Red Rock, Royal Kidney and Up-to-Date	Long-day adapted, therefore suitable for the Indian hills only; multiplication was characterized with progressive accumulation of degenerative viral diseases; physiological limitations on tuber storage and utilization in hot Indian summers

Source: Pushkarnath (1969). Potato in India-Varieties, Indian Council of Agricultural Research, New Delhi, 493pp.

National breeding Programme: During earlier phase varietal improvement for potato was a challenge to breeders in India because:
i) The introduced European varieties were all long day adapted,
ii) Their multiplication in Indian conditions was characterized by progressive accumulation of viral diseases resulting in concomitant decrease in yield, and
iii) Limitations in tuber storage and utilization in hot and humid Indian conditions.

The task was further complicated by unique reproductive features of the plant since it flowers only under long days. This condition is available in the higher elevations and hence potato hybridization was initiated at Kufri (Shimla), Himachal Pradesh. Initial attempts for breeding high yielding potato hybrids for sub-tropical plains and temperate hills was unsuccessful owing to quick degeneration of hill bread progenies in the plains during evaluation and also dormancy of hill potatoes. These bottlenecks did not allow any clonal evaluation in the plains during the appropriate season.

A regular potato breeding programme in India was started in 1949 by Central Potato Research Institute (CPRI). Its headquarters were shifted from Patna, Bihar, to Shimla, Himachal Pradesh in 1956. With perfection of seed plot technique in 1963, it now became possible to raise, maintain and evaluate segregating populations in the plains under disease-free low aphid periods. The hybridization continued to be done in high hills at Kufri. This approach brought in positive results from potato improvement programme and also revolutionized the potato seed production system in the country.

Indian potato varieties: Concerted breeding efforts of potato varietal improvement programmes at Central Potato Research Institute has led to development of 51 improved potato varieties for cultivation under diverse agroclimatic zones of the country. Presently 23 varieties are under cultivation and occupy nearly 95% of the total potato area in India. Prominent among them are Kufri Jyoti in the hills and state of West Bengal, Kufri Badshah in Gujarat, Kufri Bahar in Uttar Pradesh and Kufri Pukhraj in plains of

India. Varieties for specific problem areas are Kufri Kanchan for Darjeeling hills where wart is a serious problem and Kufri Swarna for Nilgiri hills where cyst nematodes are serious pests. Varieties specifically suitable for processing are Kufri Chipsona-1, Kufri Chipsona-3, Kufri Chipsona-4 for making chips and Kufri Frysona for French Fries. The salient features of some important varieties along with their distinguishing morphological features helpful in their identification are described below.

Important Table varieties:

Kufri Jyoti: It is a medium maturing widely adapted variety suitable for cultivation in hills, plains as well as plateau regions of India. It is moderately resistant to early and late blight and immune to wart. It has white cream, ovoid tubers with shallow eyes and cream flesh. Its canopy is compact and stem green with red brown pigment highly scattered throughout. Leaflet is ovate, flowers are white and sprouts redpurple. It is an early bulker with slow rate of degeneration.

Kufri Bahar: It is a medium maturing variety suitable for cultivation in north Indian plains. It is immune to wart and tolerant to gemini virus. It has white cream, ovoid tubers with medium-deep eyes and white flesh. Its canopy is semi-compact and stem green. Leaflet is ovate-lanceolate, flowers are white and sprouts green. It is an early bulker.

Kufri Badshah: It is a medium maturing variety suitable for cultivation in north Indian plains as well as plateau regions of India. It is resistant to early blight, late blight and PVX. It has white cream, ovoid tubers with shallow eyes and cream flesh. Its canopy is semi-compact and stem green with red brown pigment highly scattered throughout. Leaflet is ovate-lanceolate, flowers are white and sprouts redpurple.

Kufri Pukhraj: It is an early to medium maturing variety suitable for cultivation in northern plains as well as plateau regions of India. It is resistant to early blight, moderately resistant to late blight and immune to wart. It has yellow, ovoid tubers with medium-deep eyes and yellow flesh. Its canopy is semicompact and stem green with purple pigment highly scattered throughout. Leaflet is ovate-lanceolate, flowers are white and sprouts purple. It is an early bulker and suitable for low-input eco-system.

Kufri Khyati: It is an early maturing variety suitable for cultivation in northern plains of India. It is field resistant to early blight and late blight. It has white cream, ovoid tubers with medium-deep eyes and cream flesh. Its canopy is semi-compact and stem green with purple pigment lightly scattered throughout. Leaflet is ovate-lanceolate, flowers are white and sprouts red-purple. It is an early bulker and suitable for high cropping intensity.

Kufri Sadabahar: It is a medium maturing variety suitable for cultivation in Uttar Pradesh and adjoining areas. It is moderately resistant to late blight. It has white cream, ovoid tubers with shallow eyes and 19 white flesh. Its canopy is compact and stem green with purple pigment highly scattered throughout. Leaflet is ovate-lanceolate, flowers are white and sprouts red-purple.

Kufri Chandramukhi: It is an early maturing variety suitable for cultivation in northern plains as well as plateau regions of India. It has white cream, ovoid tubers with shallow eyes and white flesh. Its canopy is semi-compact and stem green with red-brown pigment highly scattered throughout. Leaflet is ovatelanceolate, flowers are red-violet and sprouts red-purple. It has very good cooking quality.

Kufri Ashoka: It is an early maturing variety suitable for cultivation in northern plains of India. It has white cream, ovoid tubers with medium-deep eyes and white cream flesh. Its canopy is semi-compact and stem green. Leaflet is ovate-lanceolate, flowers are red-violet and sprouts red-purple.

Kufri Jawahar: It is an early maturing variety suitable for cultivation in northern plains as well as plateau regions of India. It is moderately resistant to late blight and immune to wart. It has white cream, round tubers with medium-deep eyes and cream flesh. Its canopy is compact and stem green. Leaflet is ovate, flowers are white and sprouts red-purple. It has slow rate of degeneration and is suitable for inter-cropping.

Kufri Anand: It is a medium maturing variety suitable for cultivation in northern plains of India. It is moderately resistant to late blight and immune to wart. It has white cream, oblong tubers with shallow eyes and white flesh. Its canopy is semi-compact and stem green with purple pigment lightly scattered throughout. Leaflet is ovate, flowers are red-violet and sprouts red-purple.

Kufri Sutlej: It is a medium maturing variety suitable for cultivation in northern plains of India. It is moderately resistant to late blight and immune to wart. It has white cream, ovoid tubers with shallow eyes and white flesh. Its canopy is semi-compact and stem green with purple pigment lightly scattered throughout. Leaflet is ovate-lanceolate, flowers are white and sprouts green.

Kufri Sindhuri: It is a late maturing variety suitable for cultivation in northern plains of India. It is moderately resistant to early blight. It has red with stippled white cream, round tubers with deep eyes and cream flesh. Its canopy is open and stem green with purple pigment highly scattered throughout. Leaflet is lanceolate, flowers are red violet and sprouts purple. It is suitable for low-input system.

Kufri Lalima: It is a medium maturing variety suitable for cultivation in northern plains of India. It is moderately resistant to early blight. It has red, round tubers with deep eyes and white flesh. Its canopy is semi compact and stem red-purple with green pigment lightly scattered throughout. Leaflet is ovate lanceolate, flowers are red-violet and sprouts red-purple.

Kufri Arun: It is a medium maturing variety suitable for cultivation in north Indian plains. It is moderately resistant to late blight. It has white red, ovoid tubers with medium-deep eyes and cream flesh. Its canopy is semi-compact and stem red-purple with green pigment highly scattered throughout. Leaflet is lanceolate, flowers are red-violet and sprouts red-purple.

Kufri Kanchan: It is a medium maturing variety suitable for cultivation in north Bengal hills as well as Sikkim. It is moderately resistant to late blight and immune to wart. It has red, ovoid tubers with shallow eyes and cream flesh. Its canopy is semi-compact and stem red-purple with green pigment highly scattered throughout. Leaflet is ovate-lanceolate, flowers are blue-violet and sprouts pink.

Kufri Girdhari: It is a medium maturing variety suitable for cultivation in Indian hills. It is highly resistant to late blight. It has white cream, ovoid tubers with shallow eyes and white flesh. Its canopy is open and green stem. Leaflet is ovate-lanceolate, flowers are white and sprouts pink.

Kufri Himalini: It is a medium maturing variety suitable for cultivation in north Indian hills. It is resistant to late blight. It has white cream, ovoid tubers with medium-deep eyes and cream flesh.

Its canopy is semi-compact and stems green with red pigment only at base. Leaflet is ovate, flowers are red-violet and sprouts pink.

Kufri Lauvkar: It is an early maturing variety suitable for cultivation in plateau regions of India. It has white cream, round tubers with medium-deep eyes and cream flesh. Its canopy is semi-compact and stem green with purple pigment lightly scattered throughout. Leaflet is ovate, flowers are white and sprouts red-purple. It is heat tolerant.

Kufri Surya: It is an early maturing variety suitable for cultivation in northern plains as well as plateau regions of India. It is immune to wart. It has white cream, oblong tubers with shallow eyes and cream flesh. Its canopy is semi-compact and stem green with purple pigment lightly scattered throughout. Leaflet is ovate-lanceolate, flowers are red-violet and sprouts red-purple. It is heat tolerant.

Kufri Gaurav: It is an early maturing variety suitable for cultivation in north Indian plains. It has white cream, ovoid tubers with medium-deep eyes and white cream flesh. Its canopy is semi-compact and green stem. Leaflet is ovate-lanceolate, flowers are white and sprouts green. It is nutrient–use efficient variety.

Kufri Garima: It is an early maturing variety suitable for cultivation in north Indian plains and plateau regions. It has attractive light yellow, ovoid tubers with shallow eyes and light yellow flesh. Tubers do not show deformities like cracking or hollow heart. Its canopy is compact, stem predominantly green with red-brown pigment only at base. Leaflet width medium and ovate-lanceolate, flowering profuse, corolla white and sprouts red purple.

Important Processing varieties:

Kufri Chipsona-1: It is a medium maturing variety suitable for cultivation in north Indian plains. It is resistant to late blight. It has white cream, ovoid tubers with shallow eyes and white cream flesh.

Its canopy is semi-compact and stem green. Leaflet is ovate-lanceolate, flowers are white and sprouts green. It has high dry matter and low reducing sugars and produces light colour chips.

Kufri Chipsona-3: It is a medium maturing variety suitable for cultivation in north Indian plains. It is resistant to late blight. It has white cream, ovoid tubers with shallow eyes and white flesh. Its canopy is semi-compact and stem green with red-brown pigment only at base. Leaflet is ovate-lanceolate, flowers are white and sprouts red-purple. It is suitable for making chips as well as French Fries because it has high dry matter and low reducing sugars.

Kufri Chipsona-4: It is a medium maturing variety suitable for cultivation in Karnataka, West-Bengal and Madhya Pradesh. It is field resistant to late blight. It has white cream, round tubers with shallow eyes and white flesh. Its canopy is compact and stem green with red-brown pigment lightly scattered throughout. Leaflet is lanceolate, flowers are white and sprouts red-purple. It has high dry matter and low reducing sugars, and thus suitable for making chips.

Kufri Frysona: It is a medium maturing variety suitable for cultivation in north Indian plains. It is field resistant to late blight and immune to wart. It has white cream, long-oblong tubers with shallow eyes and white flesh. Its canopy is open and stem green with purple pigment highly scattered throughout. Leaflet is ovate-lanceolate, flowers are red-violet and sprouts red-purple. It has high dry matter and low reducing sugars and suitable for making French Fries.

Variety improvement programme of CPRI for over 50 years has been instrumental in fourteenfold increase in total production and three-fold increase in yield per unit area in the country. Many Indian varieties have found favour in foreign countries as well.

These are: I 654 as CCM-69.1 in Mexico, I-822 as cv.Krushi in Sri Lanka, I-1035 as cvs. Montonosa in Philippines and Mailaka in Madagascar, I-1039 as cvs. India in Bolivia and Red Skin in Vietnam and I-1085 as cvs Sita in Sri Lanka and BSUP-04 in Philippines. Further, Indian potato varieties enjoy a high degree of consumer preference in our neighbourhood. There is enormous scope for export of potato for seed and table use to these countries. But Indian potato varieties so far had an extremely limited evaluation on foreign soils. Therefore, a systematic study on adaptability of varieties in the Indian ocean rim countries, the middle East, S.W. Asia, CIS countries and Eastern Europe needs to be the major thrust of any further potato development programme.

Suggested readings

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Adoption and impact of improved potato varieties in India

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India is predominantly an agriculture based country in which agriculture and allied activities contributes about 17 per cent to the country's Gross Value Added and provides employment to about 54.6 per cent of the population. Potato plays a very important role in Indian agriculture as potato alone contributes about 21 per cent of the total vegetable area and 26 per cent of total vegetable production in India. Potato is a nutrient-rich crop which provides more calories, vitamins and nutrients per unit area than any other staple crops. FAO declared potato as the crop to address future global food security and poverty alleviation during 2008. As per FAOSTAT data for the year 2017, India with 48.6 million t is ranked second in potato production in the world, only behind China with 99.2 million t. The productivity in India is higher than in China and Russia, the third-largest potato producer. However, the productivity is lower than most of the developed European countries. One of the major reasons is that, in Europe, potato crop is grown in summer having long photoperiod of up to 14 hours and the crop duration of 140-180 days. The potato in Indian plains is, however, grown in completely contrasting situations. Nearly 85 per cent of the crop is grown during winters having short photoperiod (with about 10-11 hours sunshine) and the crop duration is also limited to 90-100 days because of short and mild winter.

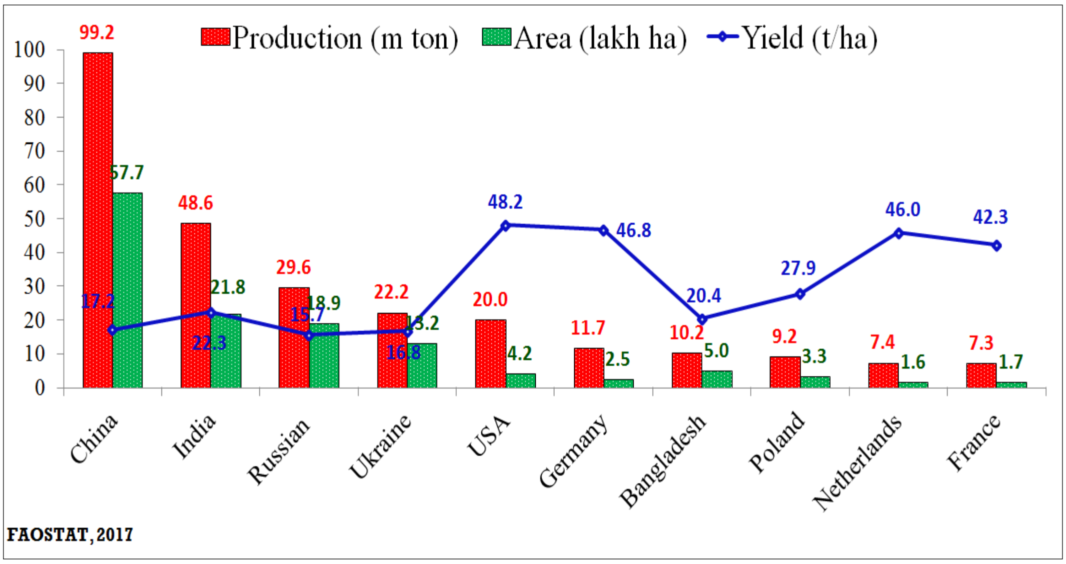
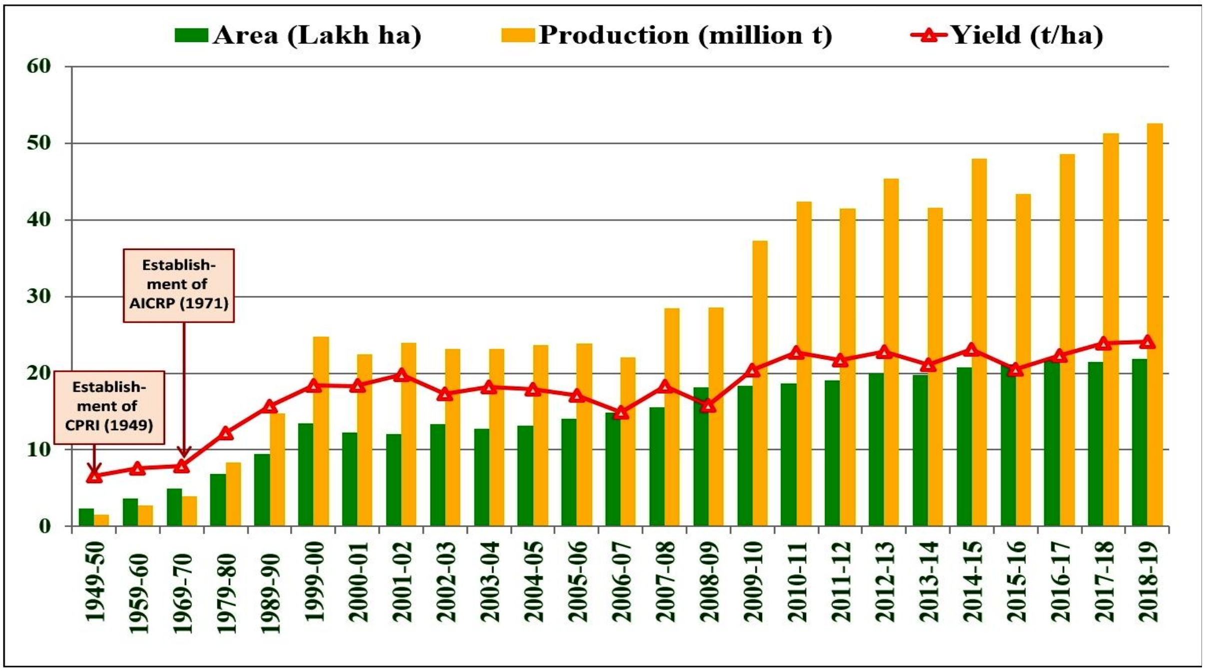


Fig.1: Top 10 potato producers in the world

Trends in area, production and productivity of potato in India

At the time of inception of CPRI, in the year 1949, India produced only 1.54 million t potatoes from 0.234 million ha area at an average productivity level of 6.58 t/ha. As per the 1st advance estimates by National Horticulture Board, the potato production in India during 2018-19 was 52.6 million t from 2.18 million ha area with a productivity of 24.13 t/ha. Over the period of 1949-50 to 2018-19, the compound annual growth rate (CAGR) in potato area, production and yield were 3.3 per cent, 5.4 per cent and 2.0 per cent per annum, respectively. It is the hard work of potato farmers, scientists and policymakers that potato area, production and productivity increased over 7 decades by 8.5, 34.06 and

3.65 times, respectively. Contribution of CPRI and AICRP on Potato has been adequately recognised by the nation on several occasions.



Compound Annual Growth Rate (%) of area, production and yield of potato in India			
Year	Area	Production	Yield
2009-10 to 2018-19	2.1	3.2	1.1
1949-50 to 2018-19	3.3	5.4	2.0

Fig. 2: Trends in area, production and yield of potato in India

Adoption of improved potato varieties in India

The adoption of improved potato varieties is critical for achieving sustainable and higher productivity and production. So far, Central Potato Research Institute, Shimla has developed 58 potato varieties for different agro-climatic regions of the country and majority of them are for north Indian plains. Potato varieties developed by CPRI are very popular among farmers and cover nearly 95% of total area under potato. Four varieties, viz. Kufri Jyoti, Kufri Bahar, Kufri Pukhraj, and Kufri Chipsona1 together contributed around 75% of total area under potato. The varietal adoption patterns of potato varieties in major producing states are as follows:

Uttar Pradesh: The study conducted during 2016-17 crop season showed that overall, varieties like Kufri Bahar (38 % of potato area), Kufri Pukhraj (21 %), Kufri Khyati (12 %) and Kufri Chipsona-1 (9 %) were the leading potato varieties in Bulanshahr and Meerut district of Uttar Pradesh.

West Bengal: The survey conducted in Bardhaman and Hooghly districts of West Bengal for 2017-18 crop season revealed that overall, Kufri Jyoti (52 % area) was the most popular variety, which was followed by Kufri Chandramukhi ((18 %) and Kufri Pukhraj (16.2 %).

Bihar: A survey for assessing varietal adoption patterns in two major potato growing districts, viz., Nalanda and Patna of Bihar during 2016-17 crop season revealed that Kufri Pukhraj (69.53 % potato area) was the most popular variety, followed by Kufri Sindhuri (6.8 %) and Kufri Khyati (5 %).

Madhya Pradesh: In Madhya Pradesh, Kufri Chipsona-3 (26.5 % area) and Kufri Chipsona-I (22.3 % area) were the leading potato variety closely followed by Kufri Jyoti (22.07% area) during 2014-15 crop season.

Gujarat: The survey conducted in Banaskantha and Aravalli district of Gujarat during 2017-18 crop season revealed that the most popular varieties were Lady Rosetta (40.5 %) and Kufri Pukhraj (33.3 %). Other important varieties were Kufri Lauvkar (12.6) and Kufri Badshah (6.3 %).

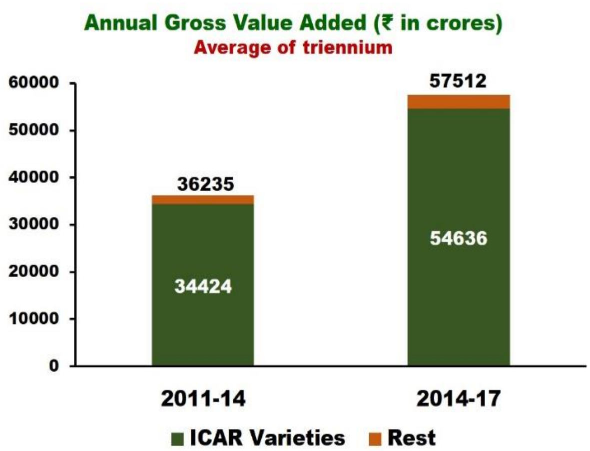
Punjab: Study in Jalandhar, Ludhiana and Hoshiarpur districts of Punjab revealed that during 2016-17, Kufri Pukhraj was the most popular variety in both Jalandhar (50%) and Hoshiarpur (76%). Other popular varieties of Jalandhar were Kufri Jyoti, Lady Rosetta and Badshah. But, in case of Ludhiana processing varieties from private companies, like Lady Rosetta (28%), FC-3 (25%) and FC-5 (15%) were popular among farmers. CPRI varieties like Kufri Chipsona-1 (16%) and Kufri Chipsona-3 (13%) were also having significant area under potato.

Assam: In Assam, Kufri Jyoti (50 % potato area) and Kufri Pukhraj (33 % area) were the most popular varieties during 2015-16 crop season.

Meghalaya: In Meghalaya, Kufri Jyoti (34% area) and Kufri Megha (14% area) were the leading potato varieties followed by Kufri Giriraj 10% area) during 2015-16.

Impact of major CPRI varieties in India

Potato varieties developed by ICAR-Central Potato Research Institute cover nearly 95% of total area under potato. India produced about 45.87 million tonnes of potato annually during the triennium 2014-17 and contributed Rs. 57,512 crore annually to the Gross Value Added (GVA) at current price. The varieties developed by ICAR-CPRI contributed Rs. 54,636 crore annually during this period.



Kufri Jyoti, a day-neutral variety released in the year 1968 played a lead role in popularizing potato throughout the country. Because of wide adaptability of this variety, potato emerged as a principle component of the profitable maize-potato-wheat sequence in the vast North-western plains. Presently it occupies about 21% area in the country and thereby contributing about Rs. 11,800/- crore to the agricultural economy.

Kufri Bahar released in 1980 became the principal potato variety of Uttar Pradesh, the highest potato producing state of the country. It occupies about 17% area in the country and contributes about Rs. 9,551/- crore to the agricultural economy.

An early bulking variety (60 days), Kufri Pukhraj released in 1998 is the leading variety today in India occupying >33% area. It contributes about Rs. 18,541 crore in the agricultural economy of the country. It is most suitable for rice-wheat based sequence in the northern plains.

Kufri Chipsona 1 released in 1998 is 4^{th} leading variety of the country today occupying about 4% area under potato and contributing about Rs. 2,247/- crore to the agricultural economy. Besides, five more processing varieties have been released by the Institute catering to almost 35% of raw material for the processing industries. Potato processing companies like M/S Frito Lay India (Pepsico), ITC Ltd., Merino Industries, Mc Cains India, PRAN Food Ltd., Haldiram, Pailan Food Ltd., Balaji Wafers, Golden Fries, Bikaji Foods International Ltd. etc. use Indian processing varieties and sell their products as >100 brand names. This has resulted in tremendous growth of processing sector from mere <1% during 1990s to > 8% now.

Impact Assessment of potato varieties using Economic Surplus Model

Kufri Pukhraj: The Economic Surplus Method with closed economy was used to measure the benefits of and returns to research and development (R&D) of an early bulker and drought-tolerant potato cv. Kufri Pukhraj in India. A period of 40 years from 1978 (the year in which breeding of Kufri Pukhraj started) to 2018 was considered for developing the cost-benefit stream. All these estimates of costs and benefits were expressed in real terms by adjusting to Wholesale Price Index with 2018 as the base year. The results of the model revealed that the total cost of R&D of Kufri Pukhraj was Rs. 12.1 crore. The Net Present Value (NPV) of the benefits of Kufri Pukhraj R&D was Rs. 9012 crore and 3328 crores at 5 and 8 per cent discount rate respectively and the internal rate of return (IRR) of the net benefit was 41 %.

Kufri Chipsona-3: Economic Surplus Model was used for assessing the impact of returns to research investment for developing processing potato cv., Kufri Chipsona-3. Research cost computed for the period 1990-91 to 2006-07 while the adoption cost was estimated during 2007-08 and 2012-13. All estimated expenses were adjusted to the consumer price index of industrial workers with the 2012-13 as base year. Returns to investment for developing Kufri Chipsona-3 were evaluated during different scenario in order to articulate different funds availability situations. It was found that the IRR was 58.90 %. The net present worth was found to be Rs. 5871 million and 2726 million at 5 % and 10 % interest rate.

Impact of climate change on potato production: present scenario and adaptation strategies

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Climate change is posing serious threat to human survival on the earth in one or the other way. The disturbances in earth's climate have been greatly accelerated during the past century. It's a well-established fact that greenhouse gas (GHG) emission is responsible for climate change and is increasing rapidly at an alarming rate.

Potato is the third major food commodity of India after rice and wheat in terms of production. India has made tremendous progress in potato production and the per capita availability of potato has increased from 4.37 kg in 1950 to 21.52 kg in 2012. However, the climate change is likely to have a negative effect on potato growth in India, including productivity, production and profitability. The increase in CO_2 is expected to bring on increase in productivity of potato as reported by many workers. However, increase in temperature and atmospheric CO_2, both are interlinked and occur simultaneously and the CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperature on tuber yield. Worldwide potato crop losses due to late blight have been estimated at €12 billion (Haverkort et al., 2009). In India, severity of late blight varies from region to region, being more severe in temperate highlands than in the sub-tropical plains with an average of 15% crop losses annually (Collins, 2000). In case of late blight, the effect of climate change on the most dreaded disease of potato in India also, could be mixed. Late blight caused by *Phytophthora infestans* is often regarded as the most important disease of potato globally. In potato cultivation, potato seed is most expensive input accounting for 40 to 50% of the production cost. Since the eastern, northeastern, Deccan and south western parts of the country are not suitable for quality seed production barring few locations, the farmers of these areas have no option but to buy the seed potato from northern India. The high hills of Himachal Pradesh, Indo-Gangetic plains of Punjab, Haryana, north-western part of Uttar Pradesh, and Bihar are suitable for nucleus and breeder seed production. However, Punjab and western Uttar Pradesh are two major states which supply quality potato seed to rest of the country. In case of climate change scenario, the temperature change is likely to affect the late blight outbreak in Punjab and western Uttar Pradesh, thus affecting the potato seed production.

Bacterial wilt is causing huge losses in warmer area of Madhya Pradesh and plateau region. Presently, in North Western Indo-gangetic region, the disease severity is very less but due to warming, the disease may enter the new areas where it is not present. The present studies were conducted to assess the yield losses due to climate change, to develop suitable adaptation strategies and to assess effect of climate change on late blight and bacterial wilt prevalence. In this paper, I'm presenting the findings of studies carried out at ICAR-CPRI, Shimla on climate change impact on potato production.

Impact on potato productivity

For impact on potato productivity, we used WOFOST (**WO**rld **FO**od **ST**udies) crop growth simulation. WOFOST, a mechanistic model which simulates the growth of a crop based upon eco-physiological processes is widely used to assess the effect of climate change on the growth and yield of many crops which includes wheat, rice, maize potato, barley, soybean, sugar beet throughout the world (Boogard *et* *al*., 1998, Wolf *et al*., 2010) and is one of three most widely used crop growth model for climate change studies (Diepen *et al*., 1987). WOFOST has been calibrated for Indian potato cultivars using the time course data on potato growth and development (Dua *et al*., 2014). Hence, WOFOST model was used for impact assessment of climate change on potato productivity and scheduling planting date and selection of suitable cultivar to minimize climate impact in Uttar Pradesh, Punjab, Madhya Pradesh, Gujarat, Bihar and West Bengal. The simulation studies were carried out for four potato cultivars, Kufri Badshah, Kufri Bahar, Kufri Pukhraj and Kufri Jyoti. The model was run for different planting dates depending upon the locations and the cultivar selected. The simulation study was carried out for potential yields of potato cultivars for all the scenarios. IMD district normals of 1971- 2000 of 61,13, 29, 13, 20 and 38 districts of Uttar Pradesh, West Bengal, Bihar, Gujarat and Madhya Pradesh respectively were used for baseline scenario (year 2000). The simulation studies were carried out for A1FI high emission scenario. For generation of scenario for 2020 and 2055, projected changes in surface air temperature for sub-regions of the Asia under SRES A1FI pathway, based on the Fourth Assessment Report (AR4) Atmosphere-Ocean General Circulation Models (AOGCMs) were added on the baseline data. Projected atmospheric CO_2 concentration based on the Bern-CC model for A1FI scenario was used for incorporating the effect of change in CO_2 concentration in WOFOST model. The figures used in this study for atmospheric CO_2 concentration were 367 ppm (for baseline), 415 ppm (for 2020) and 590 ppm (for 2055).

Punjab: The potential productivity of Kufri Badshah, Kufri Pukhraj and Kufri Jyoti was 52.6, 51.2 and 49.0 t/ha under baseline scenario. Under future climate scenario, when the effect of temperature and CO_2 fertilization was considered together, productivity of Kufri Badshah is projected to remain unchanged in 2020 (-0.08%) and will reduced by 2.62% in 2055. However, in case of Kufri Jyoti an insignificant 0.4% increase is expected in 2020 (from 48.9 to 49.0 t/ha), which will decline by 4.59% to 46.6 t/ha) in 2055 as compared to baseline yield. The maximum increase is likely in productivity of Kufri Pukhraj from 50.8 to 51.2 t/ha (0.69%) in 2020 and maximum decline (to 48.1 t/ha; 5.33%) in 2055.

Uttar Pradesh: The productivity of Kufri Badshah Kufri Bahar and Kufri Pukhraj was 46.0, 46.8 and 45.3 t/ha respectively under baseline scenario. The productivity under climate change scenario is expected to decrease by 5.5, 6.1 and 7.0 per cent respectively for Kufri Badshah, Kufri Bahar and Kufri Pukhraj during 2020 and by 9.4, 10.9, 13.4 percent respectively in 2055 as compared to the baseline scenario (Table 1).

Bihar: In the baseline scenario, the potential productivity of potato in Bihar was 40.7, 38.7 and 40.8 t/ha for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj respectively. A decrease of 5.1, 6.2 and 6.9 percent in productivity was recorded during 2020 while productivity is likely to decrease by 8.7, 10.8 and 12.7% during 2055 for the three cultivars, respectively.

West Bengal: In West Bengal under the baseline scenario, the potato productivity was 38.9, 37.2 and 39.2 t/ha for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj respectively. A decrease of 5.1, 5.9 and 6.1 percent in productivity was recorded during 2020 while productivity decreased by 8.8, 10.5 and 12.0 percent during 2055 for the three cultivars respectively.

Gujarat: The potential productivity of Kufri Badshah, Kufri Jyoti and Kufri Pukhraj was 40.3, 36.1 and 37.5 t/ha respectively under baseline scenario 2000.The productivity under climate change scenario was found to decrease by 7.6, 9.7 and 10.9 per cent respectively for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj during 2020 (Table 1). The productivity was found to increase by 19.5 per cent for Kufri

Badshah while it decreased by 22.1 and 25.5 respectively for Kufri Jyoti and Kufri Pukhraj during 2055 as compared to baseline scenario.

Madhya Pradesh: Under baseline scenario of 2000, the potential productivity of Kufri Badshah, Kufri Jyoti and Kufri Pukhraj was 43.6, 40.0 and 42.2 t/ha respectively. The productivity under climate change scenario was found to decrease by 6.4, 7.3, 7.6 per cent respectively for Kufri Badshah, Kufri Jyoti and Kufri Pukhraj during 2020 and it decreased by 10.9, 12.8 and 14.3 respectively for the three cultivars during 2055 as compared to baseline scenario.

Overall, the impact analysis using WOFOST crop growth model has shown that under A1FI scenario of climate change although there will be no change in potato productivity in Punjab in 2020, in other states the productivity is likely to decline in 2020 (Uttar Pradesh - 5.5 to 7.1%, Bihar - 5.1 to 6.9%, West Bengal - 5.1 to 6.1%, Madhya Pradesh - 6.4 to 7.6% and Gujarat - 7.6 to 10.9%) and 2055 (Uttar Pradesh - 9.4 to 13.4%, Bihar - 8.7 to 12.7%, West Bengal – 8.8 to 12.0%, Madhya Pradesh – 10.9 to 14.3% and Gujarat – 19.5 to 25.2%) (Table 1). With the simple and practical adaptation measures like change in date of planting and selection of suitable variety, the decline in productivity can be brought down to 5.2, 1.9, 4.1, +1.7 and 0.8% in 2020 and 9.2, 6.6, 8.1, 3.6 and 10.4% in 2055 in Uttar Pradesh, Bihar, West Bengal, Madhya Pradesh and Gujarat, respectively.

Table 1: Change in potato yield over baseline scenario.

State	Cultivar	Baseline yield (t/ha)	Change in yield in 2020		Change in yield in 2055	
			Without adaptation (t/ha)	With adaptation (t/ha)	Without adaptation (t/ha)	With adaptation (t/ha)
Bihar	Kufri Badshah	40.7	-5.1	-1.91	-8.7	-6.6
	Kufri Jyoti	38.7	-6.2		-10.8	
	Kufri Pukhraj	40.8	-6.9		-12.7	
West Bengal	Kufri Badshah	38.9	-5.1	-4.1	-8.8	-8.1
	Kufri Jyoti	37.2	-5.9		-10.5	
	Kufri Pukhraj	39.2	-6.1		-12.0	
366UP	Kufri Badshah	46.0	-5.5	-5.2	-9.4	-9.2
	Kufri Jyoti	46.8	-6.1		-10.9	
	Kufri Pukhraj	45.3	-7.0		-13.4	
MP	Kufri Badshah	43.6	-6.4	1.7	-10.9	-3.6
	Kufri Jyoti	40	-7.3		-12.8	
	Kufri Pukhraj	42.2	-7.6		-14.3	
Gujrat	Kufri Badshah	40.3	-7.6	-0.8	-19.5	-10.4
	Kufri Jyoti	36.1	-9.7		-22.1	
	Kufri Pukhraj	37.5	-10.9		-25.2	
Punjab	Kufri Badshah	52.6				
	Kufri Jyoti	49.0				
	Kufri Pukhraj	51.2				

Impact on Late Blight

JHULSACAST model was used to work out the effect of climate change on potato late blight outbreak, duration of favourable period and disease severity in Uttar Pradesh, Punjab and West Bengal. The model requires hourly temperature data (°C), relative humidity (RH %) and daily rain (mm) data as input. The model was run for baseline scenario (year 2000) and future climate scenarios (years 2020 and 2055). IMD district normal of 1971-2000 were used for baseline scenario (year 2000) and for future climate scenarios of the years 2020 and 2055 A1FI scenario of temperature (SRES A1FI pathway) was used. It is not possible to predict the daily humidity in years 2020 and 2055 during cropping period, therefore, we assumed that favourable RH would start from a week of emergence of the crop in western Uttar Pradesh and Punjab respectively and proceed with 10 days intervals after the setting of required RH. Thus, the model results are the outcome of the effect of temperature input. To estimate the number of sprays required in seed crop, the daily severity values were calculated on the basis of decision support system developed for western Uttar Pradesh and Punjab (http://cpri.ernet.in). The number of sprays needed in seed crop was calculated by dividing total accumulated severity by 180 for contact fungicides. The value of divisor 180 was derived empirically. The study was done for entire Punjab state, 23 contiguous districts of western Uttar Pradesh and 11 districts of West Bengal. The JHULSACAST model was run on available weather data for 13 districts of Punjab, 21 districts of western Uttar Pradesh and 11 districts of West Bengal.

Appearance of late blight is expected to be delayed in both 2020 and 2055 climatic scenarios in all the three states based on Jhulsacast Model. The number of days favorable for the disease will increase in Punjab. The earliest Late Blight appearance, which is 13-15 October, in 2000, may be delayed by 0-6 days in 2020 and 12-14 days in 2055. However, due to rise in temperature in future scenario, there will not be mid-season breaks in late blight favourable days. The late blight favorable days during 2000 were 105 and these increased by 30 and 35 days by 2020 and 2055 respectively. Hence more number of fungicide sprays will be required for the control of this disease. However, in the remaining two states the number of favorable days for late blight may decrease and hence less number of fungicides sprays will be required.

In western Uttar Pradesh, earliest late blight appearance during the potato crop season is predicted during 13th October to 1st November in baseline year 2000 and is expected to be delayed by 0 to 8 days in 2020 and 10-21 days in 2055. The delay in late blight appearance in 2020 and 2055 is due to expected increase in temperature by 1.08 and 2.98 ºC respectively over the baseline year 2000. In western Uttar Pradesh, potato growing season would be warmer which would decrease late blight favorable days by 7 and 27 in 2020 and 2055, respectively. The maximum number of sprays required to control late blight in potato seed crop thus would be 7.3 and 8 in future scenario (2020 and 2055) in comparison to 6.5 in baseline (2000) in Punjab. In contrast, there would be no change in number of sprays in year 2020 (over baseline year 2000) in western Uttar Pradesh, however, due to further increase in temperature in year 2055, it could be reduced by 2.

In West Bengal, earliest late blight appearance during the potato crop season was predicted during 4th to 11th October in baseline year 2000 and is expected to be delayed by 7.6 days in 2020. The delay in late blight appearance in 2020 is expected due to increase in temperature by 1.08 over the baseline scenario. However, due to delay in appearance of late blight in the season, the total late blight favorable period is likely to be reduced by 17.7 days in 2020, respectively. The number of sprays required to control late blight in potato seed crop would be 4.2 in future scenario of 2020 in comparison to 5.5.5 in baseline (2000) in West Bengal. Hence, less number of fungicides sprays will be required.

Impact on survival of *R. solanacearum* in potato growing districts of plateau region

For studying the survival of *Ralstonia solanacearum* in soils of plateau region of India, results of the experiment conducted under controlled condition of various temperatures on the survival of *R. solanacearum* in soil were used to develop. A logical mathematical model which give the time (in days) in which the bacterium will not survive in the soil. The model gives the results on the basis of daily mean soil temperature. For baseline survival, IMD normal were used and for future climate, temperature rises for A1F1 scenario of the climate change for 2020 and 2055 were added on the baseline temperature. The presence of *R. solani* in the soil was presumed on 1st of January and the days it will survive in the soil of 60 potato growing districts of eight states in plateau region of India were worked out, based upon soil temperature.

Tamil Nadu and Kerala: Under the baseline climate scenario (2000), the bacterium would survive till 18th March in soils of Idukki, Kannur, Malappuram, Pathanammitha, Wayanad districts of Kerala and Dharamapuri, and Virudinagar districts of Tamil Nadu and no changes are expected in 2020. However, in 2055, the bacterium is likely to survive in soil of these districts till 03 March only. The bacterium is likely to disappear 0-05 days earlier in 2020 and 05 to 15 days in 2055.

Karnataka: The bacterium could survive in soil till 18 March in Gadag, 7 April in Dharwad, Bidar, Chitradurga, Karwar, Udupi, and 27 April in Rural and Urban Bangalore districts of Karnataka in baseline scenario. In 2020, the bacterium is likely to survival in soil till 18th march in some areas of Dharwad and Chitradurg while in rest of districts, no change is expected. The bacterium is likely to disappear 0-08 day earlier in 2020 and 11-15 days in 2055.

Andhra Pradesh, Maharashtra, Odisha and Chhatisgarh: The bacterium may survive in soil from 7 to 27 April in different districts and is likely to disappear 3-8 and 11-25 days earlier in Andhra Pradesh and Maharashtra, 3-8 and 11-20 days in Odisha and 3-5 and 11-15 days in Jharkhand in 2020 and 2055, respectively.

Jharkhand: Under the baseline (2000), the bacterium could survive in soil maximum till 27 April in Gumla and 17 May in Ranchi and Singhbhum. No change is expected in Gumla in 2020, however, in Ranchi and Singhbhum, the survival is likely to be up to 6th May only.

Madhya Pradesh and Gujarat: The bacterium may survive in soil from 27 April to 17 May in different plateau districts of Madhya Pradesh and Gujarat in 2000. The bacterium is likely to disappear 3-8 days earlier in 2020 and 5-15 days in 2055 in Madhya Pradesh and 3-5 days earlier in 2020 and 11-26 days in 2055 in Gujarat.

Rajasthan: Under the baseline climate scenario (2000), the bacterium survived in soil till 17 May. The period is likely to reduce by 0-5 days in 2020 and 5-15 days in 2055.

Adaptation and Input Strategies

The various adaptation strategies to combat the impact of climate change on potato productivity may include breeding short duration and heat tolerant cultivars, developing potato cultivars that tuberises at higher night temperatures. Mining for biodiversity to heat tolerance should be given priority.

Breeding drought and salinity tolerant cultivars would be effective to face the future challenges of climate change. Use of wind breaks around fields and crop residue mulches for some period after planting, using drip and sprinkler irrigation in place of furrow and basin methods and altering cultural management in potato based cropping systems are few examples of agronomic management practices to reduce the impact of climate change. Besides, conservation tillage and on farm crop residue management are required to increase input use efficiency. Advance planning for possible relocation and identifying new areas for potato cultivation is needed. Improvement and augmentation of cold storage facilities and air conditioned transportation from producing to consumption centers will be required for storage and transportation of this semi-perishable commodity. Strengthening education, research and development in warm climate production technology for ware and seed potato crop is also required to meet the production targets in future climates.

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Nutrient management and water management for potato production

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Optimum potato growth and profitable production depend on many management factors, of which ensuring a sufficient supply of nutrients and maintaining optimum moisture is crucial. There are 14 soil-derived elements or nutrients considered to be essential for growth of plants. Relatively high demand for many nutrients and shallow root system makes fertilizer application necessary as the supply of nutrients from the soil is often not adequate to meet the demands for growth. Soil moisture affects the nutrient availability and controls the leaching. Therefore, a comprehensive nutrient and water management program is essential for producing a healthy and quality potato crop, profitable tuber yield, and minimizing undesirable impacts on the environment for determining specific nutrient needs. Nutrient recommendations soil testing, tissue analysis, and nutrient management strategies for open field crop of potato are discussed here.

Nutrient Management Strategies

Nitrogen (N):

Amongst essential elements, N is often the one most yield limiting nutrient for potato growth. Application of fertilizer N is usually necessary to ensure profitable potato production because Soil N is largely tied up in organic matter and not readily available for uptake hence application of fertilizer N is needed to produce profitable yield While deciding on N needs fertilizer value of the manures applied to previous crops as well as present crops should be taken into consideration. Early stage application of N is essential to ensure early row closure (canopy development). Both N rate and timing can have important impacts on yield and quality. Excess of N delays tuber initiation and maturity leading to excessive vine growth at the expense of tuber growth and delayed maturity results in tubers with lower specific gravity. Factors like variety, yield potential or goal, growing season, soil organic matter content, and previous crop should also be considered while deciding on the rate of N application. Nitrogen application rates vary considerably from 120 -150 kg N /ha in hills to 180-240 kg N /ha in plains depending on soil and variety and target yield Nitrogen deficiency can increase the early blight infestations. General, split applications of N are recommended for potatoes from both a production and an environmental safety point. Choice of fertilizer sources depends on cost as well as need for other nutrients also. Ammonium sulphate will supply S apart from N and calcium ammonium nitrate will supply calcium apart from N. Urea is cheaper than above mentioned fertilisers.

In soils having low nitrogen A portion of the N 50% to two third should be applied preplant or planting and the remainder hilling or earthing up stage . Split applications will generally improve N use efficiency by reducing leaching losses due to excessive rainfall and providing available N when it is needed for tuber growth. Nitrogen uptake by the potato plant is highest during the tuber bulking stage. Use of Chlorophyll meters can help in minimizing seasonal variations in N availability and the experiments conducted at different locations have indicated a saving of 10-20% compared to blanket application Many studies have been conducted to identify what source of N is best for potato production; however, interactions with variety, application method, and growing conditions make it difficult to draw a general recommendation on N source and dose. Kufri Pukhraj is more responsive to N compared to Kufri Jyoti and Common N sources include ammoniated phosphorus urea, calcium ammonium nitrate, and ammonium sulphate etc. Care should be taken not to band high amounts of ammonium containing fertilizer close to the seed as it may cause ammonia toxicity especially on high pH soils. Nitrate sources are susceptible to leaching. Urea needs to be incorporated or applied with irrigation water (fertigation) otherwise there are chances of N loss due to ammonia volatilization. Ammonium sulfate also provides sulfur and is the most acidifying N fertilizer and on a nitrogen basis, the cost of ammonium sulfate is more than that of urea. However, if sulfur is also needed, then ammonium sulfate is an economical source to use. Sources such as calcium nitrate can be effective, but are costly.

Phosphorus (P): Phosphorus is important in enhancing early crop growth and tuber set and promoting tuber maturity. A healthy potato crop removes about 25-30 kg P_2O_5. Potato being shallow rooted crop P use efficiency is hardly 10-15 fir conventional method of soil application. In Experiments conducted using omission plot techniques in consistent response has been found in soils having high level of available P (> 10 ppm Olsen's P)and in soils having high available P (> 20 ppm Olsen's P) invariably no response has been observed in alluvial soils. In soils having low P 100-150 kg P_2O_5 is recommended.

Potassium (K): Potassium plays important roles in tuber yield and quality and its potato crop takes up significant quantities of this nutrient. A healthy soil removes a170-230 kg K_2O /ha and its uptake efficiency is 50-60% thus considerable residual effects are observed in the succeeding crops unless substantial leaching does not take place in sandy soils. Soils tests have been found to be very useful in predicting K responsive soils. On low K testing soils about 100-150 kg K_2O is applied depending on the soil type. Potassium chloride (0-0-60) also known as MOP is the most economical K source. However, due to its high salt index may increase salinity problems under saline irrigation. Other important fertilizer sources are SOP (0-0-50) and Potassium nitrate (13-0-45) sources. Potassium deficiency Low K is associated with an increased incidence of internal black spot bruising. In season applications of K fertilizer tend to increase bulking, but will usually lower specific gravity.

Calcium (Ca), magnesium (Mg), and sulfur (S): In general, most soils contain sufficient amounts of secondary nutrients for potato production or these are present in one or the other commonly used fertliser sources except Magnesium. However, acid sandy soils having low organic matter may require addition of one or more of these nutrients. Calcium plays an important role in maintaining tuber quality in storage and reducing internal tuber disorders due to water or temperature stress. In variably soils containing 400 ppm extractable Ca seldom improve tuber yield and quality. In some situations, localized Ca deficiency may occur on high testing Ca soils resuting in internal breakdown problems in tubers. These problems are the result of inadequate transport of Ca in the tuber caused by water or temperature stress and not its deficiency in soils per se. Addition of calcium on high testing soils is recommended only if the potatoes storage problems have been encountered and calcium sulfate (gypsum) and calcium nitrate and single superphosphate (as a source of can be used to increase tuber calcium concentrations.. Magnesium deficiency can be a problem in soils where high rates of potassium fertilizer have been used. Response is likely if soil test Mg is less than 50 ppm and magnesium sulfate or potassium-magnesium sulfate can be used. The later source should not be used in soils having high K. Sulfur requirements can often be met from soil organic matter breakdown and irrigation water also contain some sulfate and can also provide a significant proportion of the sulfur needed for growth. Ammonium sulfate and potassium sulfate when used as N and K sources ,respectively, will supply sufficient sulfur when a need is indicated from soil or tissue tests. Elemental sulfur is not an immediately available form and must be oxidized by soil bacteria to sulfate before it is can be used by the plants. It should be applied along with FYM. The oxidation of sulfate forms sulfuric acid and will have an acidifying effect on the soil.

Micronutrients: zinc (Zn), boron (B), copper (Cu), manganese (Mn), nickel (Ni), iron Fe) chlorine (Cl), molybdenum (Mo): Micronutrients are needed in much lower quantities.In general, most soils contain sufficient amounts of micronutrients to meet plant needs and if farm yard manure is applied regularly it will supply most of the micronutrients to meet the crop demand. However, a deficiency can cause serious reduction in yields. Application of micronutrients is recommended only if a need is indicated by soil and/or tissue tests. High pH soils can limit availability of Fe, Zn and Mn. In many cases, pesticide sprays contain enough Cu and Zn to meet plant demands of these nutrients. Boron may be limiting in sandy soils and excessive B applications can be toxic. Potato responses to Ni, Cl, and Mo are not well documented.

Soil Testing: The soil test will help to determine whether nutrients or amendments are needed and if so, at what rate they should be applied. A typical soil analysis for potatoes should include pH, organic matter, N, P, K, Ca, Mg, S, Zn, Fe, Cu, Mn, Mo and B. For most accurate fertilizer recommendations, soil test interpretations should be based on local or regional research.

Soil pH: Soil pH is one of the most important chemical properties affecting nutrient use. Optimal soil pH for nutrient availability is between 6 and 7. Acid conditions are generally favored for potatoes in order to minimize the incidence of common scab (*Strepotmyces scabies*), which is most widespread when soil pH is above 5.2 and below 4.9, nutrient deficiencies and toxicities become more common. In low pH soils , <4.9 pH particular, Mn and Al toxicity and P, K, Ca, and Mg deficiencies may occur. Soil should be limed 2 during the years when potatoes are not grown. Use of scab resistant varieties is also recommended so that pH can be maintained in a more optimal range.

Tissue analysis: Tissue analysis has been used for many years as an additional nutrient management tool to: 1) diagnose a nutrient deficiency or toxicity, 2) to help predict the need for additional nutrients and 3) to monitor the effectiveness of a fertilizer programme. If the level of nutrient falls outside the optimum rage on lower side then, then corrective measures should be taken. The tissue used for nutrient analysis in potato is the petiole (leaf stem and midrib) of the fourth leaf from the shoot tip or whole leaf. Collecting older tissues will have different nutrient concentrations and can lead to erroneous interpretations. For sampling, approximately 30 to 40 leaves should be collected Most diagnostic criteria for tissue analysis are based on a sample taken during the tuber bulking stage aor when the plants are at 7-8 leaf stage (approximately 15 -20 cm long). Samples taken soon after a fertilizer application may not accurately reflect the true nutritional status of the plant For irrigated potatoes, tissue analysis should begin at least four days after a fertigation.

Irrigation Management

Irrigation is a vital for potato production to maximise both yield and quality. being herbaceous plant with shallow root system it requires light and frequent irrigation throughout period of crop growth to obtain the sustainable crop yield. In India it is grown both as rainfed as well as irrigated crop depending on the season and the region. Potato (*Solanum tuberosum* L.) is mainly grown in light textured soils. The crop is sensitive to moisture stress and most of the studies have indicated stolon initiation followed by tuberization as the most critical stages for potato. The sensitivity of potatoes to plant water stress is invariably due to their rather shallow root system and complex physiological responses to moderate plant water deficits.

On an average the water requirement of crop varies from 400-600 mm under Indian conditions depending upon soil type/texture, climate, variety and length of growing period, rainfall pattern and other management practices. The crop productivity and quality of the tubers largely depend upon proper balance between soil air and soil water in the plant root zone. Both low as well as excess water in soil during crop growth stages affect the drop performance. However, impact of excess or low soil moisture varies with the crop growth stage. Excess soil moisture it creates aeration problem and favours certain diseases and pests.

Decline in the water table in many areas of north-western and central plains of India due the over draft of ground water at rates higher than recharge has become a cause of great concern. Due to increasing water scarcity and recurring droughts in many parts of the country, more and more emphasis is being given on installing micro-irrigation particularly drip irrigation system the proven water-conserving irrigation technique. Further, the purpose of irrigation management is to maximize potato yield and quality by maintaining soil water content within optimum limits throughout the crop growing season through timely and controlled water application and this can be achieved best by drip or sprinkler irrigation. As a thumb rule the average available soil water (ASW) of the root zone should be maintained between 65 and 85 percent during the active crop growth period for optimum results. In practice, ASW in the root zone will fluctuate above and below this range for short periods of time immediately before and after irrigation. Drip irrigation systems and sprinkler systems allow for light, frequent irrigations and such fluctuations can be managed effectively by these systems.

There is no single best micro irrigation system that can be advocated to all farms. The micro irrigation systems improve efficiency of irrigation water and fertilizer nutrients, and also hydro-thermal regimes and physical conditions of the soil by maintaining proper balance between soil air and soil water in the plant's root zone for better root growth and tuber development, which results in to higher yield of quality tubers.

Sprinkler Irrigation system gives uniform distribution and the system is expected to economise on water by about 40% since it and reduces water losses in terms of deep percolation and the rate of water application is regulated according to the infiltration rate of the soil. It is recommended to apply irrigation twice in a week at 150% of CPE by using sprinkler method.

Drip Irrigation: Drip irrigation is growing as a preferred irrigation method as it can provide production and water use efficiency. Compared to furrow irrigation, drip method requires about 50% less water. Drip irrigation compared to sprinkler is advantageous in saline water areas, as it delivers the water below the level of the crop canopy, avoiding foliage scorch. It is recommended to apply irrigation using drip at alternate day on the basis of 125% of CPE.

Techniques for determining water requirement and irrigation scheduling of potato crop: Water requirement of crop constitute the amount of water required to mature the crop, encompassing consumptive water use (evapo-transpiration plus water required to build up in plant tissues) and economically unavoidable water losses in the form of deep percolation and surface run off. Water has to be applied in the right amounts at the right time in order to achieve best crop results. At the same time being a valuable resource it should not be wasted and the irrigation practices should be environmental friendly as a whole. The commonly used methods to schedule irrigation involve i) atmospheric measurements and water balance technique ii) soil moisture monitoring and iii) plant stress measurements.

Good Agricultural Practices (GAP) and IndGAP for Potato Crop Production

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The Food and Agriculture Organization (FAO) of the United nations (UN) states GAP as a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economic, social and environmental sustainability. The concept of GAP is based on fundamental principles of safe and quality food production, Conservation of environment and natural resources, sustainable farming and economic and social sustainability (FAO, 2003).

Genesis of GAP:

The increasing awareness about food quality in the food industry led to the foundation of EuroGAP. In the late 1990s many European supermarket chains and their major suppliers created a common standard for farm management practices. The standards were developed as per guidelines of Hazard Analysis and Critical Control Point (HACCP) of United Nations Food and Agriculture Organization (FAO). The GAP certification was an assurance of quality food production and environmental safety. Unlike other farm certification schemes, it has definitive rules for growers to follow, and each production unit is assessed by independent third-party auditors. EurepGAP certification comprises of control points and their compliance for the food production and was evaluated by independent third-party auditors. With increasing popularity, EuroGAP became the world's most widely implemented farm certification scheme.

GlobalGAP: With expanding the international role of EuroGAP between multiple retailers and their suppliers in establishing Good Agricultural Practices, in September 2007, EurepGAP changed its name to GLOBALG.A.P. GlobalGAP is purely a private standard and it has authorized several registered certification bodies across various countries to seek certification. Today, GlobalG.A.P. is the worldwide assured standard. In 2017, under Fruits and Vegetable (FV) Certification 182,193 Producers were certified in 125 countries covering 3.5 million hectares (ha) whereas under Flower and Ornamental certification 803 Producers were certified in 26 Countries covering a total of 25,566 ha non-Covered Crops and 2,462 ha covered Crops, 1,063 Producers certified under combinable crops (CC) certification in 31 countries covering a total of 210,071 ha and 180 producers under tea (TE) certification in India and Japan (GlobalG.A.P. annual report, 2017). The international status of GlobalG.A.P. certification and year wise increase in number of producers, which is more than double within ten years are clear indicators of its global recognition.

USDA GAP program: The United States Department of Agriculture (USDA) agricultural marketing services started an audit/certification program in 2002 to implement an audit based program to verify conformance to the 1998 Food & Drug Administration publication entitled, "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables. This is a voluntary program adopted by producers to ensure the use of GAP in farms and packers to ensure the quality requirements by retailers and food buyers. Since 2002, the program has been updated several times. In 2009, USDA-AMS participated in the GAPs Harmonization Initiative which "harmonized" 14 of the major North American GAP audit standards, which in 2011 resulted in the release and implementation of the Produce GAPs Harmonized Food Safety Standard.

The international acknowledgement for Global G.A.P., lead several Asian countries to introduced the country versions of GAPs viz., China GAP, Japan GAP, Korean GAP, Viet GAP, Thai GAP, and ASEAN GAP etc. The Chinese ministry has developed Green Food standard to develop good agricultural practices for the domestic market, whereas ChinaGAP has being developed jointly by Chinese government and GlobalGAP to supply at international market (Lei,2005). In February 2009, GLOBALGAP launched 'ChinaGAP' following successful completion of the benchmarking of ChinaGAP against the GLOBALGAP. In 2006, the Japan GAP Association was established to make JGAP as a national standard and to make JGAP internationally recognized standard, which essentially meant JGAP to be benchmarked to GLOBALG.A.P. so as to facilitate the exports of agricultural products to the EU market (Kaoru Nabeshima,2015). The Thailand government has developed Food safety and quality management system (QMS) schemes for assured quality fresh production in Thailand (Salakpetch, 2007). In 2002, the Malaysian department of agriculture has introduced farm accreditation scheme of Malaysia (SALM) to implement GAP standards for food production with ultimate goal of branding the produce with an internationally accepted mark of “Malaysia’s best” (Mohamed Mohd. Salleh, 2007).In 2006, ASEAN secretariat has developed ASEANGAP as a standard to enhance the harmonization of national GAP programmes within the ASEAN region for domestic as well as global trade.

List of GAP by ASEAN countries

Country	GAP	Responsible Party	Start Year
Indonesia		Ministry of Agriculture	2004
Thailand	QGAP	Ministry of Agriculture and cooperatives	2004
Philippines	PhilGAP	Department of Agriculture	2005
Singapore	GAP-VF	Agri-Food & Veterinary Authority	2005
Thailand	ThaiGAP	Thai Chamber of Commerce	2007
Vietnam	VietGAP	Ministry of Agriculture and Rural Development	2008
Cambodia	Cam-GAP	Ministry of Agriculture, Fishery and Forestry	2010
Laos Myanmar	LAO GAP	Ministry of Agriculture and Forestry	2011
Brunei	Brunei GAP	Ministry of Industry and Primary Resource	2013
Malaysia	MyGAP	Department of Agriculture	2013

Good Agricultural Practices in India:

Following the rising international trend and demands for farm certification, quality and food safety, Quality Council of India (QCI) has developed two certification schemes viz., BasicGAP and INDGAP for the Indian farming scenarios. The BasicGAP is meant for small or marginal farmers or for those who are interested in introducing quality farm production for fresh consumption or for processing (refer: QCI/ INDGAP/ BasicGAP/ Ver.1 Dec. 14). Whereas, INDGAP is targeted for farms who wish to seek INDGAP certification for their farm produce either for fresh consumption or for processing purpose (refer: QCI/ INDGAP/ Ver.1 Sept. 14). The Indian Good Agricultural Practices (INDGAP) takes into account the practices like soil & water management, nutrient management and disease and pest management, harvesting and post-harvest handling etc with emphasis on the quality and quantity food production. Though the INDGAP implementation is voluntary and non-discriminatory to the growers but the adoption of certain minimum standards with a well-defined certification and accreditation procedure can surely facilitate increased national and international trade of Indian farm produce. QCI has also defined the detailed certification procedure for GAP produce, where the grower can seek certification as an Individual or a group from accredited certification agencies (http://www.qcin.org/indgap-certification.php). The Indian Good Agricultural Practices is inclusive of GlobalG.A.P. standards, best practices, prevalent industry standards and related ISO standards and relevant guidelines. The Indian GAP standard covers control points and compliance criteria as per Indian Farming Practices and regulatory requirements and the main components of this standard are based modules viz., all farm base module and crop base module and crop-based modules viz., Fresh fruits and vegetables, Combinable crops, Tea and Green Coffee. ICAR-CPRI has adopted these regulations in formulating ‘Indian GAP for Production of Potato Crop’.

Key components of Indian Good Agricultural practices for potato Production:

Soil management: The success of sustainable farming relies on wise integration of site-specific knowledge and practical experiences into future management planning and practices. A wise selection of the most appropriate site will help to minimize the risk of quality deterioration of produce and will ensure safe potato production as well as environmental conservation. The practise of crop rotation is a basic strategy to control pests, diseases and weeds and maintain fertility and productivity of the soil.

Crop management: All the recommended field operation in accordance with potato crop and variety should be done to provide better environment, soil structure and texture and keep it free from weeds for initial days. So far 61 potato varieties have been bred for different agro-climatic regions of the country with 36 varieties alone for north Indian plains. Varieties have also been developed for north Indian hills and other special problem areas viz. Sikkim, North Bengal hills and south Indian hills. Among them, 22 possess multiple resistances to various biotic and abiotic stresses. Besides, nine varieties are suitable for processing purposes. Precision in planting is essential as optimum variety-specific seed rate; planting depth and geometry will result in not only into better yield but also reduce the load of chemical weed control. ICAR-CPRI has developed INFOCROP-POTATO model to simulate the potato growth and development, to determine the best growing period, to optimize management practices under different agro-ecological regions, and to forecast the accurate yield estimates.

The potato crop is input-intensive and requires optimum cultural practices for achieving higher productivity. Optimum cultural practices depend on delineated phenological phases of crop growth and development viz. pre-emergence, emergence to tuber initiation, tuber initiation to tuber bulking and tuber bulking to termination of bulking. Cultural practices are adjusted in Indian plains in a way so that tuber initiation and development coincide with the period when night temperature is less than 20oC and day temperature is below 30 ^{o}C. This phase is mainly conditioned by proper nutrition and moisture. For this purpose, fertilizer and irrigation requirement in different agro-climatic zones have been worked out through multi-locational trials. Termination of tuber bulking coincides with onset of foliage senescence. By manipulating plant nutrition and moisture, the foliage senescence is delayed for ensuring continuation of linear tuber bulking phase resulting in higher yield. Several profitable potato-based inter-cropping and crop rotations have also been developed for different regions of the country. Potato can be profitably intercropped with wheat, mustard and sugarcane. These cropping systems have helped in maintenance of soil fertility and have improved the fertilizer economy, crop yield and gross returns. Besides, potato cultivation has also been mechanized through fabrication and development of cost-effective tools and implements.

Water management: Efficient use of irrigation water is the key in GAP and hence irrigation should be triggered by appropriate forecasting and by technical equipment. Use of optimal and quality irrigation water as per crop’s requirement is GAP. The most efficient and commercially practical irrigation system should be adopted with proper drainage, water harvesting and conservation methods.

Nutrient management: Nutrient management should be soil test based and variety-specific and should be the integration of organic and inorganic sources. Apart from macro-nutrients, micro-nutrient requirements should also be fulfilled. GAP for nutrient management should include preferred use of organic manures over in-organic sources.

Weed management: Adoption of recommended integrated weed control strategy helps to address the MRL issues. Integration of cultural and mechanical weed control measures in crop cycle and crop-based cropping system should be followed for minimal use of weedicides. An expert system (Potato Pest Manager and Weed Manager) has also been developed by ICAR-CPRI for decision support with respect to identification and management of diseases, pests and weeds.

Pest and diseases management: Integrated Pest Management (IPM) is the careful consideration of all available pest control techniques and the subsequent integration of appropriate measures to avoid development of pest populations, and keeps plant protection products and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. Late blight is the most notorious disease of potato which occurs almost every year in hills and plains. Besides chemical control measures, several late blight resistant varieties have been developed. Varieties have also been bred which possess resistance to wart and cyst nematodes. Cultural and biological control measures have also been developed to control diseases and pests. Development of late blight forecasting system for hills and plains is helping in providing early warning to potato growers for adopting suitable control measures before appearance of this disease. Follow only crop-specific recommended IMP packages and crop-specific chemicals with prescribed dose, time of application, application method etc.

Harvest and post-harvest management: Harvesting at proper physiological maturity determines storability and quality traits of produce. In India, most of the potato produced in winter is stored during long hot summer. There are a number of traditional low-cost and non-refrigerated storage structures (based on evaporative or passive evaporative cooling) in use in different part of India. These traditional structures have been studied, validated and popularized for particular regions. In non-refrigerated storages, use of sprout suppressants has also been popularized to prevent excessive weight loss and shrinkage due to sprouting. However, bulk of produce requires cold stores functioning at 2-4 0C, which involves substantial cost. It also leads to accumulation of reducing sugar in tubers resulting in sweetening of potatoes. This system was improvised for table and processing potatoes by the Institute and elevated temperature (10-12 0C) storage technology was developed by using CIPC (isopropyl-N-chlorophenyl carbamate) an effective sprout inhibitor applied @ 25 mg a.i. per kg tubers.

Harvesting, handling and storage must be done as recommended. Minimum contamination is most crucial objective in handling of produce after its harvest.

Personnel and equipment: All the agro-inputs viz, fertilizers, pesticides, weedicides to be stored and used as per GAP regulations. Key resource person at farm must be familiar with all aspects of the crop, its management and produce, quality etc. Workers should also have training on specific skills, hygiene and safety aspect. All machinery used in fertilizer and chemicals application should be calibrated, maintained as per at prescription. The person responsible for various farm operations must have sound knowledge about it and should be training for it.

Workers health, safety and welfare: Farmworkers are the basis for efficient & better quality production, along with maintenance, safety and conservation of environment. Hence they should get all facilities, safety, hygiene and health as per GAP compliance. A farm should have a written risk assessment document for various on-farm and off-farm operations and a comprehensive procedure for handling emergency situation.

Traceability: In GAP certification, it's mandatory to keep a record of each and every on-farm and out-farm operations. Traceability facilitates the fast, accurate and efficient withdrawal/recall of doubtful produce from the supply chain. There should be documented identification and traceability system of produce, which facilities it's tracking.

Record keeping and internal self-assessment/internal inspection: Internal self-assessment is a useful exercise for GAP compliance. Maintaining Records of farm-level operations and input use for internal self-assessment helps in adoption of corrective measures during process of crop cultivation and marketing.

Waste and pollution management, recycling and re-use: Proper disposal of non-recyclable material is crucial. A comprehensive, documented strategy should be in place after a review of current farm practices for minimum waste production, recycling and re-use of waste.

Environment and Conservation: Farming and the environment are inseparably linked hence environmental conservation should be prioritized in farm planning, cropping scheme and individual crop cultivation. The abundance of diverse flora and fauna is beneficial for improving habitats and farm biodiversity. Consider unproductive sites (lowlands or unfertile soils) for conservation of natural flora and fauna. Select fuel-efficient farm machinery and equipment for minimum use of non-renewable energy. Prefer renewable source of energy viz., solar energy for farm power supply.

Complaints: Complaint procedure must be in place and made available on request for GAP related issues. Provision of complaints is the right choice for better compliance of GAP requirements and to strengthen confidence among different stakeholders in supply chain. Use global GAP traceability and recall standards for speedy, transparent and accurate recall procedure.

Recognition of this Scheme:

Agriculture and Processed Food Export Promotion Scheme of APEDA for the Medium Term Expenditure Framework (2017-18 to 2019-20) have subsidized the IndGAP certification cost (http://apeda.gov.in/apedawebsite/Announcements/SchemeGuidelinesMTEF27042018.pdf). Also, Ministry for Integrated Development of Horticulture has subsidize the IndGAP certification cost (https://midh.gov.in/PDF/midh(English).pdf). The financial assistance is encouraging the promotion and adoption of GAP in Indian farming scenario.

For further reading, refer/visit:

FAO 2003, Development of a framework for Good Agriculture Practices, Committee on Agriculture, 7th session, 31 march-4 April, Rome

Global GAP annual report. https://www.globalgap.org/uk_en/

Quality Council of India. (https://www.qcin.org/india-good-agriculture-practices.php)

Organic potato production technology

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Organic products are now having a niche market in the country as well as internationally and potato is one of them. Different regions of country like Indo-gangetic plains, north, eastern and southern hills, and plateau region have enormous potential for organic potato cultivation. Production technology has been developed for this by the Institute for achieving sustainable marketable yields (25-30 t/ha) better than current national average.

National Standards for Organic Production (NSOP): Standards of NSOP are to be met for certification. These consist several components which should be complied by potato growers. When potato growers go for organic agriculture, than initial transition phase is termed as 'conversion period', which is counted from day of first inspection by certification agency. It is essential for establishing organic management system and soil fertility built up at farm site. A holistic site specific plan is prepared for converting a conventional farm into organic one by adhering to all NSOP standards. This period is of at least two years before start of production cycle and certification bodies may decide for extension or reduction of this period depending on past land use and surrounding environment. Farm produce shall be properly labeled and sold as 'produce of organic agriculture in conversion' during this period.

National Programme on Organic Production (NPOP) norms for weed, pest and disease management: Basic requirements of NPOP for weed, pests and disease control should be met to avoid rejection of produce. Use of synthetic herbicides, fungicides, growth regulators, synthetic dyes, insecticides and other pesticides are prohibited. Genetically engineered organisms or products are also prohibited in organic cultivation. Farmers have to maintain product content and use records for inspection by the certification body.

Variety: NSOP norms suggest that varieties in organic farming should be adapted to local soil and climatic conditions, and should be resistant to pests and diseases. Genetic diversity should be taken into consideration while choosing varieties of different crops in a crop scheme.

Table 1: Promising potato varieties under organic farming in plains

Variety	Tuber yield (t/ ha)		Duration (Days)	Resistance
	Marketable	Total		
Kufri Khyati	28.4	31.4	70-80	Early and late blight
Kufri Mohan	28.3	29.9	90-100	Late blight
Kufri Garima	27.0	29.3	90-100	Late blight
Kufri Pushkar	26.1	27.9	90-100	Late blight, wart
Kufri Sadabahar	26.0	27.0	90-100	Late blight
Kufri Anand	26.0	27.6	90-100	Late blight, wart, tolerant to frost and hopper
Kufri Himsona	21.5	26.0	110-120	Late blight and wart
Kufri Chipsona-3	20.3	23.1	100-110	Late blight

Table 2: Potato varieties for hills

Variety	Adaptability	Maturity	Yield (t/ha)	Resistance
Kufri Girdhari	Indian hills	100-110	30-35	Late blight
Kufri Himsona	Indian hills	110-120	25-30	Late blight, wart, chipping variety
Kufri Himalini	North Indian hills	90-100	30-35	Late blight,
Kufri Jyoti	Indian hills	90-100	25-30	Early and late blight, immune to wart
Kufri Mehga	North eastern hills	90-100	25-30	Early and Late blight
Kufri Shailza	North Indian hills	90-100	30-35	Late blight
Kufri Swarna	South Indian hills	90-100	30-35	Early and late blight, wart, cyst nematode

Potato Seed: As per NSOP norms, all seed/ planting material should be certified organic. If such material is not available then chemically untreated conventional seed/ planting material may be used. Seed must be procured from a reliable source and replaced within 3-4 years. Use of genetically engineered seed, transgenic plants or plant material is not allowed in organic farming. In potato crop, healthy seed potatoes can be produced by integrating eco-friendly methods for reducing vector (aphid) population below critical limits (20 per 100 compound leaves). Monitoring of aphids is done by placing yellow water trap. Twelve yellow coloured sticky traps (1.0'X1.5'm) per hectare are placed 8-10 days after planting for trapping whitefly and aphids. Height of traps should be adjusted to canopy height. Dried neem leaves are used as mulch in organic plots to reduce insect population by their decomposition and repellant action. Weekly foliar spray of horticulture mineral oil @ 0.5% is done for reducing whitefly and aphid build up. ICAR-VPKAS, Almora and ICAR-NCIPM, New Delhi light traps are used to capture moths of several leaf cutting caterpillars. Seed tubers are withdrawn from cold store 10-15 days before planting and kept in a diffused light under shades with proper ventilation for better sprouting. These can be kept in baskets, wooden boxes and plastic trays or may be spread in a thin layer on floor.

Land preparation: In plains, sub-soiling in initial phase of organic farming is better for soil loosening. It is performed during May- June for breaking hard pan just below the plough layer. Later on higher soil organic carbon and fauna activity keep soil sufficiently aerated and loose for better root development. Pre-planting irrigation is applied 7-10 days before field preparation in case of low soil moisture. Plough the field with a mould board plough or disc harrow up to a depth of 20-25 cm followed by one or two tilling and cross planking. The field should have fine tilth and leveled for efficient use of irrigation water and proper drainage. In hills, soil is ploughed one month before planting and exposed to sunlight to destroy soil borne pest and pathogens. Lime @ 300 kg/ha and *neem* cake @ 300 kg/ ha along with other organic manure is applied before second ploughing and planting is done after 15-20 days. Last ploughing and planking is done 1-2 days before planting.

Planting time and spacing: In plains, optimum planting time starts with maximum day temperatures reaching below 32 ^{0}C. Main season ranges between October to November starting from west to eastern zone. Row-to-row and plant-to-plant spacing is kept at 67.5 cm and 20-35 cm. Plant to plant spacing varies with seed size. Medium seed size tubers (35-45 mm) are planted at 20 cm spacing. Planting depth is maintained at 8-10 cm. Bed planting (two/ three row; base 132 cm) is followed in micro-irrigation.

In hills, summer (February- July) and autumn (August- November) are two distinct planting season. In hills, summer planting started from third week of February and autumn planting started from last week of August. Ridges and furrow method is suitable for potato planting with plant spacing of 60 x 20 cm. Optimum seed size tuber is 30- 50g and it is better to plant medium size tubers in organic cultivation.

Mulching: This is very effective in controlling weeds, conserving soil moisture and decomposing organic residues in soil. Crop residue, dry straw, dry grasses, plant leaves, pine needles and other vegetative material may be utilized for this purpose. Plastic mulching is also permissible in organic agriculture as it is removed from field after use either for re-use or disposal as per guidelines of certification body.

Nutrient management: As per NSOP guidelines, only on-farm produced microbial, plant or animal origin biodegradable materials are used for plant nutrition. Outside material is used with restrictions. Non-synthetic mineral fertilizers are also regarded as supplementary source. Restrictions are there for their use such as mineral potassium, magnesium fertilizers, trace elements etc. Manures containing human excreta are prohibited for preventing transmission of pests, parasites and pathogens in food. All synthetic nitrogenous fertilizers are prohibited. Application of well decomposed biogas slurry, farmyard manure, compost, vermi-compost, crop residue recycling and any safe organic source is beneficial for potato crop. Example for food grain based organic potato cropping system is mentioned in Table 3 for plains. In hills, apply well decomposed FYM @ 20t/ha + bamboo leaves ash @ 2.5 t/ha + rock phosphate @ 140 kg/ha or vermicompost @ 12 t/ha + bamboo leaves ash @ 2.5 t/ha + rock phosphate @ 140 kg/ha or organic poultry manure @ 7.5 t/ha + bamboo leaves ash @ 2.5 t/ha + rock phosphate @ 140 kg/ha at planting. Apply dry powder form of cow dung/ FYM @ 5 t/ha at earthing up. Use of bio-fertilizers is beneficial in organic agriculture. Apply *Azotobacter*/ *Azospirillium*, Phosphate Solubalizing Bacteria (PSB) and Potash Mobilizing Bacteria as a seed treatment or Apply *Azotobacter*/ *Azospirillium* @ 2.5 kg/ha, PSB @ 2.5 kg/ha and Potash mobilizing bacteria @ 2.5 kg/ha as a soil application at planting.

Crop rotation: Potato is a shallow rooted exhaustive crop, so, preceding and succeeding crops should be deep rooted, less nutrient and water demanding. At least one leguminous, vegetables or green manure crop should be included in the system. Continuous cultivation of potato crop is avoided to reduce disease and pest build up, so, two- three year crop rotation may be adopted. Potato growers can choose potato cultivars and adjust crop duration suitable to their overall farming situation. Decision is taken similarly for other crops included in cropping/ inter-cropping systems. In west- central plains, maize- potato- onion, groundnut- potato- green gram, basmati rice- potato- late wheat, cowpea (vegetable)- potato- okra and groundnut- potato- maize+ green gram sequence were found promising. In hills, crop rotations are affected by altitude, direction of slope and availability of irrigation water. In north-western & central hills, potato- vegetable pea, potato- radish, potato-turnip, potato- carrot, potato- fenugreek, potato- spinach, maize- toria- potato, maize- vegetable pea- potato, potato+ French bean, potato+ maize, potato+ garlic are better cropping/ inter-cropping systems. Promising rotations in north- eastern hills are rice- potato, maize- potato, radish- potato, cauliflower- potato, cabbage- potato, potato- beans, potato- barley and rice- potato- green gram. Maize- potato is common system in north Bengal and Sikkim hills. In southern hills, potato- cabbage, potato- carrot, potato- radish, potato- cabbage- radish and potato + French bean are suitable potato based cropping system for organic agriculture.

Green manuring: This practice improves productivity, enhances soil fertility and controls weeds, pests and diseases. It also helps in reducing incidence of soil-borne diseases like black scurf and common scab etc. in potato crop. S*esbania,* sunhemp, cowpea and brassica etc. should be adjusted in crop plan of a field. Green manure crop should be incorporated in soil 40-50 days after sowing for its proper decomposition.

Composting and vermi-composting: Composting of crop residues and preparation of vermin-compost is common and very useful technique for utilization of farm waste into crop nutrition. This is invariably indispensible part of organic farming. Several available methods can be used for this activity.

Table 3: Example of doses and method of application for food grain based organic farming system

Nutrient management	Groundnut	Processing potato	Maize+ green gram
Conventional inorganic system	25 N-50 P_2O_5-50 K_2O kg/ha; Band placement	270 N-80 P_2O_5-150 K_2O kg/ha; Band placement and broadcasting	150 N-80 P_2O_5-80 K_2O kg/ha; Band placement and broadcasting
Integrated organic system	Maize+ *moong* bean stover: Approx. 15-19 t/ha; *in situ* incorporation + *Rhizobium, Bacillus subtilis*, *Trichoderma*; seed treatment & mixed with FYM + FYM (2 t/ha)+ vermi-compost (1 t/ha); FYM before sowing, vermi-compost at sowing	Groundnut stover: Approx. 5-10 t/ha; *in situ* incorporation + *Azotobacter*, *Bacillus subtilis*, *Trichoderma*; seed treatment & mixed with FYM+ FYM (15 t/ha)+ vermi-compost (6 t/ha); FYM before planting, vermi-compost at earthing	Potato haulms: Approx. 4-7 t/ha; *in situ* incorporation + *Azotobacter*, *Rhizobium*, *Bacillus subtilis*, *Trichoderma*; seed treatment & mixed with FYM+ FYM (6 t/ha)+ vermi-compost (3 t/ha); FYM before sowing, vermi-compost at 30-35 days
Organic system (Biofertiliser/ microbial formulation): *Rhizobium* (250g/ha seed treatment), *Bacillus subtilis* (250g/ha seed treatment), *Azotobacter* (250g/ha seed treatment), *Trichoderma* (4 kg/ha with 100 kg FYM for mixing in soil)			

Water management: Potato is sensitive to water stress, and stolon formation and tuber initiation are critical stages. In plains, irrigation is applied at 8-10 days interval in initial phase and it is increased to 12-15 days during winter in flood method. Around 50 mm water is applied in each irrigation. Watering is stopped 10-12 days before haulm cutting for better skin setting. Better productivity has been observed with sprinkler or drip irrigation as water is precisely applied in root zone and nutrient losses are minimum. In this case, irrigation is done at 15-25 mm CPE. Generally, drip irrigation is done on alternate days at 100-125% CPE for 30-45 minutes and sprinkler irrigation is done twice in a week at 125-150 CPE for 90-120 minutes in potato crop. Potatoes are grown mainly as a rain fed crop in hills, but if water is available and dry spell prolongs during the season than light irrigation may be given immediately after planting, during vegetative and tuberization phase. Micro-irrigation along with mulching can improve tuber and system productivity in hills under organic cultivation.

Weed Management: Cultural and mechanical methods are adopted for weed control i.e. proper seed bed preparation having good soil moisture, planting of well-sprouted seed tubers at optimum date, proper plant density, companion cropping, mulching, crop rotations and nutrient application in root zone. First 20-40 days in plains and 50-60 in hills are critical for weed control. In plains, inter-cultivation is done at 20- 25 days after planting when plants height is about 10-15 cm. This practice is followed by weed removal, application of organic product for nitrogen and earthing up. In hills, two inter-cultural operations are advised. First hand weeding is done at 35- 40 days after planting, while second is performed at 55- 60 days. Like plains, weeds are removed, organic product is broadcasted in furrows and earthing is done. This practice improves root zone aeration, soil moisture conservation, better utilization of organic products and avoid greening of tubers.

Hot weather cultivation: This is very economic and environmental friendly tool for keeping pests, diseases and weeds below a threshold level. In plains, advantage of hot and dry summer season is utilized in a cropping system for withering all these hazards. Two-three deep field cultivations in this period are very useful for controlling annuals and perennials like *Cynodon dactylon* L. Soil solarisation may be quite useful in specific situations or for premium potato crop like seed etc. This is done using transparent polyethylene (LLDPE) sheet of 0.05 to 010 mm thickness for 30 and 40 days during high temperature period after giving light irrigation to field 48 hours before this practice. These practice in hills may also be adopted particularly in lower altitudes and valleys.

Disease management: Potato crop is affected by various diseases, which are caused by fungi, bacteria, virus and nematodes. Major diseases are early blight, late blight, leaf spot complex, black scurf, common scab, bacterial wilt, soft rot, charcoal rot, potato virus X, S, M,V,Y, stem necrosis, apical leaf curl virus and root knot nematode etc. Integration of cultural and biological methods is permitted in organic cultivation. As chemical control is prohibited, so, suitable integrated disease management may be adopted for controlling one or more potent disease of the region. Growing resistant cultivars and using disease free seed is very important component for all diseases. Green manuring and summer ploughing during summer is also effective in checking such diseases. Tuber damage and injury must be avoided during harvest and post-harvest handling of tubers. Damaged and rotten tubers must be removed from heap before storage. Late blight is controlled by adjusting planting dates to avoid its serious attack and making heavy ridges to reduce tuber infection. Field scouting is done to identify and destroy patches of primary infection by removal of infected plants after drenching them with restricted permitted products. Irrigation should be stopped for some time when weather condition is very congenial *Trichoderma viride* @ 0.7% in liquid formulation and *Bacillus subtillus* @ 0.25% can be used for its control. Spraying should be initiated before appearance of disease and number of sprays may be more depending upon disease severity. Use of copper oxychloride @ 0.2% and copper hydroxide @ 0.2 % have shown lower disease severity, so these can be used for late blight control with permission from certification body. Avoid cultivation of solanaceous crops and apply recommended dose of organic manures/ products for sufficient nitrogen supply for controlling leaf spot complexes. Seed tuber treatment before storage with 3% boric acid for 25-30 minutes followed by drying under shade, and crop rotation takes care of most of the seed/ soil borne diseases like black scurf, fusarium wilt, dry rot, charcoal rot, bacterial wilt and common scab. Soil solarization and bio-fumigation with cruciferous plant species (mustard, radish) is also very effective in controlling such diseases. Diseases like charcoal rot and soft rot require potato harvesting before the soil temperatures exceed 28 °C. Trap crop like marigold in alternate rows can reduce root knot nematodes. Viral diseases are kept in check by field sanitation, regular rouging and controlling weeds in seed crop.

Pest Management: Control of aphids and white flies have been given in potato seed. Other major pests are leaf hoppers and mite, white grubs, thrips, cutworm, caterpillars and potato tuber moth. Avoid planting of potato crop, if temperatures are high to control leaf hoppers and mite. Summer ploughing and tillage before planting expose larvae of white grubs etc. to predators. Use of liquid culture of EPN (*Heterorhabditis indica*) prepared in water and EPN cultured in *Galleria* cocoons reduce white grub larvae in soil. Dried *neem* leaves are used as mulch in organic plots to reduce the insect population by their decomposition and repellant action. Light and frequent irrigation will keep thrips population in check. Caterpillars can be controlled by using light traps. Potato tuber moth is controlled by heavy ridging, use of water traps and covering of potato heaps with dried lantana and eucalyptus leaves.

Harvesting: This is done at right maturity of a variety. Stop irrigation 8-10 days before haulm cutting for having proper soil moisture, avoiding formation of soil clods and proper skin setting. Haulms are removed from field and digging is started 10-15 days after haulm cutting. Manual harvesting is done by using hand tools like spade and *khurpa*. Animal drawn plow is another option and harvesting is carried out in big fields by tractor operated diggers. Tubers should be kept in heaps of 1.5m height covered with thick layer of crop residues and left for skin maturity for another 10-15 days. Grading, marketing and storage is done after this process.

Certification of organic produce: Accredited certification bodies in case of NPOP and Regional Councils in case of participatory guarantee system (PGS) are responsible for certifying the organic food products. Certification of organic food is essential to ensure that they comply all the laid out standards. Organic foods should also comply for metallic contaminants, aflatoxins, naturally occurring toxic substances (NOTS), as specified under the Food Safety and Standards (Contaminants, Toxins and Residues) Regulation, 2011.

Useful Links for further information

1. Agricultural and Processed Foods Products Export Development Authority (APEDA): www.apeda.gov.in
2. ICAR-Central Potato Research Institute, Shimla -171001: www.cpri.icar.gov.in
3. *Jaivik bharat*: www.jaivikbharat.fssai.gov.in
4. National Center for Organic Farming: www.ncof.dacnet.nic.in
5. National Program for Organic Production: www.apeda.gov.in/apedawebsite/organic/organic_contents/national_programme_for_organic_production.htm
6. Participatory Guarantee System (PGS) India: www.pgsindia-ncof.gov.in/pgs_india.aspx
7. TraceNet: www.apeda.gov.in/apedawebsite/TracenetOrganic/TraceNet.htm

Fungal diseases of the potato crop and their management

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Potato, an important food has the potential to meet food demand of the fast growing human population. This is going to be the future food crop for the millions especially in the third world countries. Potato production and consumption is accelerating in most of the developing countries including India primarily because of increasing industrialization. Potatoes in India are grown under varied climatic conditions as a result the spectrum of insect-pests and diseases is very large. Therefore, management of diseases and pests is important to realize full potential of the crop. Scope of this chapter is limited to the important fungal diseases of potato, which causes considerable losses to the growers. A brief description of these diseases and their management is given in this chapter.

FOLIAR DISEASES

Late blight (*Phytophthora infestans* (Mont.) de Bary)

It is one of the most devastating diseases of potato and losses up to 85% have been reported if crop (susceptible cultivar) remains unprotected. In India, losses are more in hilly regions where the crop is grown under rain-fed conditions as compared to the plains. Disease appears every year in epiphytotic form in hilly regions whereas in the plains, although it usually appears every year but its intensity is low (traces to 25%). It is only in few years that it assumes epiphytotic form. Recently, late blight has become a serious problem in *kharif* grown potatoes and tomatoes in Karnataka state. The annual average losses to the tune of 15% have been estimated in the country.

Symptoms: Late blight affects all plant parts *i.e.* leaves, stem and tubers. It appears on the leaves as pale green, irregular spots which enlarge into large water soaked lesions. In moist weather the spots enlarge rapidly with central tissue turning necrotic and dark brown or black. Often, the spots have a purplish tinge. On the lower side, white mildew (cottony growth) ring forms around the dead areas. In dry weather the water soaked areas dry up and turn brown. On stems and petioles light brown elongate lesions develop often encircling the stem/petiole. Under favourable conditions, the whole vine may be killed and blackened and the disease spread rapidly killing the entire crop in a few days. Tubers are readily infected while in soil by rain borne spores from blighted foliage. Initially the tubers show a shallow, reddish brown dry rot that spreads irregularly from the surface through the flesh. At low storage temperatures, the lesions usually remain firm and frequently show a metallic tinge especially at the border of healthy tissues.

Epidemiology: Tubers carrying the pathogen are the real carriers and serve as the source of the disease in the subsequent season. In the plains, the pathogen over summers through infected seed tubers in cold stores. Infected seed tubers grow into healthy plants but under conditions favourable for the disease (temperature 10-20ºC and RH>80%) the resting pathogen develops within the infected seed and affects the stem base/lower leaves. Such infected stems and leaves serve as the primary source of inoculum. The pathogen sporulates on the primary lesions and the sporangia so formed are carried over by wind currents/rain splashes to other plants/fields thereby setting a chain reaction. Fungal sporangia are also washed down to soil with rain water or dew and infect the new tubers.

Appearance and buildup of late blight depend solely on weather conditions. There are specific requirements of temperature and humidity for initiation and further buildup of disease. Temperature requirements are different for fungus growth (16-20ºC), spore production (18-22ºC), spore germination

(10-20ºC) and for infection and disease development (7.2-26.6ºC with optimum 18+1ºC). Spore germination and infection requires 100 per cent humidity and spores get killed under low humidity (<75%). Fungal spores are produced during the night and are sensitive to light. Cloudiness favours disease development.

Late Blight Forecasting

Development of late blight mainly depends on moisture, temperature and cloudiness. In India, the rains are heavy and the weather is cool and cloudy/foggy during summer in the hills but in plains the weather is generally clear with scanty rains (during autumn or spring) and therefore, the disease epidemic is not a regular feature. The monsoon moves from East to West in the Himalayas. Therefore, the blight occurs early in the eastern Himalayas. Taking weather parameters in account, Bhattacharyya *et al*. (1982) developed forecasting models for Shimla, Shillong and Ootacamund i.e. i) if the 7-day moving precipitation (30 mm for Shimla, 28.9 mm for Ootacamund and 38.5 mm for Shillong observed to be critical rainfall lines) associated with mean temperature of 23.9ºC or less continues for 7 consecutive days, late blight would appear within 3 weeks. Once these conditions are met, then more accurate prediction based on RH and temperature was developed. It states that if hourly temperature remains in between 10-20^0 C associated with the RH ≥80 % for continuous 18 hr for at least 2 consecutive days, late blight would appear within a week. This model has been put to successful use for predicting late blight in Shimla hills since 1983 and it is still working very well.

Late blight forecasting in the sub-tropical plains is different to that of temperate highlands. In the hills, environmental conditions (temperature, RH, rainfall) favourable for late blight appearance are assured. There are plenty of rains during the crop season which led to high RH (>80%) for most of the crop season. Temperature remains moderate and congenial throughout. It is therefore, possible to rely on weather parameters like, rainfall, RH and temperature for making disease forecasts. Such situations, however, do not exist in the sub-tropical plains, where there are scanty rains during the crop season. In such a situation, role of micro-climate, fog, dew and sunshine becomes critical for the appearance of the disease. A computerized forecasting model ‘JHULSACAST’ has been developed for western Uttar Pradesh using temperature, RH and rainfall data. It consists of two models, one each for rainy and non-rainy years. For rainy years, if i) measurable rains (0.1-0.5 mm) for a minimum of two consecutive days, ii) 5-day moving >85% RH period 50 hrs or more, iii) 5-day moving congenial temperature (7.2-26.6ºC) for 105 hrs or more, blight would appear within 10 days time. For non-rainy years, if 7-day moving >85% RH period 60 hrs or more and 7-day moving congenial temperature (7.2-26.6ºC) for 120 hrs, blight would appear within 10 days time. Besides, decision rules for predicting first appearance of late blight in Punjab under non-rainy conditions have also been developed recently using JHULSACAST model as template. The model specifies that 7-day moving sum of RH ≥ 85% for at least 90 hr coupled with a 7-day moving sum of temperature between 7.2-26.6ºC for at least 115 hr would predict appearance of late blight within 10 days of satisfying the conditions. JHULSACAST has also been calibrated for Tarai Region of Uttarakhand and the plains of West Bengal. Based on JHULSACAST, Decision Support System (DSS) has also been developed which has three components i.e.(i) prediction of first appearance of disease, (ii) decision rules for need based fungicide application, and (iii) yield loss assessment model. Recently, INDO-BLIGHTCAST, a web based model has been developed to predict first appearance of late blight using daily weather data of meteorological stations. This is an improvement over JHULSACAST model as it is applicable pan India and requires only daily weather data and does not need local calibration for different regions.

Disease Management: The disease can be contained if farmers follow the integrated management schedule as follow:

Use of healthy seed: Only disease free seed should be used. Avoid seed from the field which has been infected by late blight in the previous year. The infected tubers should be thoroughly checked for late blight infection. The infected tubers should be removed and buried in the soil. This practice of sorting out late blight infected tubers can also be done at the time of planting. The late blight symptoms are easy to be identified in cut-pieces where bronzing of the flesh can be seen easily.

Use of resistant cultivars: Select varieties which have moderate to high degree of resistance to late blight.

Cultural methods: Important cultural methods include:

i) Selection of well drained soils for potato cultivation.
ii) High ridging to prevent exposure of infected seed tubers which serve as primary source of the disease. Besides, it helps in the reduction of new tuber infection.
iii) Scouting of the field for identifying primary infection foci and their destruction by removal of the infected plants after drenching them with recommended fungicides. Nearby plants should also be sprayed.
iv) As soon as the weather conditions become congenial for late blight, irrigation should be stopped wherever applicable. Only light irrigation may be given later, if required.
v) Destroy and remove the haulms from the field when the disease severity reaches >80% to reduce tuber infection.
vi) Harvest the crop 12-15 days after haulms cutting, sort out the late blight infected tubers and store the seed after treating it with boric acid (3%).

Chemical control: A spray schedule of minimum of four fungicide sprays is recommended. However, the number of sprays may be increased or decreased depending on disease pressure.

I spray: As a prophylactic measure, spray the crop with contact fungicides like mancozeb 75%WP (0.2%), propineb 70% WP (0.2%) or chlorothalonil (0.2%) as soon as the weather conditions become congenial for late blight, or about a week in advance of canopy closure whichever is earlier. Do not wait or allow late blight to appear and establish in the field. Always use a sticker @0.1% for proper sticking and uniform spread of fungicide on leaf surface.

II spray: As soon as the disease is noticed in the field, apply any of the systemic fungicides viz., cymoxanil-based (0.3%) or dimethomorph-based (0.3%) or fenamidone-based (0.3%) fungicides.

III spray: Apply contact fungicides viz. Mancozeb (0.2%), propineb (0.2%) or chlorothalonil (0.2%) after 8-10 days of 2nd application of fungicides. However, if weather is highly congenial, repeat application of systemic fungicides may be resorted to.

IV spray: Apply systemic fungicides or contact fungicides as mentioned above depending on disease severity and weather conditions. Ensure thorough coverage of plants top to bottom with fungicides. Special attention should be given to lower leaves which need to be covered with fungicides.

Early blight (*Alternaria solani* (Ell. & Mart.) Jones & Grout)

Early blight occurs in all the potato growing areas but is common in central India and plateau of Bihar, Jharkhand, Chhatisgarh and Maharashtra. The disease has been reported to cause significant losses (up to 20%) in *Kharif* crops in Ranchi and adjoining plateau region. In north-western and north-easten hills and plains, the disease appears regularly but in lesser significant form since late blight takes over.

Symptoms: Initially the symptoms occur on the lower and old leaves in the form of small (1-2 mm), circular to oval, brown spots. These lesions have the tendency to become large and angular at later stage. Characteristic ‘target board’ concentric rings of raised and depressed necrotic tissue can be observed, often with a chlorotic halo surrounding the lesion. The tuber symptoms comprise brown, circular to irregular and depressed lesions with underneath flesh turning dry, brown and corky. Lesions tend to enlarge during storage and affected tubers later become shriveled.

Epidemiology: The fungus can survive in soil and plant debris particularly in temperate climate. The infected tubers form the primary source of inoculum. The disease is favoured by moderate temperature (17-25^{o}C) and high humidity. Intermittent dry and wet weather is more conducive for early blight.

Phoma leaf spots (*Phoma exigua* Desm., *P. sorghina* Doerema, Doren & Kest.)
Leaf spots caused by *Phoma* spp. also occur widely both in hills and plains. Depending upon the severity, these leaf spots may cause significant yield losses.

Symptoms: Leaf spots due to *P. exigua* are larger (1-2.5 cm) with broad alternate light and dark concentric zones. Affected tubers have grey to greenish black depressed lesions (up to 3cm) on the surface. Leaf spots due to *P. sorghina* are characterized by pin head size spots, which may be oval, circular or irregular (not exceeding 4mm). Infected tubers show grey large lesions (up to 1.7cm).
Epidemiology: These fungi can survive in soil and plant debris and on infected tubers during storage. The infected tubers form the primary source of inoculum. Infection usually appears on the lower leaves near ground level and results in the infection of young immature tubers if not covered by the soil. The disease is favoured by moderate temperature (17-25^{o}C) and high humidity.
Management: The integrated management of early blight and leaf spots is as below:

i) Use disease free tubers for raising the crop.
ii) Removal and burning of haulms of the affected potato crop help in reducing the inoculum in the field.
iii) Cultivation of solanaceous crops, being collateral hosts, nearby potato field must be avoided.
iv) Spray the crop with mancozeb (0.2%), chlorothalonil (0.2%), copper oxychloride (0.3%) and Bordeaux mixture (1.0%).

Soil and tuber borne diseases
Soil and tuber borne diseases are multifaceted in nature. Most of the pathogens have a very long soil phase and also carried through potato tubers. These diseases may cause disfiguring of tubers thereby impairing the quality, tuber rots in storage & transit, and wilts and stem rots in field.

Black scurf (*Rhizoctonia solani* Kuhn)

Symptoms: Almost all plant parts are affected. The fungus attacks young sprouts through epidermis and produces dark brown lesions thereby killing the sprout before emergence, which result in gappy germination. Elongated reddish brown lesions develop on the stem at or below soil surface that may girdle the stem. When the girdling is complete the foliage curl and turn pinkish to purplish. Often aerial tubers are formed as a result of interference in starch translocation. Towards the end of the season, the fungus produces numerous hard, small, dark brown to black sclerotia on the surface of mature tubers. These sclerotia when get deposited continuously, form a black encrustations on the tuber surface. The fungus also causes foliage blight of potato.

Epidemiology: Seed tubers serve as the main source of the disease. In the hills, the fungus survives in the soil throughout the year and is a potential source of the disease. However, high summer temperatures are not conducive for the production of sclerotia and their survival. Therefore, *R. solani* has to over summer either as saprophytic mycelium or by infecting the crops grown during summer period. The soil temperature governs production of sclerotia on the tuber surface. The optimum temperature for growth of the fungus is 25-30ºC and for the germination of sclerotia is 23ºC.

Charcoal rot (*Macrophomina phaseolina* (Tassi) Goid

Symptoms: The pathogen produces three types of symptoms i.e. stem blight, charcoal tuber rot and dry tuber rot. The charcoal tuber rot phase is important under Indian conditions. The first visible symptoms are black spots (2 to 8 mm) surrounding the lenticels and eyes. As the disease advances, the tissue underneath the skin becomes uniformly black up to a depth of 2 to 5 mm. No sclerotia are formed.

Epidemiology: Both tubers and soil may serve as primary source of inoculum. However, soil is the main inoculum source. Soil temperature at or preceding harvest is the most crucial factor for disease development. Temperature below 28ºC almost completely checks the disease. Therefore, in sub-tropics, tuber rottage is less in crop lifted before middle of February. Disease buildup is faster in sandy-to-sandy loam soil as compared to clay soil.

Black dot (*Colletotrichum coccodes* (Wallr.) Hughes (Syn.: *C. atramentarium* {Bek. & Br.} Traub.)

Black dot is commonly found in most potato growing regions. It is generally considered to be a surface blemishing disease of tubers, which downgrades potatoes, destined for table purposes and may affect seed tuber sales due to disease tolerance restrictions. Recent studies indicate that the fungus may be associated with the potato relatively early in the growing season, and with many plants over a wide geographic area. Therefore, yield effects may be more significant than formerly assumed.

Symptoms: Symptoms on leaves are less common than stem or tuber symptoms in the field. Infection of vascular tissue and girdling stem lesions can induce yellowing and wilt like symptoms, which generally progress from plant apices to lower portions of the plant. Wilt symptoms may be confused with those caused by *Fusarium* or *Verticillium*. Small, black, dot-like sclerotia (microsclerotia) are formed abundantly in stem lesions, particularly late in the growing season, and are visible to the naked eye. Sclerotia may form in internal tissues as well. On roots and stolons silvery brown lesions are formed on which characteristic microsclerotia are readily formed-aiding to diagnosis. Infected remnants of stolons oftn adhere to tubers at harvest. Tubers infected with *Colletotrichum* develop dark, grayish lesions which appear similar to silver scurf. However, black dot lesions are more irregular, with undefined margins. They also usually contain microsclerotia which are smaller than those on stolons. Extensive tuber blemishes may increase tuber respiration, resulting in shriveling and tuber shrinkage.

Epidemiology: The pathogen overwinters as microsclerotia occurring free or on colonized plant debris in the soil. The fungus can persist in the soil for at least 8 years. The fungus may also overwinter as sclerotia on infected seed tubers and, therefore, infection of plants may be due to tuber –borne and/or soil borne inoculum. Conidia probably serve as the primary inoculum for infection. Conidia do not germinate at 7^0C, the optimum temperature for germination and infection is between 22 & 28^0C. Roots are the organs most susceptible to infection; stems generally become diseased only after the fungus is well established on the underground stem of the plant. Black dot is commonly associated with high temperature, poor soil drainage and sandy soils, and low nitrogen levels. Other solanaceous plant species and several weed species also act as hosts for *C. coccodes*. In storage, infection and symptom development are favoured by warm, humid conditions.

Management

i) Long rotations (at least five years between potato crops without solanaceous crops) and good irrigation management.
ii) Use disease free tubers for planting.
iii) Deep ploughing will bury infected debris and encourage decomposition.
iv) Soil application of azoxystrobin have shown efficacy against soil borne inoculum.
v) Incorporation of *Trichoderma* through fortified FYM.

Silver Scurf (*Helminthosporium solani* Dur. & Mont.)

It is a common storage disease and occurs wherever potatoes are grown. Now, it has become an economically important disease through reduction in cosmetic quality of washed fresh-packed potatoes. Silver scurf does not usually cause yield loss, but severe seed infection can affect vigour. The disease is also becoming important in potato processing, because crisps made from potatoes with severe silver scurf infection may result in blackened edges, making the product unmarketable. Fresh weight reduction of tubers may also occur due to excessive moisture loss from the tubers through lesions.

Symptoms: There are no above ground symptoms and on roots. However, lesions can be observed on stolons soon after tuber initiation. The most conspicuous symptoms are produced on tuber periderm. The lesions are roughly circular in size, expanding upto several centimeters. The edge of the lesion is regular. The disease gets its name because the lesions are mostly silvery in colour. In soil, established lesions expand rapidly within a few weeks of planting infected seed tubers. Lesions on progeny tubers spread slowly on the surface when in soil. The lesions are usually small at the harvest but enlarge during storage.

Epidemiology: Perpetuation of the disease takes place through soil as well as tuber borne inoculum. Therefore, transmission of silver scurf can occur through infected seed introduced into soil or through conidia present in soil. Conidia produced in storage conditions are released and carried to other tubers via circulating air. Under favourable conditions – moderate to warm temperatures (10-32^oC) and very high humidity or free water-conidia germinate on plant tissue by polar germ tubes and cause infection of tubers.

Management

i) Ensure planting of silver scurf free seed.
ii) Avoid delay in harvest and exposure of tubers to the pathogen in the soil.
iii) Follow rapid drying of tubers after harvest.
iv) Tubers treated with fungicides (benomyl, thiophanate-methyl, thiabendazole) at planting, at harvest, or at both times can reduce infection but their effects do not usually extend into storage.

Fusarium wilt and dry rot (*Fusarium* spp.)

Symptoms: Variety of symptoms is produced on potato including wilt, stem rot and damping off of seedlings. On tuber they produce spots, necrosis, dry rot and seed piece decay. In wilting, lower leaves turn yellow and the affected plant dries off rapidly. Both stems and tubers at stolon end show vascular browning. In some cases wilting may be accompanied by rotting of stem base. It may cause damping off of seedlings if planted early in the season when temperature is high.
Dry rot is a storage disease and does not become evident until 2-3 months of storage. Rot may occur in any part of the tuber but wounded site and stolon end are the most vulnerable. Initially the infected tissue develops slight depression, which increases, and the skin develops wrinkles in the form of irregular concentric circles. Underlying tissue assumes mealy and brown fungal mycelium.

Epidemiology: Infected tubers and soil are the primary source of inoculum. Dry rot development is affected by tuber age, tuber size, storage conditions, tuber damage and degree of curing. Dry rot infection gets aggravated 5-6 months after harvest. Store temperature ranging 20-28^{o}C is congenial for dry rot development. Wilt is mainly affected by soil temperature and relative humidity. High wilt incidence in early planted crop is mainly associated with high soil temperature.

Powdery scab (*Spongospora subterranea* (Wallr.) Lagerh

Symptoms: The fungus attacks all underground parts of the plant without showing any adverse effect on plant growth. The damage to the tubers is however, more serious. The disease does not affect the potato yields but disfigures tubers, reducing its commercial value and renders them unsuitable for seed purpose. Pimple like spots appears on the surface of young tubers. These spots are circular, smooth and light brown which gradually increase in size and ultimately rupture, exposing a cavity containing a brown powdery mass of spore balls. Deep pustules of powdery scab resemble deep pitted common scab lesions. However, powdery scab pustules are filled with mass of fungal spore ball whereas common scab lesions are empty.

Epidemiology: The fungus over winters through spores in soil and on infected seed tubers. The spores germinate during crop season and produce zoospores in soil, which infect the tubers through lenticels or directly through epidermis. Soil temperature and moisture are the main factors affecting the disease. Low soil temperature (0-15^{o}C) coupled with high soil moisture is ideal for disease development. This disease is a high altitude disease and is seldom noticed below 2500 m amsl and its incidence increases with the increase in altitude.

Wart (*Synchytrium endobioticum* (Schilb) Perc.)

Symptoms: It is a disease of potato tubers and is usually not recognized in the field until the tubers are dug out. The disease is characterized by prominent warty protuberances resembling cauliflower or bunches of 'cocks comb' like proliferated outgrowth on tuber. Sometimes small greenish warty growths on the stalks may be observed near the ground level.

Epidemiology: Wart disease is both soil and tuber borne. Once the soil is contaminated with the resting sporangia, it becomes an important source for the spread of the disease, as winter sporangia are known to remain viable for many years. The chief means by which the disease spreads is through the transportation of material containing resting spores. The disease is worst in wet season. Both winter and summer sporangia can germinate over a wide range of temperature (12-18ºC) if the moisture is favourable.

Wilts

Verticillium wilt (*Verticillium alboatrum* Reinke & Berth.)

Symptoms: The infection starts from the roots and the fungus grows into the stem and colonizes the xylem vessels thereby disrupting the water and mineral supply to the aerial parts as a result plants remain stunted, lack vigour, lower leaves tend to droop and there is loss of turgidity. Vascular bundles of stem and tuber become brown. In tuber initial infection is seen as yellowish discolouration at the stolon end. In tuber, initial infection is seen as yellowish discolouration at the stolon end.

Sclerotium wilt (*Sclerotium rolfsii* Sacc.)

Symptoms: Infection starts at the stem base in the form of 1-2 cm dark brown lesions, which gradually enlarge and encircle the stem base resulting in the collapse of plant. The pathogen produces white fungal mat and mustard sized sclerotia on the underground parts within the hyphal mat.

Sclerotinia wilt (*Sclerotinia sclerotiorum* (Lib.) de Bary)

Symptoms: The disease occurs on the stem either at the soil line or at the junction with leaf petioles. Early symptoms on stems are the appearance of water soaked areas on which white fluffy mycelial growth subsequently develops, which gradually enlarge and encircle the stem base resulting in the collapse of plant. Rotting of the stem may extend up to 5 cm above the ground. In the later stages of symptom development, large, dark, compact resting sclerotia are formed in stem pith.

Epidemiology: All the wilt causing fungi survive in the soil and plant debris although infected seed tubers my also act as the primary source of inoculum. *Sclerotium* survives in the soil in mycelial as well as in sclerotial form. The fungus may also survive on collateral hosts. The fungus gets aggravated at high soil temperature (25-30ºC) and requires alternate periods of wet and dry soil. Flooding of soil kills *S. rolfsii* thereby reduces the wilt.

Infected tubers and contaminated soil serve as the source of primary inoculum for *Verticillium* wilt. For the perpetuation of the disease the seed surface contamination has been reported to be more important than the internal seed borne inoculum. The pathogen requires comparatively low temperature and therefore, restricted to cooler parts of the country. *S. sclerotiorum* overwinters as mycelium in dead or living plants, but primarily in the form of sclerotia. In soil it can remain viable up to 5 years. It also requires comparatively low temperature (10-27ºC) and therefore, restricted to cooler regions of the country.

Management of soil and tuber borne diseases

Soil and tuber borne diseases primarily perpetuate through infected seed tubers and soil. Their management therefore, requires elimination or lowering down of the inoculum load on the tubers as well as in soil. Management strategies therefore, have to be many fold for combating these diseases.

Cultural practices

Crop rotations and green manuring: When potato crop is planted year after year in the same field, the survivability of the pathogens and their buildup gradually increases over the years. Although, most of the diseases, which infect the potato crop, have wide host range, it is still possible to keep the pathogens population within manageable limits by practicing suitable crop rotations. It has been found that long-term rotation of maize or sun hemp with potato significantly reduced black scurf and charcoal rot incidence. Sesbania, sunhemp and pearl millet are also effective against black scurf. *Verticillium* wilt can be effectively managed if potato crop is grown after two years of Kulth cultivation. Intercropping of potato with maize, rotated with bean or radish was quite effective in the management of potato wart.

Amendment of oil cakes: Oil cakes have mostly been tried for the management of black scurf and *Fusarium* wilt. Buildup of the *Fusarium* population was least in groundnut cake amended soil followed by mustard cake and cotton seed cake.

Adjustment in planting and harvesting time: Some of the soil and tuber borne diseases are temperature sensitive and can be effectively managed by altering the planting and harvesting dates. By advancing the harvest from February 16 to January 30, the incidence of black scurf was brought down by more than 50 %. Similarly, harvesting of potato tubers before the soil temperature crosses 28°C reduces charcoal rot incidence in endemic areas. By delaying the planting from October 1 to October 30 resulted in 36% reduction in *Fusarium* wilt.

Sanitation: Use of disease free seed, weed control and removal of diseased plants/debris from field are some of the cultural practices that reduce soil and tuber borne inoculum.

Soil solarization: Soil solarization by the use of transparent polyethylene sheet is an effective, simple and ecofriendly way of managing soil borne diseases. This method could be useful in tropical and sub-tropical plains where summer temperatures are very high and is practicised during the hottest period of the year. Solarization was superior to deep summer ploughing as it reduced black scurf incidence by 55.6% and russet scab by 58.4%.

Biological Control: Use of *Bacillus subtilis* (B-5) has been found effective against black scurf, common scab, Fusarium wilt and bacterial wilt. A combination of soil solarization and seed treatment with boric acid or *Trichoderma viride* improved black scurf.

Host Resistance: Disease resistant or immune varieties are the best methods to check soil and tuber borne diseases, however, such varieties are available only against few diseases. Varieties immune/resistant to wart disease are Kufri, Sherpa, K. Kanchn, K. Jyoti, Kufri Muthu, Kufri Bahar, Kufri Chmatkar, Kufri Khasigro, Kufri Kumar, Kufri Giriraj, Kufri Chipsona-2, Kufri Anand, Kufri Pukhraj, Kufri Jawahar and Kufri Sutlej. The early maturing varieties like Kufri Chndarmukhi and Up-to-Date are less prone to charcoal rot and may be cultivated in spring. Most of the varieties in India are susceptible to black scurf. However, Kufri Dewa, Kufri Bahar and Kufri Sherpa are comparatively less susceptible.

Chemical Control: Dipping of infected tubers in boric acid (3 %) for 30 minutes or spraying on tubers has been recommended for the management of tuber borne diseases (black scurf & common scab).

Viral diseases of the potato crop and their management

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Introduction

Potato production is not an easy task, as potatoes are affected by multiple key pests, including several viruses which contribute to "running out", or degeneration, of seed stocks. Viral infection cause enormous economic losses particularly in the areas of tropics and semi tropics which provide ideal conditions for the perpetuation of viruses and their vectors. So, any attempt to minimize the losses caused by these diseases must be, always, preceded by a correct and precise identification and diagnosis of the causal agent. Nevertheless, it is very difficult to diagnose the plant virus infections as the symptoms may vary depending upon the plant variety involved, the environmental conditions, strain of the virus. Sometimes different viruses can cause similar symptoms in the same plant species and sometimes the disease could result from the synergistic effect of infection caused by two or more different viruses. Tomato leaf curl New Delhi virus (ToLCNDV), potato leaf roll virus (PLRV) and potato virus Y (PVY) are the most important viruses in India. Viruses once introduced may persist and spread in agricultural environments and under favourable conditions they may multiply rapidly. Therefore, sustainable potato production is possible only if the diseases are kept under check, especially in sub tropics where the weather is highly conducive for common viral diseases.

Potato Mosaics

In general majority of the potato viruses like PVY, PVX, PVA, PVM, PVS, PAMV and PSTVd (viroid) causes mosaics mottling/crinkle, necrosis, etc., either individually or in different combinations. Whereas, *Potato leafroll virus* causes upward rolling and *Tomato leafcurl virus* causes curling of young leaves. These viruses generally infect potato and few other hosts from the family of *Solanaceae* like pepper *(capsicum spp.)*, tobacco *(Nicotiana spp.)*, tomato *(Lycopersicon esculentum)* and other families like *Chenopodiaceae, Leguminosae, Compositae and Amaranthaceae.*

Mosaics are the most common symptoms expressed by plant viruses infecting potato plants. Overlapping symptoms are invoked by different viruses individually and/or in different combinations, such as typical greening or yellows, mild or severe/rugose mosaics, faint mottle, chlorosis of plants and discolouration or distortion of foliage. Rugosity of leaves is accompanied by interveinal chlorosis and/or interveinal puckering. Besides, there can be necrosis of the veins (lower side), petioles and even inward curling of lamina which may lead to premature defoliation. Mosaics and mottle are prominent in cool and dull weathers.

Latent of faint Mosaics

Potato virus X (PVX): It’s latent in many of the cultivars whereas the severe strains can cause mosaic symptoms and the appearance of mosaics is limited by the veins. Bright day light generally affects visual symptoms, which can be observed under low light or placing a white card below the leaf.

Potato virus S (PVS): Usually latent or very mild or barely perceptible mottle and faint vein banding. Some cultivars develop mild rugosity while few strains invoke bronzing of leaves and in few cultivars tiny necrotic spots can also be seen.

Mild Mosaics

Potato virus A (PVA): Slight and transient mosaics that are particularly visible in cloudy weather. Mosaic faint mottling, slight crinkling of leaves and inter-veinal and veinal chlorosis. These symptoms can be reinforced by placing a sheet of white paper under the leaf.

Potato virus M (PVM): Spoon-shaped leaves corresponding to a soft curling of the leaves (while the potato leaf roll virus produces "cracking" of the roll). Called leaf rolling mosaic or para crinkle It occurs on developed plants, preferentially on the topmost leaves.

Potato virus a (PVA) **Potato virus M (PVM)**

Potato spindle tuber viroid (PSTVd): The symptoms of PSTVd are very obscure and unusual. Generally the plants are slightly stunted, erect, often with curling leaves darker green than healthy. Eyes are numerous in number with distinct eye brows. Tubers are cylindrically longer than normal with tapered ends with cracks upon infection with severe strain of PSTVd.

Severe Mosaic and complex Diseases

Potato virus Y (PVY): Generally the symptoms vary with the strains of the virus or variety of potato i.e., plants will be stunted with mild or severe mosaic, veinal necrosis. Ordinary strain (PVY^{O}) and stipple-streak strain (PVY^{C}) causes necrosis, yellowing of leaflets and premature leaf drops. PVY^{NTN} strains cause mild mosaic and clearly visible raised necrotic ring spots on the tuber surface which later become sunken and skin cracking.

Crinkle (PVX+PVA): Infection of PVA and PVA may lead to heavy blotching of distorted, erect leaves with wavy margins, severe stunting, mottling, necrotic spotting and streaking of leaflets.

Rugose (PVX+PVY): The primary cause of rugose mosaic is due to the infection by PVY but in combination with PVX may result in severe rugose symptoms, stunted growth and leaf drop or curling with veinal necrosis in lower leaves and severe mosaic in upper ones.

Rosette (PVX+PVS+PVM or PVX+PVA+PVY+PVM): Severe stunting of the infected plants with single or a few stems per hill, puckered, roughened leaflets with inward and yielding a few small tubers.

Disease cycle and transmission: Tubers are the main source of infection and all mosaic evoking viruses are tuber perpetuated. Highly contagious viruses and viroid are readily transmitted mechanically by leaf, root or tuber contact of diseased and healthy plants, though the viroid also readily spreads through pollen and true seed. Contagious viruses are also transmitted by the cutting knife, as well as cultivating and spraying equipment's. The other viruses are transmitted mainly by aphid species like *Myzus persicae* and *Aphis gossypii*.

Potato Leafroll

Potato leafroll is one of the most prevalent viral diseases of potato in India. All Indian potato varieties are susceptible to this virus. Infected plants produce only a few, small to medium tubers. Yield loss normally ranges from 20-50% in India but in extreme cases may be as high as 50-80 %.

Potato leafroll virus (PLRV); (syn. = phloem necrosis virus). It is the type species of the genus *Polerovirus*, in the family *Luteoviridae* . PLRV has small, isometric virions (23-25 nm dia) which are primarily confined to the phloem of the infected plants. At genome level, Indian isolates are closer to European and Canadian isolates (95.8 to 98.6 %) than to an Australian isolate (92.9 % to 93.4 % similarity). In nature, potato is the principal host of PLRV yet several plant species, mostly from *Solanaceae*, are known as hosts *viz*., *Daturastramonium*, *Physalis floridana*, *Solanum villosum*. It can also infect some non-solanaceous plants like *Amaranthus caudatus, Gomphrena globosaetc*.

The primary symptoms are confined to top young leaves, which usually stand upright, roll and turn slightly pale in certain cultivars. Most varieties, however, develop reddish/pink colour in top leaves starting at the margins, sometimes accompanied with slight rolling of the leaflets. Secondary symptoms develop when the plants are grown from infected seed tubers. Such symptoms are rather prominent in older leaves, *i.e.* absent or less pronounced on younger top leaves. Infected plants have characteristic pale, dwarfed, and upright appearance with rolling of lower leaves that turn yellow, brittle and are leathery in texture. In some cultivars, a reddish or purple discolouration develops on the margins and underside of the leaves.

Disease cycle and transmission: The virus is tuber borne, transmitted efficiently by aphid in a persistent manner (circulative type i.e. aphids normally need longer feeding periods on diseased and healthy plants). Primary infections are normally caused by the viruliferous aphids coming either from distant or nearby fields and/or diseased volunteer plants arising from the infected tubers. Potato plants infected with PLRV will produce infected tubers. If infected tubers are planted they will give rise to infected plants. The green peach aphid (*Myzus persicae*) is the most efficient and important vector of PLRV and also *Aphis gossypii*. *Macrosiphum euphorbiae* transmits potato strains less efficiently. *M. nicotianae* was found to be an efficient experimental vector. PLRV is not transmitted by mechanical inoculation, seed or pollen but it is transmitted experimentally by grafting.

Apical Leaf Curl Disease

Apical leaf curl disease was first observed during 1999 in northern India and the association of a begomovirus with this disease was confirmed through electron microscopy in the year 2001. Further the virus was confirmed as a strain variant of *Tomato leaf curl New Delhi virus* (ToLCNDV) on the basis of nucleotide sequence of genomic components (2003). The incidence of apical leaf curl disease has been observed to be higher in early planted crop when temperature is high in October, than in November planted potato crop. Recently, 40-70 per cent infection was recorded in Indo-Gangetic plains of India. There are even reports of up to 100 per cent infection causing heavy yield losses. The disease incidence has positive correlation with whitefly population and whitefly infestation period.

It is caused by a strain of *Tomato leafcurl New Delhi virus* (ToLCNDV), a bipartite geminivirus consisting of either one or two ssDNA circles of ~2.8 kb and it is transmitted through whitefly. Infected potato leaves show chlorosis, crinckling, mosaic, curling of apical leaves, pinkish tinge on leaf margins, latter entire plant appears bushy and stunted due to reduced internodal distance.

Transmission and Disease cycle: Under field conditions, the virus is transmitted by whitefly (*Bemisia tabaci*) in a persistent manner. Once an adult has acquired the virus by feeding, it retains the virus for long period. The females are more efficient in transmitting the virus than the males. It is also transmitted through seed tubers from one generation to the next generation. These vectors acquire the virus and transmit from infected plant to healthy potato plants. Once the plant is infected, the infection will be systemic in a given plant and therefore the tubers will also be infected (serves as primary source of infection) with the virus. If this infected tuber is planted then it spreads the virus into the upcoming seedling/plant and again the secondary spread will be by whitefly as mentioned earlier. Therefore, whiteflies play a vital role in secondary spread of the virus. This entire cycle repeats till proper management practices are adopted.

Stem Necrosis Disease

Potato stem necrosis disease (PSND) has become a serious problem of the early crop in the central and western parts of India. Disease incidence up to 90 % was recorded in some parts of MP and Rajasthan. Initially, it was thought to be fungal disease due to necrotic symptoms but later after detailed investigations, revealed the presence of enveloped spheroidal virus-like particles measuring ca 10 to 110 nm in diameter; particles being enclsoed in endoplasmic reticulum-like membrane. Characteristics of the virus like particles showed it to be *Groundnut bud necrosis virus* (GBNV).

It is caused by *Groundnut bud necrosis virus* (GBNV), which is spherical, enveloped particles, ranging from 70-110 nm in diameter and enveloped with glycoprotein. Under field conditions the virus is transmitted by viruliferous thrips in persistent manner. It acquires at nymphal stage and transmits in adult stage. The virus induces necrotic and chlorotic spots on leaves and stem, veinal-necrosis, leaf droop and hanging, blackening and cracking of stem. Distinct wavy concentric patterns with ligh and dark brown necrotic region cover the stem. In extreme cases of infection, cracking and blackening of stems also occur. It also infects *Amaranthus viridis,Pisum sativum*, tomato, sunflower, groundnut. The virus from these hosts induces chlorotic local lesions upon sap inoculation in cowpea var. C-152.

Transmission and Disease cycle: The virus is known to borne transmitted by thrips in a persistent manner. The vector thrips acquire the virus only as nymphs but retain and transmit it throughout their life. Four species, *Thrips hawaiensis, Megalurothrips distalis, Thrips palmi* and *Scirtothrips sp.* have been identified from early plated potato crop within a week of crop emergence. *T. Palmi* is the predominant species and probably most efficient vector. There is a strong positive correlation between the early planting and trips activity which declines with the post-ponment of date of planting to end of October or early November. The high temperature (30 to 35 ºC) and dry weather during September/October are known to be favourable for thrips activity and consequently higher disease incidence and also greater severity.

Diagnostics: Effective management of potato viral diseases depends essentially on their rapid detection, accurate identification and sieving them out through indexing. Diagnostics can be employed for varying purpose which may include:

1. To determine the presence and quantity of the virus in potato crop in order to take plant protection measures.
2. To determine the extent of viral incidence and consequent yield loss.
3. To certify seed potato planting materials for plant quarantine and certification programs.
4. To assess the effectiveness of application of cultural, physical, chemical, or biological methods of containing the viruses.
5. To assess viral infection in plant materials in breeding programs.
6. To detect and identify new viruses rapidly to prevent further spread.
7. To study taxonomic and evolutionary relationships of viral pathogens.
8. To resolve the components of complex diseases incited by two or more viruses.
9. To study pathogenesis and gene functions.

Diagnostic techniques for viruses fall into two broad categories: biological properties related to the interaction of the virus with its host and/or vector (e.g. symptomatology and transmission tests) and intrinsic properties of the virus itself (coat protein and nucleic acid). These diagnostic methods provides greater flexibility, increased sensitivity, and specificity for rapid diagnosis of virus diseases in disease surveys, epidemiological studies, plant quarantine, seed certification, and breeding programs.

Management Strategies: Diseases (mosaics) caused by viruses can be managed by adopting an integrated management as follows:

1) To avoid the spread of contagious viruses/viroid, observe strict sanitation in the field and also in stores, right from harvest to planting.
2) Disinfect all field equipments by dipping in or washing them either with 3% trisodium phosphate or calcium hypochloride (1%) solution.
3) Essentially use disease-free seed stocks from approved or reliable sources.
4) Rogue out the diseased plants carefully along with their tubers and dispose them away from the field at regular intervals during the growing season.
5) Dehaulming the crop before the aphids cross critical level to enforce rigid control of the insect vector and
6) Seed treatment with imidacloprid (200SL) @ 0.04% (4ml/10lit) for 10 minutes before planting.
7) First spray with imidacloprid (200SL) @ 0.03% (3ml/10lit) at the time of emergence of crop.
8) Second spray with thiamethoxam (25WG) @0.05% after 15 days of crop emergence.
9) Combine thermo-and chemo-therapy followed by apical meristem culture for eliminating the viruses from seed tubers to produce pre-nucleus/mother seed stocks.

Integrated management of potato viruses

No single approach as outlined above will yield desirable result. A combination of them or most of them will be the only lasting solotion. Schedule of integrated control of potato viruses include: inspection of seed production areas and rejection of fields with mosaic incidence higher than the prescribed level, killing of vines of seed crop at the recommended date or earlier and not to allow re-growth of the vines, destroy volunteer potato plants and weeds in and around the seed crop, monitor the population of vectors and application of insecticides to keep the aphid vectors below the critical level, use of properly disinfected tools, maintaining proper isolation of the seed crop from virus sources, use of the best quality certified seed tubers for planting, avoiding use of cut tubers as seed for seed crop, planting seed crop at a specified period to avoid exposure of the crop to the vectors, minimising chances of virus spread through farm machinery and stop irrigation 10-15 days before harvest to allow skin curing.

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Bacterial Diseases of Potato and their Management

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Bacterial wilt/ brown rot, soft rot, ring rot, common scab, pink eye and leaf spots are the important bacterial diseases of potato worldwide. In India ring rot (*Clavibacter michiganensis* sub sp. *sepedonicus* and pink eye (*Pseudomonas* species) do not occur whereas leaf spots (*Xanthomonas vesicatoria*) is a disease of minor importance. Among the other bacterial diseases, bacterial wilt/ brown rot is the most destructive disease followed by common scab and soft rot.

Bacterial Wilt

Bacterial wilt or brown rot is caused by *Ralstonia solanacearum*. It is one of the most damaging pathogens of potato and has been estimated to affect potato crop in 3.75 million acres in approximately 80 countries (Floyd, 2007) with global damage estimates exceeding $950 million per year (Elphinstone, 2005). Strains of this pathogen affect more than 450 plant species in over 54 botanical families throughout the world, including a wide range of crop plants, ornamentals and weeds. In India, Losses up to 75 per cent have been recorded under extreme conditions (Gadewar *et al*., 1991). With increase in global temperature, the disease is likely to spread to new areas and affect potato cultivation there.

The disease causes wilting of plants in standing crop and also causes rot of infected tubers in field, storage and transit. Another indirect loss results from the spread of the disease through latently infected tubers (infected tubers without exhibiting visible symptoms) when used as seed. Potato breeder seed production cannot be undertaken in fields having even slightest bacterial wilt incidence. There is zero tolerance to this disease in most international seed certification systems.

Symptoms

The earliest symptom of the disease is slight wilting in leaves of top branches during hot sunny days. The leaves show drooping due to loss of turgidity followed by total unrecoverable wilt (Fig 1a). In well-established infections, cross-sections of stems reveal brown discoloration of infected tissues (Fig 1b). In advanced stages of wilt, cut end of base of the stem may show dull white ooze on squeezing.

Fig 1: Symptoms of bacterial wilt (a); brown discoloration of stem tissues (b); bacterial streaming in clear water from stem cut section of potato (c) infected with *R. solanacearum*

Bacterial wilt in field can be distinguished from other fungal wilts by placing the stem cut sections in clear water as shown in Fig 1c. Within a few minutes, a whitish thread like streaming can be observed coming out from cut end into water. This streaming represents the bacterial ooze exuding from the cut ends of colonized vascular bundles. The same test can also be carried out to see infection in tuber.

In tubers, two types of symptoms are produced; they are vascular rot and pitted lesion on surface. In vascular rot, the vascular tissues of a transversely cut tuber show water soaked brown circles where dirty white sticky drops appear in about 2-3 minutes (Fig 2b). In advanced stages of wilt, bacterial mass may ooze out from eyes (Fig 2c). Such eyes may carry soil glued with the bacterial ooze. The other kind of symptoms is observed as lesions on tuber. The lesions are produced due to infection through lenticels (skin pore). Initially, water soaked spots develop which enlarge in the form of pitted lesion (Fig2a). The tubers may not rot in storage and also may not show vascular browning. These symptoms on tuber surface are more common in north eastern region of India.

Fig 2: External symptoms on tubers (a); vascular browning of tubers (b); rotting of tubers in the field (c) due to *R. solanacearum*

Causal organism

Ralstonia solanacearum is a Gram-negative, rod-shaped, strictly aerobic bacterium that measures 0.5-0.7 x 1.5-2.5 µm in size. For most strains, the optimal growth temperature is between 28 and 32°C; however some strains have a lower optimal growth temperature of 27°C (EPPO, 2004). Strains of *R. solanacearum* have conventionally been classified into five races (related to the ability to wilt members of the family *Solanaceae* (r1), banana (r2), potato and tomato in temperate conditions (r3), ginger (r4) and mulberry (r5) and six biovars (metabolic profiles related to the ability to metabolize a panel of three sugar alcohols and three disaccharides). Based on this classification, potatoes are known to be affected by either r1 (bv 1, 3 and 4), frequent at warmer areas and lower elevations in the tropics, and r3 (bv 2), more common in higher elevations or latitudes. Recently, a new classification scheme has been described for strains of *R. solanacearum*, based on variation of DNA sequences (Fegan and Prior, 2005). Four phylotypes were identified within the species that broadly reflect the ancestral relationships and geographical origin of the strains. Phylotype I contains strains of Asiatic origin which belong to bv 3, 4, and 5. Phylotype II (American origin) contains r1bv1, r2bv1 (Moko disease causing strains), r3bv2 and bv2T strains. Phylotype III contains strains from Africa and Indian Ocean, which belong to bv1 and bv2T. Phylotype IV contains strains from Indonesia, Japan and a single strain from Australia. Each phylotype can further be subdivided into sequevars based on differences in the sequence of a portion of the *endoglucanase (egl)* gene. In India, the bacterial wilt of potato is known to be caused by strains of phylotype I, IIB and IV of *R. solanacearum* (Sagar *et al*., 2014).

Disease occurrence and distribution

Bacterial wilt or brown rot has a worldwide distribution (Elphinstone, 2005). It is a destructive disease of potato especially in tropical and subtropical parts of Asia, Africa, South and Central America and in some soils and waterways in Europe and Australia. In India, the disease is endemic in Karnataka, Western Maharashtra, Madhya Pradesh, eastern plains of Assam, Orissa and West Bengal, Chhota Nagpur plateau, north-western Kumaon hills, eastern hills of West Bengal, Meghalaya, Manipur, Tripura, Mizoram, Arunachal Pradesh and in Nilgiris, Annamalai and Palani hills of Tamil Nadu (Shekhawat *et al*., 2000). Bacterial wilt is a serious problem in Malwa region and adjoining areas in Madhya Pradesh where potato is grown for processing industry (Sagar *et al*., 2013). However, it has not been noticed in the north-western high hills (excluding Kumaon hills) and in the North-western and North-central plains which are major seed producing zones of the country and need to be protected from the introduction of the disease.

Disease cycle

Infected tubers and plant debris in infested soil are two major sources of inoculum. The pathogen infects roots of healthy plants through wounds. Nematodes such as *Meloidogyne incognita* which affect potato roots and tubers increase wilt incidence. Inoculum potential of about 10^7 cfu/g soil favours infection which however is dependent on other predisposing factors. Race 1 has greater ability to survive in soil than race 3 because of the better competitiveness; wide host range and higher aggressiveness of race 1. Mean soil temperature below 15ºC and above 35ºC do not favour the disease development. Soil moisture influences the disease in at least four ways; (i) increasing survival of the bacterium in the soil, (ii) increasing infection (iii) increasing disease development after infection, and (iv) increasing exit of the bacterium from host and spread through the soil. *Ralstonia solanacearum* is capable of causing brown rot in a wide range of soil types and levels of acidity. In majority of the cases, the disease has been reported in acidic soils (pH 4.3 to 6.8) and only in a few cases in alkaline soils (Shekhawat *et al*., 1992).

Several other factors that affect pathogen survival in soil and water also affect disease development. The soil type and physicochemical properties have significant influence on survival of the pathogen. Soils having high clay and silt content with higher water holding capacity are favourable for long survival while high sand contents disfavor its survival. Also, soil moisture and temperature exert a combined effect on survival of the pathogen. The congenial conditions for slow decline of population and virulence for race 1 and 3 are temperature between 10-30ºC, soil moisture between 20-60 WHC, heavy soils and aerobic conditions (Shekhawat *et al*., 1992).

Survival

The pathogen survives through infected seed tubers and in plant debris in soil. Symptomless plants may harbour the bacterium and transmit it to progeny tubers as latent infection. This could lead to severe disease outbreaks when the tubers are grown at disease free sites. High soil moisture, temperature, oxygen stress and soil type affect the survival of the pathogen. The pathogen population declines gradually in soil devoid of host plants and their debris (Shekhawat *et al*., 1992).

Spread

Transmission of *R. solanacearum* from one area to another occurs through infected seed, irrigation water and farm implements. Under favorable conditions, potato plants infected with *R. solanacearum* may not show any disease symptoms. In this case, latently infected tubers used for potato seed production may play a major role in spread of the bacterium from infected potato seed production sites to healthy potato-growing sites (Elphinstone, 2005).

Management

The control of bacterial wilt has proved to be very difficult because of both the seed and soil borne nature of the pathogen and especially in the case of race 1 due to its broad host range. Chemical control is nearly impossible. Soil fumigants have shown either slight or no effects. Antibiotics such as streptomycin, ampicillin, tetracycline and penicillin hardly have any effect; in fact, streptomycin application increased the incidence of bacterial wilt in Egypt (Farag *et al.*, 1986). Biological control has been investigated, but is still in its infancy. Potato cultivars developed in Colombia with a *Solanum phureja* and *S. demissum* background showed resistance to *R. solanacearum* (French, 1985; Hartman and Elphistone, 1994), but the race and strain diversity of the pathogen made it difficult to utilize these in other countries. The absolute control of bacterial wilt, at present, is difficult to achieve, however, economic losses can be brought down considerably using the following eco-friendly package of practices:

Healthy seed: Use of healthy planting material can take care of almost 80% of bacterial wilt problem. Fortunately, bacterial wilt free areas in western and central Indo-Gangetic plains can be the source of disease free seed in India. Tubers should not be cut since the cutting knife spreads the disease and also cut tubers can contact disease from soil easily.

Field sanitation and cultural management: Where the field is already infested, the disease can be minimized by the following agronomic practices:

1. Two to three years' crop rotation with non-host crops like cereals, garlic, onion, cabbage and *sanai* (Indian Senna) reduces the wilt infestation. Solanaceous crops like tomato, brinjal, capsicum, chilli, tobacco etc. should not be cultivated in rotation with potato. Paddy, sugarcane and soybean, though are not hosts of *R. solanacearum*, still they carry the pathogen and contribute to the disease perpetuation and therefore, should be avoided.
2. Pathogen enters in plant through root or stolen injuries. Such injuries cannot be avoided during intercultural operations. Therefore, tillage should be restricted to the minimum and it is advisable to follow full earthing-up at planting.
3. The pathogen perpetuates in the root system of many weeds and crops. Field should be cleaned from weeds and root/foliage remnants and burn them. The pathogen in remnants can be exposed to high temperature above 40ºC in summer in plains and plateau and low temperature below 5ºC in hills by giving deep ploughing. This may cause extinction of pathogen from the field.

Chemical control: Application of stable bleaching powder @ 12 kg/ha at the time of potato planting in furrows along with fertiliser reduces pathogen population from field and gives effective control.

Based on intensive ecological and epidemiological studies at ICAR-Central Potato Research Institute, Shimla, the following practices are recommended for checking the bacterial wilt in different agro-climatic zones of the country.

Zone I: It comprises of non-endemic areas like Gujarat, Maharashtra, north-western and north-central plains. This zone is characterised by hot and dry summer with scanty vegetation (April-June); temperature may go up to 40-43ºC. The bacterial wilt is no more a major problem. Therefore, deep ploughing in summer and use of disease free seed is adequate for the disease control.

Zone II: It includes north-western mid hills (up to 2200 masl), north-eastern hills and the Nilgiris. The zone is characterised by mild summer, profuse vegetation with a maximum temperature range of 26-30^{0}C. Winter temperature may go as low as 3-6ºC. Many weed hosts can provide perpetual niche for colonisation and survival of the bacteria. The use of disease free seed plus application of stable bleaching powder @ 12kg/ha mixed with fertiliser at planting, ploughing the field in September-

October and exposing the soil to winter temperature are adequate for disease control. The application of bleaching powder can be substituted by 2 year crop rotation with crops like wheat, barley, finger millet, cabbage, cauliflower, knol-khol, carrot, onion, garlic etc. Early planting preferably in February and early harvesting are recommended to minimise the exposure of the crop to high temperature which favours the disease.

Zone III: It includes eastern plains and Deccan plateau. The area is relatively rich in vegetation. Day temperature sometimes reaches 38°C. Heavy precipitation occurs due to western disturbances. Eastern plains and Deccan plateau have many symptomless carriers of the pathogen. Therefore, management of the disease is most difficult. However, the disease can be kept under check with practices like use of disease free seed, application of bleaching powder, blind earthing-up and ploughing in March and leaving the soil exposed to summer temperatures during April- May and crop rotations along with clean cultivation.

Zone IV: It includes north western high hills (above 2200 masl excluding Kumaon hills). This zone has a temperate climate with severe winters; daily temperature ranges from –10 to 5°C during December–January. Snow is common during these months. Bacterial wilt is not endemic and the use of disease free seed alone is adequate.

Soft Rot or Black Leg

Bacterial soft rot can cause significant loss of potato tubers at harvest, transit and storage. Losses due to poor handling of the produce, poorly ventilated storage or transit may go up to 100 per cent (Somani and Shekhawat, 1990). Soft rot bacteria usually infect potato tubers which have been damaged by mechanical injury or in the presence of other tuber borne pathogens. Bacterial soft rot develops much faster under warm and humid conditions. The disease also results in blackleg of foliage during the crop growing season.

Symptoms

Initially a small area of tuber tissue around lenticels or stolon attachment point becomes water soaked and develops soft lesions (Fig 3a). Under low humidity, the initial soft rot lesions may become dry and sunken. Under high humidity, the lesions may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. The tuber skin remains intact and sometimes the rotten tubers are swollen due to gas formation.

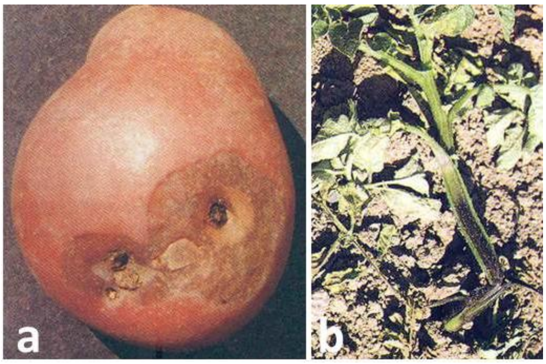

Fig 3: Soft rot symptoms on tubers (a); black leg symptoms (b)

At harvest, many small rotten tubers with intact skin can be seen. The infected seed tubers rot before emergence resulting in poor stand of the crop. In cooler regions, another kind of symptoms called black leg phase develops from soft rot infected seed tubers. The affected haulms become black at collar region just above the ground (Fig 3b). Infected plants develop yellowing, start wilting and die early without producing any tubers. Water soaked lesions develop on succulent stems, petioles, and leaves. On stem and petioles, the lesions first enlarge into stripes, turn black and then invade the affected parts causing soft rot and toppling of the stem and leaves (Perombelon and Kelman, 1980; Somani and Shekhawat, 1990).

Causal Organism

Pectobacterium atrosepticum (syn. *Erwinia carotovora* sub sp. *atroseptica*), *Pectobacterium carotovorum* sub sp. *carotovorum* (Jones) (syn. *Erwinia carotovora* subsp. *carotovora*), *Dickeya* spp. (including *D. dianthicola, D. dadantii, D. zeae*) (syn. *Erwinia chrysanthemi*), *Bacillus polymyxa, B. subtilis, B. mesentericus, B. megaterium* de Bary, *Pseudomonas marginalis* (Brown) Stevens, *P. viridiflava* (Burkholder) Dowson, *Clostridium* spp., *Micrococcus* spp., and *Flavobacterium* have been found to cause soft rot. *Pectobacterium atrosepticum* is the primary enterobacteria causing soft rots. These are gram negative bacteria, rod shaped with peritrichus flagella which can grow both under aerobic and anaerobic conditions. These produce pectolytic enzymes and degrade pectin in middle lamella of host cells, breakdown tissues and cause soft rot and decay of the tubers. The decaying tissue become slimy and foul smelling and brown liquid oozes out from the soft rot affected tubers. About 1500 strains of pectinolytic *Erwinia* have been isolated from infected plants and tubers (Sledz *et al*. 2000). The pathogen produce certain volatile compounds such as ammonia, trimethylamine and several volatile sulphides and early detection of such volatile compounds in storage could be used as a method to detect the disease at initial stage.

Disease occurrence and distribution

Bacterial soft rot is found wherever potatoes are grown. The disease affect the crop at all stages of growth but it is more serious on potato tubers under poor storage conditions especially in warm and wet climate. Black-leg (*Pectobacterium atrosepticum*) phase of the disease is not common in India. It occurs only rarely in the Shimla hills in HP, the Kumaon hills in Uttarakhand, Ootacamund in Nilgiris and also in Bihar plains. Stem and petiole rot due to *Pectobacterium carotovora* sub sp. *carotovora* has also been observed in Shimla, Jalandhar, Ambala, Panipat, Meerut, Agra, Kanpur, Allahabad, and Burdwan.

Disease cycle

Soft rot bacteria may be carried latently in lenticels, wounds and on surface of tubers without any visible symptoms and spread to healthy tubers in stores, during seed cutting, handling and planting . Water film on surface of tuber which cause proliferation of lenticels and creates anaerobic conditions and injury on surface of tuber predispose potatoes to soft rot. From soft rot infected seed tubers bacteria may enter vascular tissues of developing stems and can develop black leg under favourable conditions. From black leg infected plants the pathogen can reach daughter tubers through stolons and initiate tuber decay at the site of tuber attachment (Shekhawat *et al*, 1984). Decaying tubers in soil could serve as source of contamination for healthy tubers. The threshold level for disease development is about 103 cells of *E. carotovora* sub sp. *atroseptica* per tuber. Tubers harvested in wet soil, poor ventilation in transit and storage promotes the rot.

Survival

Soft rot bacteria may survive in soil, on tuber surface, lenticels, periderm, cortex, ground tissue and vascular tissue. Rotting and decay of infected tubers in fields or stores may cause extensive contamination of adjacent healthy tubers, which serves as the most important source of primary inoculums. Contaminated irrigation water, rain splashes, farm implements, soil micro-fauna, nematodes, earthworms, larvae and adults of some insects etc. also help in secondary spread of the disease. Excessive moisture creating anaerobic condition, high temperature, excess nitrogen, tuber injuries and poor ventilation during storage are the important factors helping in disease development.

Spread

In warm climates, where one potato crop follows another or where only short rotation cycles are applied, the bacteria can pass easily from one crop to the next, especially in poorly drained soil. The bacteria can be disseminated in the potato fields by irrigation water, insects, rain or bacterial aerosols. The pathogen may also spread through water during washing of the produce with contaminated water. Soft rot causing bacteria can also spread easily from diseased to healthy tubers during storage, handling and grading. Insects especially maggots of *Hylemyia* species may also transmit the bacteria from one tuber to another.

Management

Soft rot bacteria are carried deep inside the tuber, in lenticels and surface wounds making it difficult to eradicate. These quiescent bacteria proliferate in high moisture condition and require water film that cause anaerobic conditions leading to disease development. Surface injury predisposes the tubers to soft rot infection. Based on ecology and epidemiology of the disease following management practices have been worked out:

1. Avoidance of excess irrigation, provide proper drainage and restrict nitrogen dose to minimum (150 kg/ha)
2. Adjustment in planting time to avoid hot weather during plant emergence. Harvest the crop before soil temperature rises above 28°C
3. Harvesting the crop only when the tuber skin is fully cured
4. Avoidance of injury to tubers and sorting out bruised/injured tubers
5. Treat tubers meant for seed purpose) before storage with 3% boric acid for 30 minutes and dry under shade
6. Storage of the produce either in well-ventilated cool stores or cold stores

Common Scab

Common scab of potato caused by *Streptomyces* species causes superficial lesions on surface of potato tubers and affect quality of the produce. The affected tubers fetch low price in market due to poor appearance and also because deeper peeling is required before consumption. Seed lots exceeding 5 per cent incidence is rejected by seed certification agencies (in India) causing huge loss to seed industry. This disease was first recorded in Patna during 1958. Since then, it has become endemic in various potato growing states. Its real impact is felt in states like Punjab, Uttar Pradesh and Lahaul valley of Himachal Pradesh where potato production is for seed industry.

Symptoms

Scab begins as small reddish or brownish spot on the surface of the potato tubers and its initial infection takes place during juvenile period of tuber. Infection takes place mainly through lenticels and surrounding periderm turns brown and rough. Lesion becomes corky due to elongation and division of invaded cells. Under Indian conditions multiple kinds of symptoms have been recorded and they are grouped as (1) a mere brownish roughening or abrasion of tuber skin (2) proliferated lenticels with hard corky deposition, might lead to star shaped lesion (3) raised rough and corky pustules (4) 3-4 mm deep pits surrounded by hard corky tissue (5) concentric series of wrinkled layers of cork around central black core (Fig 4).

Causal organism

At least 13 different *Streptomyces* spp. have been found to cause common scab on potato worldwide (Hao *et al*., 2009). The prominent among them are *Streptomyces scabis* (Thaxter) Lambert and Loria, *S. acidiscabies* Bambert and Loria, *S. turgidscabis* Takeunchi, *S. collinus* Lindenbein; *S. griseus* (Krainsky) Waksman & Henria; *S. longisporoflavus*, *S. cinereus, S. violanceoruber, S. alborgriseolus*, *S. griseoflavus* and *S. catenulae*. *Streptomyces* are bacteria which resemble fungi due to formation of vegetative substrate mycelium that develop aerial filaments. However, the filaments are of smaller dimensions than the true fungi. These filaments produce spores through fragmentation. *Streptomyces* spp. may be pathogenic or non-pathogenic. The pathogenic species produce thaxtomins which are phytotoxins and cause hypertrophy and cell death. Considerable variation exists within the pathogen with respect to their pigment production in media, colour and shape of sporulating filaments and use of specific sugars. *S. scabies* form grey, spiral spore chains on several media and produce brown pigment whereas *S. acidiscabis* produce peach coloured wavy chains of spores and brown pigment in medium. The identification and taxonomy of *Streptomyces* spp. has been based on morphological and physiological characteristics combined with thaxtomin production and pathogenicity tests *in vitro* and *in vivo*. Ability to produce thaxtomin toxin is strongly correlated with the pathogen's pathogenicity Common scab occurs in most potato producing areas in Africa, Asia, Europe, North and South America. In India, the disease is prevalent in almost all potato growing regions. It is spreading fast in some areas in Indo Gangetic plains due to cultivation of potato year after year in the same field.

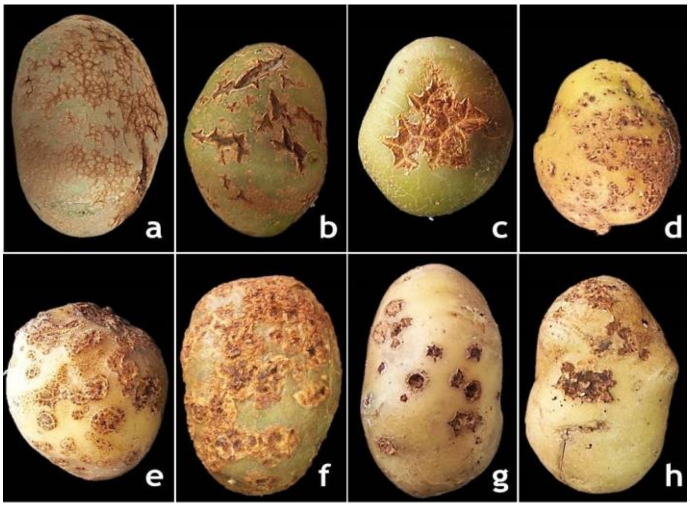

Fig 4: Various types of scab symptoms caused by *Streptomyces* species on potato tubers

Disease occurrence and distribution

Disease cycle

The pathogen is both seed and soil borne in nature. It is generally introduced into fields through infected seed tubers and survives indefinitely once the soil is contaminated. The newly formed tubers, just at the beginning of tuberization, are susceptible to *Streptomyces* species. The pathogen finds its entry into the tubers through stomata or lenticels. Mature tubers with a well-developed periderm are not susceptible to infection. The soil pH between 5.2 to 8.0 or more (Butler and Jones, 1961), temperature in the range of 20 to 30°C (Gaumann and Hafliger, 1945) and low soil moisture (Singh and Singh, 1981) favours the disease development. Other conditions that favour common scab development include continuous cultivation of potatoes and coarse soils that dry out quickly. The pathogen is aerobic in nature and therefore, maintaining high soil moisture for 10-20 days after tuber initiation can help in reducing the common scab.

Disease management

The pathogen is difficult to be eradicated because of long survival both on seed tubers and in soils. Therefore, following practices to minimize the inoculum and creating adverse condition for pathogen spread/disease development are recommended:

1. Use of only disease free seed tubers
2. Tuber treatment with boric acid (3per cent for 30 min.) and drying under shade before cold storage
3. Repeated irrigation to keep the moisture near to field capacity right from tuber initiation until the tubers measure 1 cm in dia
4. Maintenance of high moisture in ridges at least for a few weeks during the initial tubulisation phase
5. Crop rotation with wheat, pea, oats, barley, lupin, soybean, sorghum, bajra, and adopt green manuring to keep the disease in check.
6. Ploughing fields in April and leaving the soil exposed to high temperatures during summer (May to June) in the North Indian plains.

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Insect pest of potato under protected cultivation

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Introduction

India has a great diversity of insect pests that attack potato. These pests can damage potato plants by feeding on leaves, reducing the photosynthetic area and efficiency by attacking stems, weakening plants and inhibiting nutrient transport, and by attacking the potato tubers destined for consumption or for use as seed. Presence of warm, humid conditions and abundant food under protected structures make the favorable condition to flourish the insects. In field conditions natural enemies keeps the insects pest under check, lakes under protected cultivations. The damage caused by arthropod pests under protected cultivation varies from pest to pest and the stringent conditions maintained while entry, and other operations. The potato cultivation may be seriously threatened mainly by sucking pests as these pests can get access to protected cultivation through the entry point, or any hole on the structures.

Aphids (Aphididae: Hemiptera)

Aphids are the most important pests of potato worldwide. Aphids are sap feeding insects but the major damage inflicted by aphids in potato crops is by transmission of numerous potato viruses limiting disease free seed production with a progressive decline in yield. The losses in yield by the aphid transmitted viruses range from 40 to 85%. Common potato viruses transmitted by aphids include *Potato virus Y* (PVY), *Potato leaf roll virus* (PLRV), *Potato virus A* (PVA), *Potato virus M* (PVM) and *Potato virus S* (PVS). Blackman and Eastop (1994; 2000) listed more than 22 species of aphids that commonly infest potato plants. Verma and Chandla (1990) described five major species infesting potato under Indian conditions viz., *Myzus persicae* (peach-potato aphid or green peach aphid), *Aphis gossypii* (melon aphid or cotton aphid), *A. fabae* (black bean aphid), *Rhopalosiphoninus latysiphon* (bulb and potato Aphid) and *Rhopalosiphum rufiabdominalis* (rice root aphid) with notes on biology, life cycle, migration and management.

Biology and Life cycle of major aphid species

Aphids reproduce asexually on potato crops. The nymphs undergo four moults to become adults. Both winged and wingless adults are produced at different points of time or together with variable proportions. The winged aphids are mainly responsible for the spread of the viruses. Individual species show a lot of variation with respect to life cycle patterns. The life cycles of most important aphids infesting potato crops are described as follows.

Fig. 1: Alate (left) and apterous (right) viviparous females of *Myzus persicae*

Fig. 2: Apterous viviparous females of *Aphis gossypii* (left), *A. fabae* group (mid.), and *A. spiraecola* (right)

Nature and symptoms of damage

Both nymphs and adults suck the sap from phloem of potato stems, leaves and roots using their stylets during which virus acquisition and inoculation occur. The non-persistent viruses are transmitted during the brief stylet probes while as the persistent viruses require longer acquisition period ca. 20 minutes. Therefore, the latter are generally transmitted by colonising aphids only. Direct damage due to feeding injury of aphids is almost non-significant in potato while as the transmitted viruses lead to a wide variety of symptoms such as mosaics, yellows, mottle, roll, crinkle, rugose and rosette of potato leaves.

Management

1. Continuous monitoring of the aphid populations is necessary. Aphid populations can be monitored using yellow sticky traps, yellow water pan traps or manual scouting by leaf count method.
2. Spray of Imidacloprid 17.8% S.L @ 0.03% at 75% crop emergence is recommended and same may be repeated at an interval of 12-15 days depending on the stage of crop and level of infestation. The following sprays should preferably be alternated with Dimethoate 30 EC @ 0.03 per cent, Flonicamid 50 WG @ 0.03% and mineral oil @1-3%.

3. Application of mineral oils @ 1-3% successfully protects potato plants from aphids and aphid transmitted potato viruses, in particular the non-persistent viruses.
4. Application of Phorate 10G @ 15 kg/ha in furrows at planting or earthing up keeps the aphid vectors under check up to 45-60 days provided there is enough soil moisture.

1.1. Whiteflies (Aleurodidae: Hemiptera)

Whitefly, *Bemisia tabaci* (Gennadius), is a polyphagous pest of tropical and subtropical areas is a major component in the potato seed production complex in India (Chandel *et al*., 2010) (Fig. 3). Although it does not cause significant direct damage to potato in the field conditions ,but inflict major losses by transmitting the *Tomato leaf curl New Delhi virus* (ToLCNDV) that causes to Potato Apical Leaf Curl Virus (PALCV) Disease (Usharani *et al*., 2004). The whitefly may cause significant direct losses in protected cultivations due to congenial environment. The disease incidence is higher particularly in the Indo-Gangetic plains (40–100% infection) which leads to heavy yield losses in susceptible varieties (Lakra, 2002; Venkatasalam *et al*., 2011). Besides *B. tabaci*, the greenhouse whitefly, *Trialeurodes vaporariorum* is also known to infest potato in glass house condition and in temperate areas. The green-house whitefly is not of much concern and is manageable through general IPM practices in potato crops.


Fig. 3: Adults of cotton whitefly, *Bemisia tabaci* on potato leaves

Biology and life cycle

Whiteflies lifecycle has six stages *viz*., egg, four nymphal instars, and the adult. The female lays on an average 150-300 eggs singly on the under surface of the leaf, which takes on an 4-7 days to hatch. The first instar is the only mobile nymphal stage that moves to look for feeding sites. The other instars don't move and complete their life cycle on the same leaf. The nymphs become adults in 10-14 days. The healthy adult lives for 10-20 days. The total life cycle is completed in 20-30 days under favourable weather conditions.

Nature and symptoms of damage

Whitefly may causes severe damage to potato plants directly by sucking plant sap by remaining underside of leaves and indirectly by transmitting the important viruses in the genus *Begomovirus* under the protected cultivations. Both nymphs and adults suck plant sap from the underside of the leaf, during feeding whitefly also excrete honey dew on which black sooty mould fungus develops which hamper the photosynthesis of plants.

Management

1. Place yellow sticky traps (15 x 30 cm2) just above the canopy height @ 60 traps per hectare at equidistance from each other for mass trapping.

2. Treatment of planting material with Imidacloprid 17.8 SL at 0.04% for 10 minutes and its foliar application at 0.03% at 75% crop emergence followed by Thiamethoxam 25WG @ 0.05% after 15 days is recommended. The sprays can be repeated as per requirement. Various new chemistry molecules like Spiromesifen, IGRs, and knockdown insecticides are also being used across the locations.

Leafhoppers (Hemiptera: Cicadellidae)

Potato leafhopper is a polyphagous pest has worldwide distribution causing significant economic losses to many crops including potato. In India, the leaf hoppers are distributed in all potato growing regions. The potato leaf hopper (*Empoasca devastans* Distant) is known to be most important species, and has long been recognized as a major pest of potato. Potato also witness other leafhopper species to various potato growing regions these include *Amrasca biguttula biguttula* (Ishida), *E. solanifolia* Pruthi, *E. fabae* Harris, *E. kerri motti* Pruthi, *Alebroides nigroscutulatus* Distant, *Seriana equata* Singh and *E. punjabensis* Pruthi.

Life cycle and Damage

Adults *Empoasca devastans* are pale green marked with a row of white spots on the anterior margins of the pronotum. The female lays on an average of 200-300 eggs into veins and petiole of leaves. It takes about 10 days to hatch which give rise to light green, translucent, wingless nymphs which feed by remaining under surface of leaves. It takes about 15 days to develop adults into adult. The adults survive for 30-60 days depending on the weather conditions. The leafhopper can complete two generations on potato in a year. Both nymph and adult are responsible for enormous direct losses sucking cell sap by remaining undersides of leaves. During feeding, leafhoppers inject watery saliva contains enzymes that reduces plant photosynthate movement that causes yellowing, browning, cupping and curling of leaves. The hopper damage can be easily identified by v-shaped burn on leaf tips, starting from the tip of leaves. The leaf hopper is also causing indirect losses by spreading potato viruses like potato yellow dwarf virus and beet curly top virus. It is also act as a vector of purple top of potato, which is caused by aster yellows mycoplasma- like organisms (Misra, 1995).

Management

1. Following certain cultural practices like regular inspection, removal of weeds near field vicinity which act as a source of re-infestation, following proper plant spacing, judicious use of nitrogenous fertilizers and balance use of plant nutrients. Leaf hopper incidence can be minimized by spraying insecticides like diamethoate 30EC @ 2 ml/ liter. Soil application of phorate 10G @ 10 kg/ ha at the time of field preparation give promising results against leaf hoppers (Pandey, 2002).

Mite

The Mite attacking potato is commonly known as yellow mite or broad mites (Fig 4), *Polyphagotarsonemus latus* Banks; it has worldwide distribution and may pose serious threat to potato production.

Biology and Damage

The mites are tiny in size the female is measure about 0.2 mm long and the body is swollen in profile and has light yellow to amber body color. Males look similar to female except size and lake median strip.

Fig 4. *Polyphagotarsonemus latus*

The *P. latus* have four life stages egg, larvae, nymph and adult. The adult female lays about 30 to 76 eggs on underside of leaves which hatch in two to three days. The newly emerged larvae are slow moving and do not disperse much after two to three days the larvae turn to quiescent larvae (nymph) stage. The quiescent male pick quiescent female up and carry them to the new foliage. When females emerge from the quiescent stage is generally known as yellow mite.

Mites are usually found on the upper part of the plant. They feed on apical shoots and on lower surface of young leaves by sucking the cell sap. The feeding produces typical symptoms like bronzing, curling and discoloration of leaves.

Management

Dry weather conditions favor the mite build up so maintaining sufficient moisture through irrigation reduces the mite attack. The mite damage can be avoided by application of wettable sulfur @ 3 gms/ liter The mite eggs cannot be killed by above mentioned mitecides, hence spray of following miticides should be repeated alternatively after eight to ten days. New chemistry acaricides like, Spiromesifen 22.9% W/W SC, Hexythiazox 5.45% EC can be used to manage this menace.

Thrips (Thysanoptera: Thripdae)

Thrips are one of the important pests of potato responsible for direct as well as indirect losses by transmitting tospo viruses. *Thrips palmi* Karny, *Scirtothrips dorsalis* Hood, *Caliothrips collaris* (Bagnall) and *Haplothrips sp*. (Thysanoptera: Phlaeothripidae) are the thrips species associated with potato. Among these, *T. palmi* is one of the predominant species distributed across the potato growing states of India (Fig.5),

Figure 5. Adult Thrips

Biology and life cycle

Adults of *Thrips palmi* are pale yellowish to whitish in colour with numerous dark setae on the body and have pale slender fringed wings. Adult measures about 0.8 to 1.0 mm in length, with females slightly larger than males. Development duration varies from 12 to 20 days depends on weather conditions. Females may lay about 200 eggs in leaf tissues, in a slit cut made by female. The eggs take on an average 4.3 to 16 days to hatch. Larvae resemble adults except for the wing pads and smaller size.

The larvae take 5-15 days to develop to inactive and non-feeding prepupal stages. The pre-pupae and pupae take about 3-12 days to convert into fully grown adult depending on prevailing temperature. The thrips build up is favoured by high temperatures (30–35°C) and low humidity during September–October and these conditions coincide with the early growth phase of potato production in plains.

Nature and Symptoms of damage

Both adult and nymph feed gregariously on leaves, firstly along the midribs and veins and also attack stems particularly at or near the growing tip. They are found in large numbers amongst the flower petals and developing ovaries and the feeding leaves many scars and deformities. Both adults and nymphs are responsible of crop damage by scraping epidermal tissues near the leaves tips and suck the oozing sap resulting in silvering of leaves. With continuous feeding the tips of leaves wither, curl up and die. Thrips also act as a vector of potato stem necrosis disease which brings about 15-30% yield loss in potato in northern Gujarat, parts of Madhya Pradesh and Rajasthan.

Management

1. Installation of Blue sticky traps.
2. The thrips population must be monitored regularly as soon as thrips or its damage symptoms appears, application of Imidacloprid 17.8 SL (0.05%) and Thiamethoxam 25 WG (0.025%) of water provides good control. If the thrips population still persist, then the spray can be alternated with Dimethoate 30EC @ 0.03 %.

Soil and Tuber Pests

Cutworms (Noctuidae: Lepidoptera)

Cutworms are polyphagous and destructive insect pests and are cosmopolitan in distribution. In India, cutworm problem is severe in northern region. Common species include *Agrotis segetum* Denis & Schiffer muller and *Agrotis ipsilon*. *A. segetum* is commonly found in hills whereas *A. ipsilon* is more common in plains. The peak activity of cutworms reported to occurs during May-June in Shimla hills, in August in Peninsular India and in March-April in Bihar and Punjab. In Bihar the tuber infestation up to 12.7 % and in Himachal Pradesh 9-16 % has been reported (Chandel *et al*., 2008).

Biology and Damage

Female moth lays about 600 to 800 eggs eggs either singly or in clusters on vegetation, moist ground or in cracks in the soil. Egg period lasts for about 10-28 days. Young caterpillars are smooth, stout, cylindrical, blackish brown dorsally and greyish green laterally. Fully grown larvae measure 4 to 5 cm in length. Newly hatched larvae feed on the leaves and later on the stems. Older larvae feed at the base of the plants or on roots or stems underground. They are nocturnal in habit and hide during day time under the soil or plant debris. Pupation takes place in an earthen cell in the soil. The life cycle can be completed in 6 weeks under warm conditions.

Other species: *Agrotis flammatra*; *Agrotis spinnifera*; *Agrotis interacta.* larvae are the only damaging stage of pest. Young larvae cause damage by feeding on leaves, stems/seedlings at ground level the larvae also feed on tuber and make irregular holes.

Management

1. Deep summer ploughing before planting to expose various immature stages of pest to natural enemies and high temperature
2. Flooding helps in killing of cutworms in the soil.
3. Installation of light traps for mass collection and destruction of adult moths

4. Hand collection and destruction of early instar gregarious larvae
5. Application of Chlorpyriphos 20 EC @ 2 ml per lit of water at 2 % plant damage with irrigation water.

White grubs (Scarabaeidae: Coleoptera)

White grubs, are highly polyphagous and cosmopolitan in distribution. Potato is mainly attacked by different species across the country among these *Holotrichia longipennis* (Blanchard) and *Brahmina coracea* (Hope) are the predominant in the hills. *Holotrichia serrata* is prevalent in Karnataka, Maharashtra, Andra Pradesh, Tamil Nadu, Kerala, South Rajasthan, the tarai belt of Uttrakhand, and south Bihar (Chandel *et al*., 2008).

Biology and Life cycle:

The adults emerge soon after first pre monsoon shower for soil at dusk, feeds on the leaves of trees Like *Acasia* spp., roses, peach, apricot, pear and apple at hills and Neem at plains etc. and mate during night. At dawn they return to the ground, where the females lay 15-20 eggs in earthen cells. The eggs take 21 to 28 days to hatch. The young grubs feed on the plant roots and rootlets throughout the summer. Larvae pupate inside the soil and convert to adult. The adult beetles start coming out of soil at dusk soon after pre monsoon showers in next year.

Nature and Symptoms of Damage:

- Grubs are the damaging stage. Second and third instar grub which feeds on the underground parts of plant such as roots and rootlets, making shallow and circular holes in the tubers (Fig. 5).

Management

1. Removal of weed plants in the vicinity of crop field. The host trees (*Rubinia*, *Polygonum*, Kaithe and temperate fruit crops) of adult beetles should be pruned.
2. Installation of light traps during May-June at night for mass collection of beetles and killing them in kerosene/chemical treated water.
3. Seed potatoes should be planted at 8-10 cm depth than normal depth of 6 cm.
4. Application of entomogenous fungus, *Metarrhizium anisopliae* @ 5 gm per lit of water.
5. Application of Phorate 10G @ 10-15 kg/ha near plant base at the time of earthing up or drenching of ridges with Chlorphyriphos 20 EC @ 2.5 ml per liter of water when adult beetles appears.
6. Spray host trees with Chlorphyriphos 20 EC @ 2 ml per liter of water immediately after first monsoon showers.

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Potato Nematodes and their management

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Introduction

The Potato cyst nematode (PCN) (*Globodera* spp.) and root knot nematodes (RKN) (*Meloidogyne* spp.) are amongst the most economically important nematode pests of potato. The earliest record of parasitic nematode infestation in potato crop was of the cyst nematode recorded in the year 1881 by Julius Kuhn from Germany. Whereas, RKN was recorded in 1889 by Neal from Florida in USA and ten species are reported to infect potatoes. Two species of PCN *viz.*, *Globodera rostochiensis* (Woll) and *G. pallida* (Stone) also popularly called the Golden nematodes hindering the sustainable production of potato in many countries worldwide including India. They are subjected to stringent quarantine and/or regulatory procedures, wherever they occur and present a serious threat to domestic and international commerce in potatoes. In India, the RKNs infection in potato tubers was first noticed by Dr. Thirumalachar in 1951. He observed scab like warts on potato tubers from Shimla during 1950 which were caused by the root-knot nematodes.

1. Potato cyst nematodes (*Globodera* species)

In India, Dr. F.G.W. Jones first detected the potato cyst nematode in 1961 from a field in Vijayanagaram farm in Udhagamandalam, The Nilgiris district, Tamil Nadu. Later on, their occurrence was reported from other parts of Nilgiri, Kodaikanal hills, adjoining hills of Karnataka, Idukki District in Western Ghats of Kerala and recently, in the hilly regions of Himachal Pradesh. Accordingly, Tamil Nadu Government imposed domestic quarantine during 1971 to ensure strict checking of seed potato for marketing from infested field of Udhagamandalam. In addition, Government of India restricted the movement of potato seeds from some areas of Himachal Pradesh, Jammu & Kashmir and Uttarakhand hills (Gazette Notification S.O.No 5642 (E) dated 2nd Nov, 2018). In India, the differential host reactions of PCN populations from The Nilgiris and Kodaikanal hills revealed that the pathotypes Ro1 of *G. rostochiensis* and Pa2 of *G. pallida* are the most prevalent forms. The other prevalent pathotypes are Ro2 and Ro5 of the former and Pa1 and Pa3 of the later.

Spread of PCN

The PCN normally spreads by the movement of infested soil containing cysts and larvae, movement of seed potatoes from infested fields to the clean fields, irrigation and rain water, raising of seedling from infested area and planting to clean area, movement of compost from infested area, use of agricultural implements first in the infested area and then in clean plots, through shoes of the workers and hoofs of cattle and through the use of old gunny bags in which the potatoes from infested plots were packed/stored previously.

Host range

Potato (*Solanum tuberosum*), tomato (*Lycopersicon esculentum*) and eggplant (*Solanum melongena*) are the agronomic crops attacked by both species on PCN. Other host range of PCN includes mainly *Solanum* species *viz., Datura, Hyoscyamus, Lycopersicon, Physalis, Physoclaina, Salpiglossis* and *Saracha* and *Oxalis tuberosa* Molina, a native Andean tuber crop of economic importance, is also considered to be a host of PCN.

Biology

The hatching of cysts is stimulated by the chemical substances called hatching factors present in the potato root diffusates (PRD) of the host plant roots. The second stage juvenile (J_2) coming out of the cysts moves actively in soil and invade the roots by rupturing with its stylet. It enters through the epidermal cell walls and eventually settles with its head towards the stele and feeds on cells in pericycle, cortex or endodermis by forming a feeding tube. This induces enlargement of root cells and breakdown of their walls to form a large 'syncytium' that provides nourishment for nematode development. The nematode molts and remains in the syncytium until its development is complete. The sex of the nematode is determined during J_3 stage. The females become sedentary, swollen and remain attached to the roots and posterior part of the body comes out by rupturing the root cells. Males retain their thread shape and come out of the roots to locate and mate the females. The immature females of *G. rostochiensis* are golden yellow in colour while *G. pallida* are white or cream in colour (Fig 2). The white PCN remain white or cream-coloured before finally turning brown whereas the yellow PCN passes through a prolonged golden-yellow phase before it also turns brown. After the female dies, the body wall thickens to form a hard brown cyst that is resistant to adverse weather conditions. Each cyst contains 200-500 eggs and is easily dislodged in soil at harvest. The cysts can survive in soil for 20-30 years even in the absence of a suitable host. The life cycle is completed in 35-40 days and generally, one generation is completed in one crop season.

Symptoms & yield loss

The disease caused by this nematode is often referred to as 'potato sickness'. The presence of the golden nematode in soil is often unnoticed in lightly infested crop which does not show any above ground symptoms at all. This is because at low PCN population densities, most plants can tolerate nematode invasion and respond by developing more lateral roots as wound response, without affecting their growth and yield. However, as the degree of invasion increases, the plant is unable to compensate and ultimately exhibits a range of symptoms. When the infestation is sufficiently heavy and localized, small patches of poorly growing plants appear in the field wilting may occur during hot parts of the day (Fig 1). As the season advances, the lower leaves turn yellow and brown and wither, leaving only the young leaves at the top, the entire plant now presenting a somewhat 'tufted head' appearance. The browning and withering of the foliage gradually extends and ultimately causes the premature death of the plant. The root system is poorly developed and the yield and size of the tubers are reduced considerably depending upon the degree of infestation.

Globally, an average yield loss of nine per cent, which is about 43 million tonnes, has been estimated due to this nematode alone. In India, the tuber yield loss estimates vary from 5 to 80% depending on the initial inoculum level. The economic threshold level for crop loss due to PCN is usually around 20 eggs per g of soil, which may vary with the environmental interactions and host tolerance.

Management

Once established, PCN are very difficult to be eradicated from infested fields. As no single method of control is fully effective in giving desirable level of nematode suppression, an integrated nematode management package incorporating judicious blend of various management options such as host resistance, chemical, biological and cultural methods are being advocated to bring down the PCN population to levels that permit profitable cultivation of potato.

Cultural control

Crop rotation

Crop rotation of three to four years involving potato, French beans, peas and peas give nematode reduction and increased the yield of potato. Three to four year rotation with crops like radish, cabbage, cauliflower, turnip, garlic, carrot, green manure crop like lupin etc. brings down the cyst population by more than 50%.

Intercropping

Intercropping of potato with French Beans (3:1), mustard (1:1), radish (2:1) is effective in decreasing the population of PCNs.

Trap cropping

Trap cropping with susceptible potato cutivar, Kufri Jyoti attracted more juveniles than the resistant potato, Kufri Swarna and recorded 53% reduction in nematode population but the trap crops should be destroyed before the completion of PCN life cycle (35-40 days after planting).

Host plant resistance

First cyst nematode resistant cultivar Kufri Swarna was released in year 1985, subsequently "Kufri Neelima" during 2012 and the recent one was Kufri Shayadri during 2019 for Nilgiri hills from ICAR-CPRS, Udhagamandalam.

Chemical control

Application of Furadon 3G at 2 kg a.i./ha at the time of planting is being recommended as a part of package of practices for potato in the Nilgiris to bring down the PCN population Recently, new fumigant molecule Dazomet (Basamid 90G) @ 40-50 g/m^2 also found to be effective in bringing down the PCN population but after application the soil needs to be covered with polythene sheet which may not be possible in larger areas. However, repeated use of nematicides is not only expensive but also hazardous to environment.

After harvesting and curing, seed potato tubers can be treated with Sodium hypochlorite (NaOCl) @2.0% for 30 minutes for disintegration of cyst wall. The solution once prepared can be used for soaking the seed tubers twelve times for a period of 30 minutes per soak without affecting the efficacy on cyst degradation. Even after twelve times if the farmer wishes to use the same solution further, the soaking time is to be increased from 30 to 40 minutes. In addition this treatment had no adverse effect on sprouting of seed tubers.

Bio-control agents and organic amendments

Application of bio-control agents *viz.*, *Pseudomonas fluorescens* and *Paecilomyces lilacinus* and organic amendments like neem cake (5 t/ha) blended with *Trichoderma viride* (5 kg/ha) show promise in suppressing PCN population. Under organic management, incorporation of radish leaves @ 1 kg/m^2 and covering with polyethylene sheet also recorded maximum growth parameters, yield and minimum PCN population.

Integrated management

Inter-cropping of potato with mustard in 1:1 plant ratios combined with carbofuran 3G (1kg a.i./ha) application reduced PCN infestation and enhanced potato yield. Application of *P. fluorescens* (2.5 kg/ha) + neem cake (1 t/ha) + mustard intercrop (between potato rows) + carbofuran 3G (1 kg a.i./ha) increased the tuber yield and decreased the PCN population. For eradication of PCN by soil solarisation (4 weeks) followed by application of neem cake (5 t/ha) in combination with *Trichoderma viride* (5 kg/ha) recorded decrease in PCN population.

Root knot nematode (RKN)

In India, the dominant RKN species affecting potato both in hills and plains has been *Meloidogyne incognita* while *M. javanica* infestation is in mid hills and plains of northern India. *M. hapla* is confined to hilly tracts of Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir and Tamil Nadu. *M. arenaria* is reported form the plains of Uttar Pradesh. Till now, pathotypes belong to particular RKN species have not reported.

Host range

Root-knot nematode species found to infect more than 2000 plants worldwide that includes many important cereals, pulses, vegetables, fruits and ornamental including potato.

Biology

The vermiform second stage juveniles hatch out from the egg masses penetrate the young potato roots and starts feeding. This leads to the formation of specialized, enlarged cells called 'giant cells' which provide nourishment to the nematodes throughout its development. The second stage juveniles (J_2) undergo molting and pass through J_3 and J_4 stages and finally become adult females or males. The adult females are sedentary and pear shaped while males are migratory and vermiform or thread shaped. Males move out of the root to locate and mate the females. The females lay about 300 to 400 eggs in gelatinous matrix, usually adhering to the root galls. At the time of tuber formation, the juveniles usually enter the tubers since the root system would have started decaying. Life cycle is completed in 25-30 days during summer and 65-100 days in winter.

Symptoms & yield loss

The above ground symptoms include stunting and yellowing of plants with chlorotic leaves due to the hindrance in water and nutrient uptake by roots. In roots, the characteristic swellings called 'galls' are formed. The warty 'pimple-like' blemishes on the tubers due to nematode infection reduce the commercial value and keeping quality of potato. Brown spots are evident in the flesh of the cut tubers due to the presence of nematodes. An initial inoculum of 200 juveniles per 100 ml soil resulted in an overall yield reduction of 40% with 100% tuber infestation.

Management

Cultural control

Use of healthy seed tubers and avoiding seed tubers from infected areas. Deep ploughing during summer months exposes the infective juvenile stages of the nematode to direct sun, thereby killing them. Adopting good sanitation and keeping the field free of weeds which otherwise would serve as alternate hosts for root-knot nematode. Crop rotation with non-host crops like maize or wheat helps in minimizing the nematode damage. Early planting of spring crop in first week of January and late planting of autumn crop in second and third week of October reduce nematode infection in potato due to the lower temperature prevailing during crop period. Growing trap crops such as marigold, *Tagetes patula* in alternate rows with potato reduce nematode population in soil.

Chemical control

Application of carbofuran 3G@ 1-2 kg/ha will reduce nematode infestation and increased yield. The efficiency of pesticides will increase when applied in two split doses once at planting and then at the time of earthing up.

Integrated management

Since a single method of control is uneconomical and not adequate for better nematode management, a judicious blend of the above methods is always advisable for achieving higher production. Using of nematode-free seed tubers, crop rotation with maize or wheat and application of carbofuran 3G@ 1-2 kg/ha at the time of potato planting. A two-year adoption of INM for root-knot gives efficient and economical production system.

Fig. 1 Symptoms of field infected with potato cyst nematode

Fig. 2 Infection of *Globodera* species

Potato seed production: Opportunities, challenges and way forward

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Potato is one of the most important horticultural crop world over including India. Among the various root and tuber crops grown in India, potato has the largest share in both area and production. Presently, India has attained potato production of 46.39 million ton from an area equal to 2.02 million hectare (FAOSTAT, 2015). Strong indigenous potato research and development program having domestic varietal development and seed production system is primarily responsible for this advantage. The full production potential of Indian potato varieties has not been exploited so far and there is a lot of scope to increase the productivity of potato in India.

Largely, potato is a vegetatively propagated crop where potato tubers are used as seed but under certain conditions botanical seed (true potato seed) may also be used. On account of vegetative propagation, potato is subjected to large number of pests, seed-borne diseases including viruses which are of particular importance. Due to vegetative mode of propagation, any virus infection in the seed stock continues from generation to generation with increase in titer of the virus. Continuous use of the virus infected seed potatoes for many years' leads to a stage where tuber yields become uneconomical and such a seed stock is called 'degenerated'. It is therefore imperative to use good quality seed for economic production. Hence, continuous supply of healthy seed tubers in sufficient quantity is essential for obtaining the high yields.

Due to high seed rates (2.5-3.0 ton/ ha), seed makes the major input in potato cultivation accounting for almost 40- 50% of the cost of production. True Potato Seed (TPS), which seems to address the major issues associated with vegetative means of potato propagation, has the problem of lateness and heterogeneity. On account of these two problems this technology could not get popularity among the potato growers. Thus, the availability of good quality seed tubers at affordable prices is a major issue for potato cultivation in India.

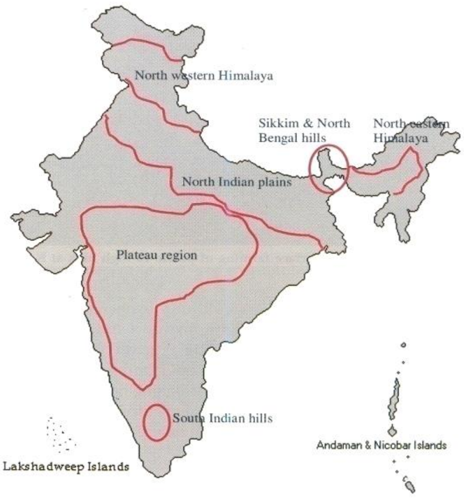
India was meeting its seed potato requirements partly through imports and partly by multiplication in the high hills devoid of vector pressure till 1939. The seed potatoes were imported from various European countries on yearly basis, but with the onset of 2nd World War, European countries put a blanket ban on the export of potato seed to India. To meet this exigency, Imperial Agriculture Research Institute started potato breeder seed production scheme at Shimla and Kufri during 1935. It was the beginning of seed potato industry in the country. There were several problems associated with hill seed *viz.* i) Hill seed was not of right physiological age for use in the plains, ii) it carried soil and tuber-borne pathogens not often found in plains iii) long distance transport and iv) area in hills was insufficient to feed the large requirements of plains.

Seed stocks from the hilly areas of Himachal Pradesh, Jammu-Kashmir, Garhwal hills and Darjeeling were used to be transported to far off states like Maharashtra, Karnataka, MP, UP, WB and Odisha. Seed stocks in hills used to be harvested in September-October. Due to its dormant nature, it could not be used immediately for planting in the plains during October-November. Therefore, a system of late planting (last week of December) was started in the plains. The produce of this crop was used to be preserved in cold stores or farm houses for next early or main crop planting. However, due to late planting, the crop got exposed to high aphid population which resulted in accumulation of aphid transmitted viruses in the seed stocks causing poor productivity during subsequent generations. Keeping in view the limited area for healthy seed production in the hills and infiltration of viruses in late grown spring crop in the plains, efforts were made by CPRI to survey the important potato growing regions of the country from 1952 onwards. During the survey, a remarkable consistency in the aphid population build up was noticed. In the North-Western and Central Indo-Gangatic plains the aphid population remained very low during October to December.

This laid the foundation of development of "Seed Plot Technique" in 1959 which helped production of good quality seed in the plains so as to meet the bulk seed requirement for ware potato production in the sub-tropical plains.

Potato growing areas in country: Potato production in India is highly concentrated in north Indian plains (**Fig. 1a**). Only three major potato producing states of north Indian plains, *viz.* Uttar Pradesh, West Bengal and Bihar produce nearly three quarters of potato in the country. If two other states of north Indian plains *viz.* Punjab and Haryana are also considered then these five states account for nearly 82% of national potato production. In total, plains contribute about 90% of the total area under potato followed by 4% in the plateau region and 6% in the hills (**Fig. 1 b**).

1(a)



1(b).

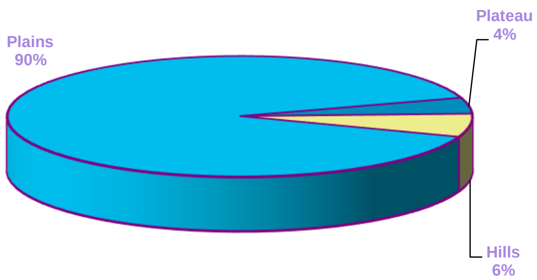


Fig. 1(a & b): Areas under potato cultivation in India.

States like Gujarat, Madhya Pradesh and Karnataka may be smaller players in the field of potato production but these states possess very important place in the production of processing quality potatoes. McCain Foods India sources almost entire supply of raw material from the state of Gujarat.

Seed Potato Production

During the last five decades, seed production has shown spectacular progress in technology development as well as in production strategies. The improvement in quality and quantity of seed potatoes is commendable. At present 94% of the total quantity of seed is produced in eight states of sub-tropical plains and the remaining 6% in hilly states. India is the only leading country in Asia which has developed scientific seed production technology for sub-tropics by taking advantage of low aphid period and absence of soil borne pests and diseases.

Basic requirement for seed production

Basic requirements like suitable areas, soils, fertilizers, manures and suitable varieties *etc.* play vital role in a successful seed production programme. A quality seed can be produced in areas and fields, which are free from serious soil borne pathogens and pests. Among the hills, high hills of Himachal Pradesh above 7000' msl are suitable for the production nucleus and breeders seed. Indo-Gangetic plains of Punjab, Haryana, north-western parts of Uttar Pradesh, Madhya Pradesh and Bihar are also suitable for the production of basic stages of seed during low aphid period from October to January and presently are the primary source of high quality seed. Parts of Madhya Pradesh, Bihar and entire West

Bengal, Odisha, Rajasthan and Gujarat are only secondary source of seed production due to brown rot and aphids. The optimum temperature is 18-22ºC for foliar growth while 10-16ºC is good for tuberization. The crop period and varieties for different seed production zones are given in **Table1**.

Table 1: Crop period and suitable varieties for seed production in different regions.

Zones	Crop Period	Varieties
North-Western hills	Summer (15th April –October)	Kufri Jyoti, K. Himalini, K. Girdhari Kufri Shailja, Kufri Kanchan, Kufri Chandramukhi
North-Western plains	Autumn (1st week October – January)	Kufri Jyoti, K. Chandramukhi, K. Pukhraj, K. Badshah, K. Khyati, K. Sutlej, K. Ashoka, , K. Surya
North -Central plains (MP)	Autumn (3rd week October – January)	Kufri Jyoti, K. Chandramukhi, K. Sindhuri, K. Lauvkar, K. Chipsona I III & IV.
North -Central plains (UP)	Autumn (2nd week October – January)	K. Bahar, K. Sadabahar, K. Badshah, K. Anand, K. Gaurav, K. Chipsona I, III & IV, K. Frysona, K. Surya
North-Eastern plains	Autumn (4th week October – January)	K. Jyoti, K. Chandramukhi, K. Sindhuri, K. Lalima, K. Ashoka, K. Pukhraj, K. Surya, K. Arun, K. Chipsona I, III & IV.

Seed production systems in India

There are two systems of seed production in India. There are organized/scientific seed production and unorganized or informal seed production system (Khurana *et al.,* 2003).

Organized seed potato production:

The organized seed production programme is in operation at Central Potato Research Institute at its five stations *viz.* Kufri in hills and Modipuram, Gwalior, Jalandhar and Patna in plains. The state governments, state seed corporations, national seed corporation and some other agencies are co-ordinating this programme. In this system, seed is produced by employing the modern scientific methods involving the following categories.

i) Nucleus seed
ii) Breeder Seed
iii) Foundation seed
iv) Certified seed.

Nucleus and breeder seed potato production for the country is being taken up by Central Potato Research Institute solely under both conventional and hi-tech (micro-propagation) systems, whereas, the subsequent stages are taken care of by other co-ordinating agencies.

i) Development of nucleus seed potato
a) Conventional System (Clonal Selection and Tuber Indexing):

Taking advantage of seed plot technique, a well organized scientific strategy of breeder seed production was envisaged after 1970 through clonal selection, tuber indexing and stage-wise field multiplication of healthy indexed tubers in subsequent four generations. The conventional system has several limitations like, i) low rate of multiplication ii) more number of disease free propagules are required in the initial stage iii) development of 100% healthy seed stock from infected material is slow and time taking iv) progressive accumulation of degenerative viral diseases in each field exposure and, v) many field multiplications of initial disease-free material (8 years).

b) Hi-tech system (meristem tip culture, micro-propagation and aeroponics):

Keeping in view the limitations of conventional system, ICAR-CPRI, Shimla has standardized a number of hi-tech seed production systems based on tissue culture and micropropagation technologies. Adoption of those systems of seed production will improve the quality of breeder seed, enhance seed multiplication rate and reduce field exposure of seed crop by at least 2 years. The systems were thoroughly tested at seed production farm of ICAR-CPRI before passing them on to farmers and other stakeholders. Adoption of hi-tech seed production systems developed by the institute has led to opening of more than 20 tissue culture production units throughout the country. Several Government/Private seed producing organizations procure virus-free *in vitro* mother cultures of important notified and released potato varieties every year from ICAR-CPRI, Shimla for further multiplication in their hi-tech seed production programmes.

ii) Production of breeder seed

The produce of nucleus seed (Stage-II) is multiplied in 3rd year as pre-basic seed in Stage-III at a normal spacing of 60 x 20cm. This is further multiplied in 4th year as Stage-IV. The produce of fourth year multiplication (Stage-IV) is called **breeder seed** of potato.

Whereas, the mini-tubers produced either from micro-plants or micro-tubers under the poly-house or net-house conditions are multiplied in the field as Generation 1 (Gen.1) at a normal spacing of 60 x 20cm. The produce of Gen. 1 is further multiplied in second year as Generation 2 (Gen. 2). The produce of Gen.2 is called the breeder seed of potato.

The breeder seed of potato produced through micro-propagation is found to be better in health standards than the one produced through conventional system as the field exposures of seed material are reduced to two than four under the clonal system and thus the chances of getting it infected with viruses etc. are exactly the half than the conventional system.

Table 2a: Nucleus and breeder seed production procedure under conventional system.

Field/ Subsequently Stage-I	75 - 80 plants	Singled out from growing crop; indexed individually (4 tubers/plant)
Stage-I	Clonal field multiplication	Spaced 1 x 1m/ 1.2 x 1.2m, 200% tested; rogued; dehaulmed; individual harvest
Stage-II	Separate clones in rows in field	1.0 or 1.2 x 0.2m; 5% clones tested; rogued; dehaulmed, bulk harvest.
Stage-III	Bulk multiplication	0.6 x 0.2m; 300pl/ha tested; rogued; dehaulmed; bulk harvest
Stage-IV	Production of breeders seed	0.6 x 0.2m; 150pl/ha tested; rogued; dehaulmed; quality monitored & bulk harvest.

Table 2b: Nucleus and breeder seed production procedure under Hi-tech system (micro-propagation).

Nucleus seed production	Grow healthy ELISA tested 8-10 tubers.	Test again the plants through ELISA, PCR and ISEM, also give thermotherapy/ chemotherapy treatment and harvest the tubers.
	Let the healthy tubers to sprout or grow as plants, isolate meri-stems, or take nodal cutting/ sprouts	Start meristem culture/ sprout-culture / nodal-culture in lab. and test each mericlone.
	Sub-culture the healthy meri-clones or plants developed in meri-stem culture / sprout culture/nodal culture for 8-10 times.	Randomly check for viruses through ELISA/PCR/ISEM
	Micro-plants can be planted directly under poly/net house for the production of mini-tubers or developed to micro-tubers in flasks under controlled conditions	Check test 5% plants in poly/net houses raised from micro-plants and micro-tubers and do the bulk harvest
Generation 1	Multiply the mini-tubers in the field for the first year as Gen.1	0.6 x 0.2m; 300pl/ha tested; rogued; dehaulmed; bulk harvest
Generation 2	Multiply the produce of Gen. 1 in the field for one more year as Gen.2	0.6 x 0.2m; 150pl/ha tested; rogued; quality monitored; dehaulmed & bulk harvest.

iii) Foundation seed (FS-I & FS-II)

Breeder seed of potato produced by CPRI is supplied to state agriculture/ horticulture departments & National Seeds Corporation for its further multiplication two times as FS-I and II under strict health standards. The FS-I & II seed is inspected and certified by the State Seed Certification Agencies.

However, the current status of breeder seed multiplication by the state governments is not as per the desired seed multiplication chain. The state Govt. organizations multiply the breeder seed one time only up to FS-1.This way there is huge shortage of certified seed in the country.

iv) Certified seed

Certified seed is a further multiplication of foundation-II (FS-II) seed at registered grower's field by following the package of practice in the areas suitable for quality seed production.

Unorganized Seed Production System

Under the unorganized system, the private seed growers, seed traders, private seed companies etc. are involved in seed potato production.

A major portion of seed in the country is produced by these organizations. Largely, the quality of this type of seed is not monitored by any government organization. Therefore, diseases & pests may spread unnoticed from one region to another.

Beside this ICAR-CPRI produces ~ 3,187 metric tonnes of nucleus and breeder seed of 25 popular potato varieties; out of which 70% is through conventional system whereas, 30% through hi-tech systems. As there is limited scope to increase quantity of breeder seed production at ICAR-CPRI farms due to limitation of farm land, possibilities are being explored with the help of SAUs/KVKs/Pvt. farmers to identify the new areas of seed production, multiplication of breeder seed into FS-I, FS-II and

Certified Seed under MoU and to produce seed through hi-tech systems with the help of entrepreneurs/private companies.

Possibility of quality seed production in non-conventional areas in India:

To ensure the better seed availability in the country, possibilities for the production of quality seed potatoes in non-conventional areas must be explored. Such possibilities in non-conventional areas along with the class of seed which can be grown are given in **table 3** below:

Table 3: Possibilities of seed potato production in non-conventional areas.

State	**Type of seed**	**Suitability status**
Rajasthan(Northern)	Foundation and Certified seed	Low vector pressure
West Bengal (Southern)	Foundation and Certified seed (for local use)	High vector pressure
Maharashtra, Karnataka, AP	Quality seed (for local use)	Very high vector pressure and soil borne brown rot
Arunachal Pradesh, Sikkim, Meghalaya, Manipur, Nagaland, Mizoram, Tripura	Foundation, Certified and quality seed (for local use)	High vector pressure, presence of brown rot

Constraints in Seed Potato production:

At present, seed potato production is facing the following major constraints:

- Low rate of multiplication (1:6) and high seed rate (2.5 -3.0 ton/ha).
- Proportion of seed- sized tuber in the produce is low.
- Production costs are very high due to stringent quality control.
- Failure of state departments to multiply the breeder seed as per the guidelines.
- Inadequate infrastructure support and mechanization.
- Non-availability of labour.
- Non-adoption of tissue culture based seed production as per DBT/Scientific guidelines.

Future challenges: The cope up with the present problems associated with seed potatoes as well as to address the farsighted issues, the work on the following lines needs to be done:

- Identification of new seed producing areas using GIS & Crop modeling in non-traditional areas.
- Development & standardization of low cost and efficient mass propagation methods – aeroponics, bio-reactor technology.
- Studies on vector dynamics and its implications on seed quality.
- Development of homozygous TPS populations using apomixis and monohaploidy.
- Impact of climate change on vector dynamics.
- Shortening of potato growing window should be explored.
- Emerging new virus diseases like PALCV, CMV, PAMV, PVYn needs attention.
- Increasing pressure of soil & tuber borne diseases like common scab, russet scab, black scurf, brown rot, *Sclerotium* wilt, *Sclerotinia* stem rot, *Verticillium* wilt and nematodes needs priority management.
- Monoculture of potato as well as increasing cropping intensity needs to be discouraged.
- Mechanization of potato cultivation to overcome the problem of labour scarcity in potato cultivation.

Possible solutions:

- ❖ Attempts should be made for the horizontal increase in area under foundation and certified seed by involving state agricultural universities and other seed producing agencies *viz.* KVKs, private sector companies, growers associations, co-operative societies and progressive growers for multiplication of breeder seed in three assured multiplication cycles. .
- ❖ Mechanism for the strict monitoring of breeder seed multiplication activities should be developed.
- ❖ Farmers based module development and initiatives for quality seed production should be initiated on priority.
- ❖ Increase in area under quality seed production at farmer level should be explored.
- ❖ Vertical increase in multiplication rate by adopting modern high-tech system of seed production should be expanded.
- ❖ Possibilities for production of quality seed in non-traditional areas for regional and local use should be explored.
- ❖ Potato should be declared as food crop and Minimum Support Price (MSP) should be ensured by Govt. of India.

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Hi-tech seed production in potato

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Hi-tech seed potato production including aeroponics is a potential alternative to overcome the everlasting shortage of quality seed potatoes in the country, as the. Due to the advantages that seeds under hi-tech system are produced from typically pathogen tested basic material and can be produced in any region under controlled conditions. Seed potato production involving micro-propagation is finding favour among the seed potato entrepreneurs. The new / Hi-tech system of seed potato production involves raising of *in vitro* plantlets followed by production of mini-tubers under protected conditions and their subsequent multiplications in the field.

Seed production through hi-tech system has been started by Central Potato Research Institute Shimla in the recent past. Under this system, there are three different sub-systems:

i). Microplant based seed production system
ii). Microtuber based seed production system
iii). Aeroponic based seed production system.

Under hi-tech seed production system, nucleus planting material will be produced in the laboratory under controlled condition. The virus free plants will be used as mother plant for micropropagation. The microplants/microtubers will be planted in net-house at 30x10 cm spacing for production of mini-tubers (G-0). The minitubers produced in generation-0 will be multiplied in generation-I at a spacing of 45-60 x 15 cm. The produce of generation-I is further multiplied in generation-II. The produce of stage IV and generation-II will be called as breeder seed and supplied to public and private organization for further multiplication in three clonal cycle's viz. Foundation-1, Foundation-2, Certified Seed. The adoption of hi-tech seed production technologies developed by the Institute has led to opening of more than 20 tissue culture labs throughout the country. Several private seed companies such as M/s Reliance Life Sciences, Navi Mumbai; Cadila Pharmaceuiticals Ltd., Ahmedabad; KF Bioplants, Pvt. Ltd., Pune/Banglore; Transgene Bioplants Pvt. Ltd., Chandigarh etc. are taking virus free in-vitro plantlets from CPRI for further multiplication in their seed production programme.

Micropropagation of disease free mother plant: Soon after varietal release, 10-20 healthy uniform tubers are selected and planted under controlled conditions in the pots in poly/net house for indexing against the viruses. The ideal temperature for plant growth as well as virus multiplication should be 20-25^{0}C. The plants are tested by ELISA for virus freedom after 6 to 7 weeks of planting or 6 to 8 leaf stage. The infected plants with viruses during ELISA testing should be destroyed and only the healthy plants should be retained for further testing by polymerase chain reaction (PCR) for virus freedom. The infected plants obtained during PCR testing are removed. Finally healthy plants obtained during series of testing will be used as mother plant for micropropagation.

Development of healthy mother plants from virus infected plant: Sometimes we may not be getting even a single plant completely free from viruses after releasing of the variety. In such situation, meristem tip culture coupled with thermotherapy has become a powerful and successful tool for virus elimination from infected plants and has been successfully applied in potato for development of virus-free plants. The steps followed during virus elimination through meristem tip culture are described.

The plants are tested against potato viruses and viroids like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. In case, no plant is found free from the virus infection then the plants that are infected with minimum number of viruses are selected for meristem tip culture. Using nodal/sprout cuttings, the *in vitro* stocks of selected plants are developed and further sub-cultured in Ribavarin (20 ppm) modified MS media for chemotherapy. This culture is then given thermotherapy at 37^0C and 16 h photo period (120-200 µmol/m^2/s^{-1}) in the culture room for nearly 20 days. Using stereomicroscope, the apical/axillary meristem (0.2 to 0.3 mm) is excised from *in vitro* plants aseptically with the help of sterile scalpel, needle and blade. The excised meristem is grown in the test tubes containing MS medium with growth regulators and incubated in the culture tubes at 25ºC and 16 h photo period (120-200 µmol/m^2/s^{-1}) in the culture room until the meristem germinates. The meri-clones are then sub-cultured through nodal cutting after it attains a height of 4-5 cm and the pedigree is maintained. The fully grown mericlones should be tested against potato viruses like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. The virus-free cultures should be sub-cultured once in every 3-4 weeks so as to get more number of virus-free microplants. The microplants should be hardened for 2 to 3 weeks in the poly/net house before planting in the pots filled with peat moss under mist in poly house. The plants are further tested against all above said potato viruses through ELISA, EM and PCR after 40-45 days of planting. Remove the infected plants obtained during testing and retain only the healthy plants. Finally healthy plants obtained during series of testing will be used as mother plant for micropropagation.

1. **Microplant based seed production system:** Three to four weeks old microplants are transferred to protrays filled with sterilized peat moss. The microplants can be planted in portray with root or without root (cuttings). For planting with root, the media sticking to the root should be properly washed off. After transplanting, drenching is done with the mancozeb (0.25%) solution. The portrays are then transferred to the growth chambers and kept in dark for 48 h subsequently in 16 h photoperiod for 2-3 days. Once the plantlets are established in portrays (4-5 days), these portrays are transferred to hardening chamber and kept at 27ºC for 10-15 days. The hardened plantlets should be removed from portrays along with peat moss and transplanted on nursery beds in mixture of soil, sand and FYM (2:1:1) in rows at 30 x 10 cm spacing under insect proof net house condition. 5% of the plants are tested by ELISA. Rogue out all virus infected plants, off-type plants, abnormal and stunted observed during inspection**.** Allow the microplant crop to mature and harvest the minitubers. Each microplant shall yield 8-10 minitubers. Seed crop should be harvested 15 to 20 days after haulms cutting when the tuber skin is hardened. The seed tubers thus produced are minitubers. Curing is done by keeping the seed tubers in heap for about 15 to 20 days in a cool shady place. After curing, the seed tuber should be graded into >3 g and treat with 3 per cent boric acid solution for 10-15 minutes to prevent surface borne pathogen inoculum. Minitubers harvested from microplants (Generation-0) are called as nucleus seed. Store the minitubers in country store in hills while cold store at 3-4°C in the plains. Minitubers weighing >3 g will be planted in Generation-l in the field during next season. Whereas, <3 g minitubers may be recycled once again in Generation-0 under controlled poly/net house conditions if the crop meets the G-0 criteria, the produce can be used for raising G-1 crop in the field.
2. **Microtuber based seed production system:** The microplants are tested for virus freedom before initiating microtuber production. The virus-free stock plants are mass multiplied through nodal cuttings on semisolid MS medium in culture tubes (25 x 150 mm) following the standard procedure upto 10 cycles. 3-4 weeks old explants are transferred into 250 ml conical flasks or culture bottles containing 25-35 ml liquid MS medium without agar. The culture tubes are incubated at 25^0C and 16 h photo period (120-200 µmol/m^2/s^{-1}) in the culture room. After 3-4 weeks of incubation, the unutilized liquid propagation medium is decant from the conical flask/culture bottle under aseptic conditions and 30 ml

of microtuber induction medium is poured into it. The microtuber induction medium is based on MS basal media supplemented with 10 mgl^{-1} N^6-benzyladenine (BAP) and 80 gl^{-1} sucrose/commercial sugar. After adding induction medium, the cultures are incubated under complete dark condition at 15^0C for 60 to 90 days depending on the genotype. Microtubers develop epigeally at the apical as well as axillary buds of the shoots. In general, 15 to 20 microtubers weighing 50-300 mg are produced in each flask/culture bottles. Before harvesting, greening of the microtubers is done in the culture room by incubating microtuber induced cultures under 16 h photoperiod (approximately 30 µmol m^{-2} s^{-1}light intensity) at 22-24°C for 10 to 15 days. Then carefully remove the cultures along with microtubers from conical flasks or culture bottles and manually harvest the green microtubers. Avoid damaging the microtubers, especially the thin periderm during harvest. The harvested microtubers are then washed and treated with 0.25% mancozeb for 10 minutes, and allowed to dry in the dark at 20^0C for 2 days. Grading of microtubers in <4m, 4-6mm and >6 mm should be done while packing. Pack the treated microtubers in perforated polythene covers and store in a refrigerator for 4-5 months until planting. Take out the microtubers from the refrigerator after about one month before planting for breaking the dormancy.

3. **Aeroponic seed production system:** The conventional system is quite effective but it has low multiplication rate and higher field exposure increases the risk of viral infection. Keeping this in view, tissue culture based system of quality seed production was integrated with breeder seed production programme. The conventional way of producing potato minitubers through micro propagation is to multiply *in vitro* material in insect proof net houses. The conventional method uses substrate made of soil and mixture of various components. This method usually produces 10-12 minitubers per plant depending on cultivar. The aeroponic system offers the potential to increase production in terms of number of minitubers per plant from three to four times. Aeroponics is the process of growing plants in an air mist environment without the use of soil or an aggregate medium.

Aeroponic system mainly consist of an electrical unit, lightproof growth chambers, nutrient solution chamber, high pressure pump, filters and spray nozzles. Interiors of growth chambers are covered with black lining to avoid any admittance of light to the root zone of plants. Aeroponic unit can be placed under insect-proof net house under natural conditions or under controlled environment conditions. For aeroponics, *in vitro* grown 15-21 days old microplants are required to be hardened before shifting to this system. For hardening, microplants are allowed gradually to acclimatize the outside conditions and are kept at 25-27°C for 7-10days. These hardened plantlets of about 15 cm height are planted in the holes made in the roof of the grow boxes of the aeroponic unit. All essential nutrient elements required for the plant growth are dissolved in water in nutrient tank. With the help of an automatically operated pump, the nutrient solution is regularly sprayed inside the chamber for desired duration of on/off time. By misting the solution round the clock 100% relative humidity was maintained inside the root zone. Rooting starts in a week and developed inside the growth chamber. Stolon and tuber formation initiated at different intervals depending upon cultivar. Sequential picking was done at regular interval. Tubers were harvested when they attained the desired size of 3-10g. Roots, stolons and tubers develop inside the chamber and leaves are exposed to light. Nutrient solution is replenished from time to time and desired pH of 6.0 of the solution is maintained. Tubers are harvested sequentially as they attain the desired size. These minitubers are sequentially cured at decreasing humidity and temperature and stored at 2-4°C and used for planting in the next generation.

The aeroponic minitubers are thus harvested are called as generation-0 (G-0) and are strictly planted under nethouse in Generation-1 (Gen. 1) at a spacing of 30 x 15 cm depending upon the size of mini-tuber. The produce of Gen. 1 is called as pre-basic seed. The produce of Gen. 1 (pre-basic seed) is further multiplied in generation-II (Gen. 2) at a spacing of 45-60 x 20 cm and the produce of Gen. 2 is called as breeder seed or basic seed.

Way Forward:

Seed potato production involving micro-propagation (tissue culture) techniques can overcome many of the problems associated with the conventional multiplication system. The everlasting shortage of seed potatoes in most of the potato growing nations can be overcome through micro-propagation techniques on account of faster rate of multiplication. Besides, rapid multiplication, disease freedom on account of multiplication of disease free mother stocks under controlled conditions followed by reduced number of field exposures as compared to conventional multiplication system is an added advantage of seed potato production through tissue culture techniques. Due to these numerous advantages, the new hi-tech system of seed potato production involving micro-propagation is finding favour among the seed potato entrepreneurs.

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Economics of seed potato production in India

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Introduction

Potato is the third most important food crop in the world after Rice and wheat. China, Russia, India, the United States, and Ukraine are the largest producers of potatoes. Asia alone accounts for half of the world's potato production, with China and India accounting for nearly 35% of the production. India is second largest potato producer after China with a total of 51.3 million MT production during 2017-18 that accounts for about 13.22 percent of world potato production (388.2 million MT)

The potato is one of the most widely cultivated vegetable crops in India. During 2017-2018, it accounted for about 27.82 percent of the total 184.39 million tonnes of vegetable production in the country. Current share of potato to agricultural GDP is about 3% out of 1.32% of cultivable area. Agriculture including allied activities contributed for about 14.39% and its GVA is around Rs.18.43 lakh crore at the constant prices in the FY 2018-19 (Economic survey, 2019). Potato is mostly grown as cash crop and provides good returns to farmers when grown using modern technique. It is also grown as intercrop in cereals to get, additional benefits. The contribution of potato to the national agricultural economy is manifold. For a developing country like India, where labour is surplus and limited capital, high yielding and labour intensive crops like potato, have added advantage in increasing food production and employment generation. Potato being a labour intensive crop requires about 145 man-days for cultivation of one hectare of land. Nearly 310.59 million man-days of employment have been generated only by potato cultivation in the country during 2018.

The choice of a commercial crop enterprise like potato depends on its profitability relative to other potential crop enterprises. This becomes more important in case where the farm holdings are small and dwindling fast. If we take into account the fact that potato is cultivated by farmers belonging to all size class of holdings. The farmer is motivated by various factors such as risk and uncertainty, his family needs and other socio-economic considerations in the formulation of his farm plans. But, in the ultimate analysis, the net returns per rupee of investment are the key factor for allocation of the farm resources. In this perspective, an understanding of the methodology to investigate costs and returns of crop enterprises and the economics of potato production assumes added importance for the farmers, researchers, policy makers etc. It helps particularly the growers in taking decisions on efficient use of inputs, allocating resources to different enterprises/crops for maximizing production, selecting crop combinations and deciding the levels of input use so as to economize expenditure and maximize returns.

Potato yields are affected by several factors, but the basic factor is seed quality, especially its biological quality. Application of fertilizers and irrigation, as well as appropriate crop management, could be more effective when good quality seed is used. Good returns from potato production are the driving force for using quality seed. As long as potato growers can achieve higher profits, they are willing to use quality seed. The key is that the profit from using quality seed must offsets its higher cost. Potato production can be increase by increasing productivity per unit area of land. Increasing productivity rather than area expansion will be the key factor to meet the increasing potato demand in the future.

The use of quality seed involves two aspects: whether seed of good quality and in large enough quantities can be supplied and whether growers are willing to use quality seed considering the cost—

benefit ratio. Both aspects are related to market conditions. The only factor motivating growers to grow potatoes is competitive returns compared to other crops. If higher profits can be achieved, growers would be eager to get quality seed, and then seed producers could have a market for their product.

Potato growing has become a major source of income for farmers in many part of India particularly, UP, West Bengal, Bihar and Punjab. Since the profits from increasing yield are higher by using quality seed, growers are willing to buy good quality seed. However, good quality seed are very costly and account for about 25-40% of total cost of potato production and hence it becomes imperative to ensure supply of quality seed potato at lower price to farmers. For the purpose, it is utmost important for a person/institution involved in seed production to know the economics of seed potato to economise the cost of seed potato production.

Concepts, methods and estimation of costs

Methods for Costing

Cost of cultivation can be calculated by following the survey method or cost accounting method. Normally, the cost of cultivation is estimated by using the survey method in the country. The cost accounting is used when the researcher wants to generate data for a number of years. This method is also useful while assessing the income from agricultural products and in determining the prices of the agricultural products. Cost accounting involves detailed enquiry entailing stay of the investigator in the village/cluster for longer time and frequent visits to the sampled farmers. Farmer/producer himself/herself can use this method to estimate cost of production on his/her own farm.

Classification of items of cost

Cost of production of any crop is the sum total of several components of cost. Accurate measurements of all the components of costs is thus of crucial importance for correct assessment of cost of production of any commodity. Costs incurred on a farm can be classified as cash cost or non-cash cost.

Cash cost and non-cash cost

Cash Costs are the costs for which farmer/producer spends money for acquisition of material inputs like seeds, fertilizer, chemicals or labour inputs like hired labour etc. On the other hand, non-cash costs are attributable to items of cost, which do not require spending money. These may be items of cost like family labour, payments made in kind, home grown seeds, manure etc., exchange labour, depreciation, interest on operating capital etc.

The distinction between cash and non-cash costs is of significance particularly in the context of developing countries where majority of farmers are small farmers. They generally lack resources for investment and thus are under compulsion to barrow at the start of the season. Higher the amount borrowed, greater is the risk attached. Non-cash costs account for a substantial portion of the total cost in developing countries.

Variable cost and Fixed Cost

Another way of classifying costs are treating them as **variable or fixed costs**, although some of the costs may be treated as fixed or variable depending on the time at which they are incurred. This is due to the fact that in short term some of the costs are variable while others are fixed. However, in the long run, all costs are variable. Thus labour employed on a daily basis is variable while a permanent farm labour is to be considered fixed for a short period of time.

Variable costs vary directly with the production. The greater the production, greater are the variable costs. Variable costs may be either cash costs or non-cash costs. Examples of variable cash costs are seeds, fertilizers, hired labour etc. On the other hand payments made in kind are the variable non-cash costs. Care need to be taken that the payments made in kind are accounting for only once. *Unpaid family labour is considered as a variable cost only if there are alternative employment opportunities*. In case alternative employment opportunities do not exist the unpaid family labour cost need not be included. Again whether or not to include the unpaid family labour cost will depend on the objective of the study. Thus, if 15 farms of different labour sources are to be compared, ignoring the unpaid family labour cost will underestimate the cost.

Fixed costs are the costs incurred whether or not the production takes place. These could be cash or non-cash. Thus, land rent paid is an example of fixed cash cost. Land rent paid in kind, depreciation of farm machinery, tools and equipments, farm buildings and the cost of maintaining farm work animals are the examples of fixed non-cash costs.

Indicators

Although there are no standard indicators on which cost of production data are collected, the commonly used indicators are:

(i) **Physical inputs:** This may include value of seed (purchased or home grown), value of insecticide and pesticide, value of manure (owned and purchased), value of fertilizers, irrigation charges, value of own or hired machinery
(ii) Human labour: This include casual or permanent labour attached to farm
(iii) Animal labour: This may be hired or own
(iv) Family labour
(v) Machine labour, both owned and hired
(vi) Land revenue
(vii) Rent paid for leased in land or rental value of own land
(viii) Other costs: Interest on working capital, land revenue, depreciation of machinery
(ix) Miscellaneous expenses

It may be noted that the animal labour are generally not used in the developed countries for cultivation of crops

Methods of measurement of cost items

Method of measurement of cost items will depend on the item on which cost is measured. Given below are some of the methods of valuation of items of cost.

Purchased price: This is a method of valuation of item of cost on the basis of current price as actual purchase price. It is used for those items of cost which have both short life span and whose values do not change substantially during short time periods. For example, inputs like fertilizers, chemicals, feeds, seeds, containers, and veterinary medicines can be evaluated on the basis of purchase price. Normal market value or average selling price is used for items whose value does not change in a year. Thus land value can be evaluated by this method.

Present market value

Items, which are not purchased regularly but are traded in the market, are evaluated on present market value. Thus this method may be suitable for items like home grown seeds, manures, value of animals and man labour, products not sold but given away as gifts etc. Depending on the age, livestock in the farm can be evaluated on market value. Crops grown in the field could be valued depending on the plant stage growth.

Net selling price

It is the selling price minus cost of marketing. Used for farm products sold.

Imputed value

There are certain items for which no money is actually spent but they do contribute towards the growth of a crop. Proper evaluation of such items in terms of money equivalent is important for correct assessment of cost of production. Thus family labour is an important input in the enterprise, but no money is paid by the farmer to his family members for the work done on the farm. Cost assessment in respect of such items is made by using imputed value of cost. Family labour cost is generally imputed on the basis of prevailing wage rate in the locality. It may be noted that the family of a farmer may comprise male, female or young children all of which may be doing some work on the farm. Although some operations like plucking of leaves can be carried out more efficiently by the women, it is generally the case that the adult males can perform agricultural operation more efficiently than the females or the young ones. Thus the method of imputation of family labour cost would depend upon the particular member of family involved in the farm operation. A general rule may be framed whereby the work performed by women and young ones can be converted into male equivalents using the standards given below in Table.

Age group	Age	Unit Equivalents
Child	0-9	0.0
Youth	10-15	0.5
Adult	16-59	1.0
Old	60 and above	0.5

Replacement cost less depreciation

It is generally used for property whose value changes considerably from year to year.

Income capitalization

This concept is based on the premise that purchase of property is in real terms a income for the future. Thus the present value of an asset is judged in terms of income it is likely to generate in the future. It is computed as

$ICV= PV_o+ R_n/(1+r)^n$

Where,

ICV = Income Capitalization Value; PVo = Present value of the property

R = Expected income per year ; i = Interest rate

n = Number of years income is expected

Original cost less depreciation

This method is appropriate for items which are purchased to be used for a long period of time and for which there is practically no market for resale. Thus this method of valuation is most useful for items like farm buildings, farm machineries, tools and equipments. Present value of each item is worked out by subtracting the depreciation successively from the original value. Depreciation can be worked out on the basis of any of the three methods given below:

(i) Straight line method
(ii) Declining balance method
(iii) Sum of the year digits method

Straight-line method

Using this method the yearly depreciation is computed by dividing the purchased value of an item with its expected life span. Thus,

Annual depreciation = Acquisition cost / Life span

If any item has a scrap value after its usefulness has expired then the annual depreciation is given by

Annual depreciation = (Purchased value – Scrap value)/ Life span

Declining balance method

It supposes that the depreciation value decreases as the age of an item increases. Depreciation under this method is calculated as

Annual depreciation = Book value x depreciation rate.

Sum of the years digits method

Depreciation using this method is calculated on the assumption that the depreciation in the initial years is more than it is in the later years. Annual depreciation thus is calculated on the basis of the formula

Annual depreciation = ((purchased value -scrap value) x Remaining years of life)/ Sum of the years digits of life span

It may be seen that under the straight line method equal amounts are subtracted every year while in the sum of years digit method the depreciation is faster during earlier years than during the later years. The declining balance method presupposes that there is a scrap value for every commodity. The declining balance and sum of years digit methods are to be used when the farmer expects bigger return to his investment during the first few years.

Allocation of joint costs

In case more than one crop is grown on a farm it is very important to determine cost incurred on various items as are used on individual crops. While correct assessment of crop specific costs are impossible, reasonably good estimates of costs can be obtained by following the standard procedures of allocation of joint costs as given below:

Depreciation of farm buildings

Can be charged to the individual enterprise in proportion to the total area under a enterprise in case the building is used for different enterprises. However, if the building is used for single enterprise, the entire depreciation can be charged to that particular enterprise.

Depreciation of farm machinery, tools and implements

As in case of farm buildings here also the depreciation or minor repairs can be charged to individual enterprise in proportion to the area under a given enterprise. Alternatively, time spent on individual enterprise by a given machine / tool and implement can form the basis for charging depreciation.

Taxes and rental for land

These can be allocated to the different enterprises in proportion to the land occupied by the individual enterprise.

Maintenance of farm animal costs

These would be allocated on the basis of proportion of time the animal labour is used for the respective enterprise.

Crops grown in a mixture

Many a times, crops are grown in a mixture. Due to this, it is not possible to determine the cost on various items attributable to individual crops. In such cases the expenditure, which is common to the farm as a whole, are apportioned to individual crops. Thus the cost on maintenance of bullock can be allocated in proportion to the number of hour the bullocks are used for individual crop. Depreciation, land revenue etc. can be apportioned in proportion to the area under each crop. Cost of cultivation of main product can be obtained by deducting from the total cost of cultivation the value of the by-product.

Family Labour

Evaluation of cost incurred on account of family labour is bit cumbersome. This is due to the fact that family labour may comprise people of different age groups and sex. Then, there is a custom dimension attached to this item of cost. Further, there may be a particular kind of work, which can be done better by men than women and must in fact be done by men or women. A possible solution may lie in converting all work done by men and women into men equivalent. Specifically, work done by a youth below 15 years of age can be taken as equivalent to half the adult. Similarly, work performed by a woman can be taken as equivalent to 0.8 men equivalent. It may be noted that these are general guidelines. The exact calculations will vary from situation to situation. For instance, there are certain items of work like plucking of tea, harvesting and planting rice which can be better performed by women than men.

Thus in this particular case there is no justification for evaluating the work performed by women as equal to 0.8 men equivalent.

Different components of variable costs may be evaluated as follows:

Animal Labour

The animal labour may be evaluated as sum of

(a)

(i) Fodder and feed

(ii) Wages of the cattle attendant

(i) Interest

(ii) Depreciation

(iii) Other general charges

Minus, cost of veterinary charges, cost of ropes, chains etc.

(b) (i) Value of manure

(ii) Work done outside the farm

(iii) Appreciation or profit due to sale of animals

Then the daily cost of animal labour is obtained as : (a-b)/ number of days worked in the year

Cost of farm produced seed, fodder and feed

The cost on account of farm-produced commodities can be obtained as per the prevailing locality prices of these commodities.

Farmyard manure Farm produced manure can be evaluated as per the prevailing locality rates. In case it is purchased, then the evaluation is to be done on the basis of purchase price.

Chemical fertilizer

It can be evaluated at the purchase price including the transport charges.

Cost of insecticides and pesticides

It can be evaluated at the purchase price.

Owned/hired, bullock and tractor labour

It may be evaluated at the rate of hire charges for bullock / tractor. The own/bullock / tractor labour can be charged on the basis of operational expenditure per hour.

Hired and permanent labour charges

These may be evaluated on the basis of hours worked on the field and wages paid for such work.

Cost of owned/hired irrigation

It may be evaluated on the basis of actual amount paid. In case of own irrigation the cost estimates can be based on operational cost per hour.

Interest on working capital

The paid out cost constitutes the working capital. The prevailing bank rate of interest can be taken to work out the interest on working capital for the duration of the crop. **Different components of fixed costs may be evaluated as follows:**

Family labour

The value of family labour can be imputed on the basis of wages of attached farm labour and number of men hours used.

Interest on fixed capital

The present value of assets, equipments form the fixed capital. Interest on this can be calculated in the same way as in case of interest on working capital.

Owned machine charges

Calculated on the basis of cost of maintenance of farm machinery, which may include a) Diesel b) Power c) Lubricants d) Depreciation e) Repair and f) Other expenses, if any

Rent on lease-in land

It can be calculated on the basis of actual rent paid.

Rental value of own land

It can be evaluated on the basis of interest on the value of land for the period of the crop. Or else, it can be taken as rent paid for a similar land in a given area.

Management cost

The management cost can be taken as a certain percentage of the total paid out cost

Cost concepts. The comprehensive scheme for studying the cost of cultivation of principal crops was initiated in 1970-71 in the country. The cost concepts such as cost A1, cost A2, cost B and cost C and procedure for evaluation and allocation of joint costs were laid down (Kapre, 1974). These have been further improved and redefined (Govt. of India, 1990). Different cost concepts have their own implications in policy formulation. Accordingly, the items of costs and these concepts of costs are as follows:

Cost A1 – It includes all actual expenses in cash and kind in production by the owner farmer given below:

i) Value of hired human labour
ii) Value of hired bullock labour
iii) Value of machine labour, owned and hired
iv) Value of owned bullock labour
v) Value of owned machinery
vi) Value of hired machinery
vii) Value of seed (a) farm produced & (b) purchased viii) Value of insecticides and pesticides ix) Value of manure (owned and purchased) x) Value of fertilizers xi) Depreciation of implements and machinery xii) Irrigation charges xiii) Land revenue xiv) Interest on working capital xv) Misc. expenses (artisans etc.)

Cost A2: Cost A1 + rent paid for leased-in land.

Cost B: Cost A2 + rental value of owned land (net of land revenue) & interest on owned fixed capital excluding land.

Cost C: Cost B + imputed value of family labour.

Cost A2 = Cost A1 + Rent Paid for leased in-land

Cost B1 = Cost A1 + Interest on value of owned fixed capital assets (excluding land)

Cost B2 = Cost B1 + Rental value of owned land (net of land revenue) and rent paid for leased-in land

Cost C1 = Cost B1 + imputed value of family labour

Cost C2 = Cost B2 + Imputed value of family labour

Cost C2* = Cost C2 + Additional value of human labour based on use of higher wage rate in consideration of statutory minimum wage rate. (This is an intermediate concept).

Cost C3 = Cost C2* + 10 percent of cost C2* to account for managerial input of the farmer

Procedures for Imputation of Costs

Whereas the valuation of purchased inputs could be made on the basis of expenditure incurred, there were problems with respect to some of the inputs used in the production of crops supplied by the farm family itself. The procedures adopted for evaluation of imputed cost of these inputs were as under:

Family Labour:

Charged on the basis of wages paid to attached farm labours.

Owned Animal Labour: Evaluated on the basis of cost of maintenance which included the following: (a) Cost of green and dry fodder (b) Cost of concentrates (c) Cost of labour for upkeep of livestock (d) Depreciation on animals and cattle sheds (e) Other miscellaneous expenses like salt, drugs etc.

Owned Machinery Charges: Also charged on the basis of cost of maintenance. The maintenance cost comprised: (a) Diesel (b) Power (c) Lubricants (d) Depreciation (e) Repair (f) Other expenses, if any

Implements: Cost on implements was imputed on the basis of depreciation and repairs.

Farm Produced Manure: Evaluated on the basis of prevailing prices in the village. **Owned Land:** Estimated on the basis of prevailing rents in the village for identical type of land, or on the basis of farmers' response subject to the ceiling on fair rents in the land legislation of the concerned state.

Interest on owned fixed capital: Charged at the rate of 10 per cent on the present value of fixed assets.

Interest on working capital: Charged at the rate of 12.5 per cent on the working capital for half the duration of the crop

Kind payments: Evaluated on the basis of prevailing rates in the village at the time such payments were made

Main produce by products: Imputed on the basis of post-harvest prices prevailing in the sampled villages.

Allocation and Apportionment of Joint Costs: Some of the items of cost were applicable to the entire farm. Costs on such items were apportioned to the individual enterprise by using following methods:

a) *Maintenance of the bullocks:* The total cost under this was apportioned in proportion to the number of bullock pair hours used for each of the enterprise.

b) *Depreciation, land revenue etc.:* Allocated in proportion to the area under different enterprises.

Cost of production of main product: This was worked out by subtracting from the total cost of cultivation the value of the by-product. The net cost of cultivation was divided by the yield of main product to get unit cost of production.

Farm efficiency measures

To evaluate the farm income and profits, the following measures of farm income and profit efficiency were employed.

Gross farm income (GFI): It is defined as gross value of output including by-product priced at farm harvest rates.

Net farm income (NFI): This represents the remuneration for the farmers' management and has been calculated by deducting farm expenses from the gross farm income. NFI = GFI – Cost C

Family labour income (FLI): This represents returns to family labour and has been calculated by deducting Cost B from the Gross Farm Income. FLI = GFI – Cost B

Farm business income (FBI): It is defined as the return to labour, owned land, owned fixed capital and management and is calculated by deducting Cost A from the Gross Farm Income. FBI = GFI – Cost A

Farm investment income: It is defined as the sum total of net farm income, interest on owned fixed capital and rental value of land

Economics of ware potato production

a) Costs and Returns from potato in the hills: The economics of potato in Shimla hills of Himachal Pradesh is was estimated. The total cost of cultivation (cost C3) was Rs.97421.2 per hectare in 2016-17 in Himachal Pradesh, while the net returns was Rs.2828 and output-input ratio was 1.03. Component-wise analysis of cost of cultivation shows that the human labour accounted for the highest average cost of 36.46%, followed by seed input 29.09%, rental value of own land 14.5%, bullock labour 3.21% fertilizers and manure 10.29%. The other cost factors such as plant protection, interest on working capital, interest on fixed capital and depreciation together contributed 6.45% towards the cost of cultivation of Rs.86510.9/ha. Family business income estimated was RsR.48827/ha and Farm investment income was Rs.17639/ha.

b) Costs and Returns from potato in plains: The plains, particularly in the Gangetic region are the potato bowl of India. It accounts for about 80% of potato production. Uttar Pradesh is the leading potato growing state of the country contributing about 28.7% of area and 30.32% of production during 2017-18.The estimates by Directorate of Economics and Statistics, Department of Agricultural Cooperation, Government of India for the year 2016-17 in major potato growing states of the country showed that the total cost of cultivation was Rs.93220 /ha in UP while that in West Bengal was Rs.131612/ha (Table 2). Component-wise cost of cultivation revealed that human labour, seed, fertilizer and manure cost were the major items of cost accounting for about 32.4%, 17.64%, 18.1% respectively in the state of West Bengal and 19.71%, 21.88% and 11.6% respectively in the state of UP. The net return in potato production was Rs11546/ha in case of UP and Rs.(-31312.6)/ ha in case of West Bengal whereas Family Business income for Rs.47746 and Rs.18443 per hectare respectively in the state of UP and West Bengal.

Economics of Seed Potato Production

It is recognized that the informal seed potato production system meets the major requirement of seed potatoes in India. The input-output relationship, profitability and resource use efficiency in seed potato production was examined in Jalandhar district during 2003-04. The overall cost of seed potato production was estimated at Rs. 250/q. Expenditure towards seed was highest (32.84%) followed by manures and fertilizers (13.73%), farm machineries (11.29%), hired human labour (9.01%). Net income was Rs.11,405/ha. Further, cost of production decreases with the increase in technology adoption due to increase in yield. Moreover it was found that seed potato production in Punjab was under decreasing return to scale.

Conclusion

Although potato production is a very remunerative crop enterprise yet its profitability is dented by the periodical gluts and price crashes. Being a vegetatively propagated crop, seed quality and adoption of the Seed Plot Technique (SPT) are critical for improvement of potato productivity and profitability. To sustain crop production at desired levels the government should develop a horticultural price policy. Since production and marketing are inter-related, the multifarious marketing problems need to be resolved with the help of a package of measures ensuring better returns to the growers especially small and marginal farmers. This can be achieved through promoting higher potato consumption for augmenting internal disposal and also encouraging value addition and by encouraging the exports.

Suggested Readings

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Table1: Sate-wise Input use in potato production and their price during 2016-17

Items **States**	**Himachal Pradesh**	**Uttar Pradesh**	**West Bengal**	**Bihar**
Material & Labour Input				
Seed (Kg./ha)	1170.05	3064.72	1250.25	2042.88
Fertilizer (Kg. Nutrients/ha)	123.38	363.40	668.20	118.93
Manure (q/ha)	58.00	61.61	26.81	13.26
Human Labour* (Man Hrs./ha)	684.83	650.70	1262.30	652.97
Animal Labour (Pair Hrs./ha)	75.38	1.66	20.35	0.00
Rate per Unit (Rs.)				
Seed (Kg.)	21.51	6.66	18.57	10.07
Fertilizer (Kg. Nutrients)	32.75	27.84	31.30	34.59
Manure (Qtl.)	83.77	11.31	107.30	99.20
Human Labour (Man Hrs.)	46.06	28.24	33.81	26.60
Animal Labour (Pair Hrs.)	36.81	101.39	63.06	0.00
Implicit Rate (Rs./q)	784.12	518.14	351.17	616.42
Number of Holdings in Sample	36	82	137	44
Number of Tehsils in Sample	9	23	19	11
Average Yield (q/ha))	106.03	209.24	280.55	187.13
Break-Up Human Labour Hours:				
Family	670.56	302.66	656.65	243.29
Attached	0.00	0.00	0.18	14.87
Casual	14.27	348.04	605.47	394.81
Total	684.83	650.70	1262.30	652.97

Source: Directorate of Economics and Statistics, Department of Agricultural Cooperation, Government of India

Table2: Sate-wise breakup of cost of Potato cultivation

(Rs./ha)

Cost Components	**Himachal Pradesh**	**Uttar Pradesh**	**West Bengal**

			% to total		% to total		% to total
Operational Cost		70597.9	81.6	64788.5	69.5	105747.2	80.4
Human Labour	Family	31055.73		8845.04		24262.06	
	Attached	0.00		0.00		7.32	
	Casual	488.23		9529.19		18403.95	
	Total	31543.96	36.46	18374.23	19.71	42673.33	32.4
Animal Labour	Hired	413.51		0.00		444.92	
	Owned	2360.75		168.43		837.96	
	Total	2774.26	3.21	168.43	0.18	1282.88	0.97
Machine Labour	Hired	339.17		7725.81		5214.73	
	Owned	138.17		997.37		429.09	
	Total	477.34	0.55	8723.18	9.36	5643.82	4.29
Seed		25168.00	29.09	20398.19	21.88	23217.93	17.64
Fertilizer & Manure	Fertilizer	4041.1		10117.8		20911.6	
	Manure	4858.8		697.1		2877.2	
	Total	8899.9	10.29	10814.9	11.60	23788.7	18.1
Insecticides		457.7	0.53	519.5	0.56	3231.6	2.5
Irrigation Charges		78.6	0.09	4094.8	4.39	3439.6	2.6
Miscellaneous		0.0	0.00	0.0	0.00	0.0	0.0
Working Capital (WC)		69399.7		63093.2		103277.9	
Interest on WC		1198.3	1.39	1695.3	1.82	2469.24	1.9
Total Variable cost (A)		70597.9	81.61	64788.5	69.50	105747.2	80.4
Fixed Costs (B)		15912.9	18.39	28431.9	30.50	25864.8	19.7
Rental Value of Owned Land		12543.07		21694.7		21108.8	
Rent Paid for Leased-in-Land		132.29		1922.2		2689.4	
Land Revenue taxes etc.		11.77		9.98		34.9	
Depreciation on Implements & Building		957.69		1066.90		336.64	
Interest on Fixed Capital		2268.13		3738.03		1694.99	
Total Cost [A+B]		86510.9		93220.4		131612.0	
Cost of Production (Rs./q)		815.91		445.52		469.12	

Source: Directorate of Economics and Statistics, Department of Agricultural Cooperation, Government of India

Table3: Sate-wise cost of cultivation as per CACP cost concept

(Rs./ha)

Cost Components	HP	UP	West Bengal
Cost A1	40511.69	57020.33	81856.71
Cost A2	40643.98	58942.55	84546.14
Cost B1	42779.82	60758.37	83551.71
Cost B2	55455.17	84375.31	107350.00
Cost C1	73835.55	69603.41	107813.80

Cost C2	86510.92	93220.36	131612.00
Cost C2 Revised	88564.72	93220.36	131612.00
Cost C3	97421.2	102542.4	144773.20
Cost of Production over different (Rs./q)			
Cost A1	380.07	272.57	291.71
Cost A2	381.14	282.36	301.17
Cost B1	400.25	290.86	297.72
Cost B2	519.25	404.21	382.52
Cost C1	696.89	332.17	384.31
Cost C2	815.90	445.52	469.12
Cost C2 Revised	835.28	445.52	469.12
Cost C3	918.81	490.07	516.03
Value of Main Product (Rs./ha)	89338.8	104766.8	100299.4
Price	842.58	500.70	357.51
Farm Efficiency measures			
Gross farm Income (GFI)	89338.8	104766.8	100299.4
Net farm Income= GFI - Total Cost	2827.88	11546.44	-31312.6
Family Business Income= GFI-Cost A1	48827.11	47746.47	18442.69
Farm investment Income= NFI+ Interest on own fixed capital+ rental value of own land)	17639.08	36979.2	-8508.76
Output Input ratio	1.03	1.12	0.76

Source: Directorate of Economics and Statistics, Department of Agricultural Cooperation, Government of India

Purpose specific storage to reduce losses and retain quality in potatoes

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About 90% of potatoes grown in India are harvested in February-March. Temperatures begin to rise at harvesting time and therefore, potatoes have to be stored during the hot summer months. The requirement for ware potatoes for 6-7 months during the year are met with stored potatoes. Pre-storage factors, *viz.* tuber maturity, proper skin curing, tuber health, variety etc. have significant implications on the ultimate quality of stored potatoes in all the methods of storage. Potato storage methods being practiced in India can be broadly divided in to two categories *viz.* refrigerated storage and non-refrigerated storage.

Refrigerated Storage:

Storage at 2-4 ºC: Cold storage facility was developed primarily for the storage of seed potatoes, but they are also being used for the storage of table potatoes. About 93% of the cold storage capacity in the country is being used exclusively for the storage of potatoes. Seed potatoes are stored in cold stores, which maintain temperature 2-4ºC and 90-95% RH. At this temperature, sprouting does not take place, weight loss is minimum and seed maintains it proper vigour which is essential for taking subsequent crop. But 2-4ºC is not the ideal storage temperature for table potatoes as at this temperature; they become sweet due to sugar accumulation and are not preferred for consumption. Due to increased awareness, consumer preferences have changed and the requirements of potatoes with less sugar development are met through storage at elevated temperatures.

Storage at 10-12ºC*:* Potatoes meant for table use and processing are stored at 10-12ºC, in most of the countries. When potatoes are stored at this temperature, accumulation of reducing sugars is minimum and therefore they do not become sweet. Besides, the chips produced from these potatoes are light in colour. However, at this storage temperature, potatoes sprout. Therefore, it is necessary to treat the stored potatoes with a sprout suppressant like CIPC (isopropyl N- (3-chlorophenyl) carbamate). CIPC is available in liquid formulation and is applied in the form of a fog using a fogging machine. It is applied @ 35 ml (50% a. i.) per ton of potatoes. CIPC treated potatoes are safe for consumption 30 days after treatment as the CIPC residue is within the acceptable limit of 25 mg CIPC/kg of potatoes. This storage technology has been tried by several cold stores in the country during the last decade with encouraging results. This technology needs further improvement for successful storage of potatoes meant either for ware purpose or for processing use for 7-8 months.

Non-refrigerated Storage:

On-farm storage: Though the refrigerated storage is essential for long-term storage but for short-term storage of 3-4 months non-refrigerated methods can be used profitably. Traditionally, farmers in India have been storing potatoes in cool dry rooms, heaps and pits. The pit method is very popular in the Malwa region of Madhya Pradesh. Heaps are made by heaping potatoes in the shade of a tree to a maximum height of 1m and covering them with 1 foot thick wheat /rice straw or sugarcane trash. Pits are also dug under the tree shade and these are of two types, *viz. Pukka and Katcha.* Generally 5-30 tonnes of potatoes are stored in heaps and 10-40 tonnes of potatoes are stored in pits. Traditional storage methods are in use in states of Assam, Bihar, UP, MP, Gujrat Maharashtra and Karnatka and these have several advantages. They are cheap and no investment is needed on storage structure. Furthermore, the materials required are locally available. The temperature in heaps and pits vary from 23-32ºC and the RH: 60-96%. The higher temperatures prevailing in heaps and pits prevent accumulation of reducing sugars and therefore these potatoes are preferred for table use as well as for processing. The reducing sugar content normally does not exceed 150mg/100 g tuber fresh weight and the chips are generally acceptable (score <3). The only disadvantage of traditional methods is that storage losses are high due to rotting. Improving the efficiency of these storage methods can reduce storage losses. Experiments carried out by CPRI at three locations viz. Jalandhar, Modipuram and Patna have shown that it is possible to store potatoes on-farm for 3-4 months with acceptable storage losses. Potatoes of Kufri Jyoti can be stored in heaps for 105 days with total loss of 10.9% at Jalandhar, for 90 days with total loss of 7.1% at Modipuram and for 80 days with total loss of 27% at Patna. On-farm storage in heaps is recommended for short term for ware use and also for processing purposes.

Evaporatively cooled potato store*:* The insulated potato store (capacity: 20 tonnes) is equipped with passive evaporative cooling which does not require any other source of energy for cooling. These ECPS were evaluated at Jalandhar and Modipuram and it was found that the daily maximum temperatures in the ECPS remains 6-13 ºC lower than the ambient during March-June. RH remains high at 70-95 %. Due to moderate temperature and high RH the weight loss in potato tubers is significantly reduced. Ware potatoes can be stored in good condition up to the beginning of June when the price in the market is much higher than the prices at the time of harvest. During storage the reducing sugar decrease and potatoes are not as sweet as the cold stored potatoes. Potatoes stored in ECPS fetch premium price as they are suitable for ware consumption as well as for processing. The storage life as well as tuber quality can be further improved by using sprout inhibitor like CIPC. This technology is suitable for 80-90 days in regions where the temperatures are high and humidity is low during the storage period.

Post harvest management of potatoes

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Introduction

Potato contains approximately 80% water and is a semi-perishable commodity. About 90% of the potatoes produced in our country are grown in the Indo-Gangetic plains and are harvested during January to March, the beginning of the long hot summer. This makes it very difficult to store the harvested potatoes, as under these conditions potatoes cannot be stored without refrigeration for more than 3-4 months after harvest because of enormous losses due to rottage, shrinkage, sprouting and attack of different microbes and pests. According to an estimate, a higher proportion of potatoes (16%) in the country is wasted as post-harvest losses (PHLs) than that used as seed (8.5%) or processing (7.5%). This is an unfortunate situation that nearly 1 million t in excess to the total potato production in Canada during the triennium ending 2010 (FAOSTAT) itself was wasted in India. Losses occur at every stage of the supply chain. These losses result due to lack of proper storage facilities, absence of proper handling, transportation, pre- and post-harvest treatment. Besides, the attack of pathogens at conducive temperatures and environment increase the losses tremendously and therefore, proper handling, desired treatments and safe post-harvest environment are required to reduce the losses in potatoes after harvest.

Post-harvest losses

Hot summer temperatures, lack of state of the art cold storage facilities and massive transportation of potatoes from northern to southern states are the causes of the high wastage of potato in absolute terms. Various factors which play key role in post-harvest loss of potatoes are being discussed in subsequent heads.

Pathogenic Factors

Losses in potatoes caused by pathogens are greater than the losses due to physiological causes. Physical damage to tubers during harvesting and handling aggravates the attack of bacteria and fungi leading to quantitative losses. Generally, the more common storage diseases caused by fungi are late blight, dry rot and pink rot. The most severe bacterial disease that causes rotting is soft rot. When infection occurs in the field, rotting begins in the field and continues during storage. When infection occurs after harvesting, it is generally through mechanical injury as in the case of dry rot. High humidity and condensation of water on tuber surface can lead to infection by soft rot. Among the insect pests, tuber moth causes maximum damage during storage and is common in potatoes stored under higher temperatures, as is the case with non-refrigerated storage.

Fungal diseases: Among the diseases of fungal origin, the most important ones causing pre and post-harvest losses are the late blight and the dry rot. **Late Blight** is caused by *Phytophthora infestans* and the disease affects all plant parts, viz., leaves, stems and tubers. Tubers develop reddish brown, shallow to deep, dry rot lesions. The affected tuber flesh becomes 'caramelised' with a sugary texture. Tubers carrying the pathogen are the real carriers and serve as the source of the disease in the subsequent season. When the storage conditions are good, the rot remains dry and doesn't extend. However, when the storage conditions are faulty, the dead tissues open a route to the secondary soft rot. The **Dry Rot** caused by *Fusarium sp.,* on the other hand, appears during storage. The skin wrinkles forming irregular concentric rings, and in general tuber tissue decay forms pockets of pink, red or bluish colour, which contains spore masses in the mycelium. The disease incidence can be reduced with proper curing and avoiding bruising during harvest and transport.


Tubers infected with late blight and dry rot

Bacterial diseases: Among the main diseases of bacterial origin, Bacterial wilt (*Ralstonia solanacearum*) and soft rot (*Erwinia carotovora var. carotovora* and *Erwinia carotovora var. atroséptica*) are the major threats. **Brown rot** is a destructive disease to the plant and causes rotting of the tubers in transit or storage. The **Soft Rot** causes high amount of losses particularly during storage and every year about 2% losses have been estimated due to rots. Excessive moisture, high temperature, excess nitrogen, tuber injuries and poor ventilation during storage are the important factors helping the disease development and spread. Initially, a small area of tuber tissue around lenticel or stolon attachment point becomes water-soaked and soft. Under low humidity, the initial soft rot lesions become dark and sunken, while under high humidity, the lesion may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. At harvest, many small rotted tubers with intact skin can be seen. Among the control measures, avoiding excess irrigation and nitrogen, providing proper drainage prevents the spread of the disease. Harvesting the crop before soil temperature rises above 28°C is recommended. The crop should be harvested only when the tuber skin is fully cured. Care should be taken to avoid injury to tubers and bruised injured tubers are sorted out. Treating the tubers with 3% boric acid for 30 min and drying them under shade minimizes infection during storage.


Tubers infected with brown rot and soft rot

***Potato Tuber Moth (PTM)*: PTM** *(Pthorimea operculella)* in larvae state damages foliage mining between the inferior epidermis and superior of the leaves. It is also introduced in the tuber mining burrows and filling them with their excrements. The initial invasion happens in the field and continues in storage. The tunnels formed in the tubers make them unfit for any consumption and in conducive conditions, the rottage by secondary pathogens is aggravated. Therefore, in the areas of PTM infestation in traditional and room temperature storage, proper care like removal of infested tubers, restriction of PTM entry into storage and use of dried leaves of some herbs (e.g. Lantana) in storage is recommended.

Losses due to Pre- Storage Factors

The quality during potato storage depends on the quality of tubers reaching the store and its management starts from the production stage itself. Cultural practices affect the quality of tuber since potatoes grown in improperly prepared fields are mechanically damaged at harvesting and have reduced storability. Adequate pest and disease management are also necessary for producing potatoes with good keeping quality. Hence, management of pre-storage factors that affect the keeping quality of potato is prime step in good storage management and about 3-8% losses have been attributed to these factors. The potatoes need to be harvested in dry weather and irrigation has to be stopped two weeks before dehaulming. Harvesting is done 10-15 days after haulm cutting for facilitating skin setting. Besides this, curing /suberization (the process by which wounds are healed in potatoes under optimum conditions of <25^{o}C temperature and 95% relative humidity) is also important. Potatoes harvested under wet soil conditions must be dried before storage because even little moisture on the surface of the tubers could lead to infection and rotting during the storage. Only mature tubers with good skin setting are ideal for storage under any storage system.

Uncured and a cured potato tuber and curing in field

Losses at Harvesting and Handling

The mechanical damage during harvest is responsible for loss initiation in potatoes in form of cuts and bruises hence care should be taken to ensure that cuts and bruises are minimized and the exposure to sun should be avoided. Exposure from sun heat causes excessive rotting and damages can take place as a result of direct contact with the sun at the time of harvest. This may also occur before harvesting when the plant is dead or cut. Potatoes harvested in hot weather rot more than those removed in more temperate conditions. When air temperature is 32°C or higher, it is not advisable to dry potatoes and optimum temperature of air for drying has been recommended as 26.5°C or less. Proper care at the time of harvesting, curing of potatoes in temporary heaps and careful handling may help in reducing the losses to a great extent.

Losses during Storage

Losses during storage are affected by factors like physiological tuber condition, mechanical damage suffered during harvest and handling, as well as by storage conditions. Mechanical damage (cuts and bruises) facilitates invasion and development of microorganisms that cause illnesses and rotting. It is appreciated that weight loss shows a lineal relationship with regard to nature or magnitude of physical damage. On the other hand, losses by rottage increase exponentially with regard to the magnitude of physical damage. In general, it is necessary to reduce tubers physical damage to minimize losses during storage.

Losses during Transport, Marketing and Distribution

Losses to potato crop during transport, marketing and distribution have been estimated to be about 3-8%. It is recommended that transport of potatoes should be completed rapidly to avoid sun damage. Transferring tubers in sacks generate a larger percentage of damages unless the handling is done very carefully. Thus crop handling inside the field or transport to exterior with trucks or trailers has great importance. There are mechanical damages to potatoes before leaving the field. These damages become more evident later during storage. To avoid mechanical damages in all the operations, it is necessary to convince the personnel to utilize proper handling like: Potatoes should be placed inside containers and not thrown from distance, truck drivers should not stand on potato sacks but on the platform of the truck and full sacks of potatoes should be placed in position and not thrown at truck loading and discharging. Use of soft linings is recommended in trailers and trucks that transport potatoes. A straw bed should be used in trucks, or pads can be made with sewn sacks half filled with straw and laying potato bags on these shall significantly reduce the bruising. It is also necessary to securely tie the load to avoid movement of sacks, resulting in bruising. Another point is that potatoes should be handled the absolute minimum number of times possible. All labour involved with potato handling should be supervised carefully to guarantee an appropriate operation.

Storage practices to minimize losses

In India, potatoes are generally stored in cold stores and used for both seed and table purposes. Seed potatoes are best stored in cold store maintained at 2-4°C and at about 95% relative humidity. But cold stored potatoes are not suitable for table and processing purposes. Potatoes stored in cold store accumulated sugars and become sweet in taste and are therefore, less suitable for consumption. Because of high accumulation of reducing sugars, these potatoes produce dark coloured chips which are unacceptable both colour-wise and taste-wise. Thus, the storage requirements of potatoes should be in accordance with the purpose for which potatoes are stored. It is suggested that cold stores maintained at 2-4°C should be used exclusively for the storage of seed potatoes only. Table and processing potatoes should be stored at 10-12°C, after treating the potatoes with a sprout suppressant for long-term storage. For short-term storage of table and processing potatoes, non-refrigerated storage methods like heaps can be used profitably. Handling of potatoes with due care is expected to reduce the post-harvest losses.

***Storage of Seed*:**

Seed potatoes are best stored at 2-4°C and 90-95% RH in cold stores, because at this temperature, sprouting does not occur and weight loss is minimum. The farmers have to pay the rent for storing potatoes in these cold stores and they take out these potatoes at the time of planting in the next potato season. The only problem regarding the storage of seed potatoes in cold stores is the uneven distribution of these cold stores over locations and non-regulatory storage charges.

A traditional cold storage and stack of potatoes inside the store

Storage of Table and Processing Potatoes:

The potatoes to be used for table and processing purposes have different storage requirement than the seed potatoes. Essentially storage for table and processing potatoes may be divided into two categories viz. Non-refrigerated storage systems and refrigerated storage systems as discussed below.

Non-refrigerated storage systems for table and processing potatoes: These are the storage systems where no artificial refrigeration is used. These storage methods can be used to store potatoes for 3-4 months (i.e. up to June) after harvest in February/March. However, once the monsoon begins, potatoes cannot be stored in a non-refrigerated store because it works only under dry conditions. Short-term storage of potatoes for 3-4 months is good enough because it helps avoid distress sale immediately after harvest and the farmer can get better returns by selling the potatoes in May or June, when potato prices start rising. It is relatively easy to store potatoes under non-refrigerated conditions when they are dormant. Indian potato varieties have a dormancy period of 6-8 weeks. Once the dormancy period is over, sprouting begins. Weight loss in potatoes during storage is mainly due to water loss from the tubers and the weight loss is much more in sprouted tubers. The extent of rotting is high under non-refrigerated storage systems as the temperature and humidity conditions are favourable for aggravating the infection.

A modified potato heap

Refrigerated storage for table and processing potatoes: Fresh potatoes are available for consumption only for a few months, after the harvest. For a major part of the year, potatoes from cold stores are consumed. Though cold storage facility was developed primarily for the storage of seed potatoes, they have been used for the storage of table potatoes as well. But, 2-4°C is not the ideal storage temperature for table and processing potatoes as at this temperature, potatoes become sweet due to sugar accumulation and are not preferred for consumption. Further, cold stored potatoes do not keep well once they are taken out of the store. Therefore, storage of table and processing potatoes is suggested at 10-12°C. This method of potato storage is comparatively new to our country, but a good number of cold stores (approximately 700) are now storing potatoes by this technology and these potatoes are being marketed as low sugar potatoes (table) and depending on the variety stored, potatoes are suitable for processing as well up to about 6-7 months. However, at this storage temperature, potatoes sprout. Therefore, it is necessary to treat the stored potatoes with a sprout suppressant like CIPC (Isopropyl N-(3-chlorophenyl) carbamate). The treated potatoes are safe for consumption after 3-4 weeks of treatment.

A commercial cold store using 10-12°C storage technology, potatoes and chips

Challenges and opportunities in potato processing

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Potato (*Solanum tuberosum* L.) is grown in about 150 countries and is the world's single most important non-cereal crop with a vital role in the global food system. It can be compared only with rice, wheat, and maize for its contribution towards securing the food and nutrition and eradicating malnutrition and hunger, especially in developing the world. The crop has the capacity to produce more food per unit time and area and has high nutritional value to sustain the burgeoning population. Potato is a wholesome food containing carbohydrates (16%), proteins (2%), minerals (1%), dietary fibres (0.6%) and is a good source of vitamin C and antioxidants. It is a versatile food as it can be cooked in many ways, can be processed into a number of products each having its characteristic taste and can fit into any meal. In the past few years' Indian potato processing industry has emerged fast due to economic liberalization coupled with growing urbanization, expanding market options and development of indigenous processing varieties. Potato processing industry mainly comprises 4 segments: potato chips, French fries, potato flakes/powder and other processed products such as dehydrated chips, aloo bhujia, samosa, tikkis, and similar products. However, potato chips still continue to be the most popular processed product constitute more than 85% of the savory snack business. The major challenge lies in arranging round the year supply of processing varieties at a reasonable price and some quality attributes of potato for uninterrupted processing. The availability of processing varieties and standardization of storage techniques for processing potatoes at 10–12°C with sprout suppressant isopropyl N-(3-chlorophenyl) carbamate have revolutionized the processing scenario. Even though there are 2-3 months during which it is difficult to get quality potato for processing. Therefore, availability of desired quality and quantity of raw material is the foremost challenge for processing units. In past few years ICAR-Central Potato Research Institute, Shimla has made tremendous efforts to develop processing suitable varieties and came up with some good processing varieties. Moreover, recently ICAR-CPRI has developed some other novel processed products from potatoes which are shelf-stable and don't have much stringent requirement for quality attributes which have a profound effect on fried potato products.

Challenges in potato processing

Potato is being processed into different products by the application of different processing techniques. Therefore, the requirements of the raw material vary for each product as the quality of the finished product is highly influenced by the quality of raw material used for their preparation. From the processing perspective quality of the potato majorly depends upon the morphological characters as well as the biochemical composition.

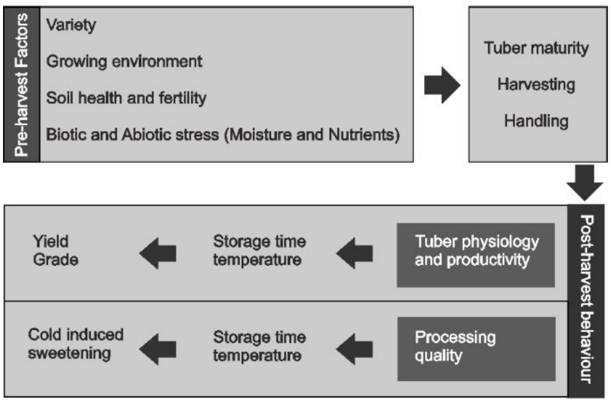

Figure: Factors affecting the pre-harvest and post-harvest behaviour of stored tubers

Desirable processing quality characteristics

Shape, size and colour

Shape, size, and colour are some of the most important morphological characters for potato processing. In general, round to round oval-shaped potatoes having a diameter of 45–80 mm are preferred for uniform size potato chips and long-oval shaped tubers with more than 75 mm length for French fries. Although the requirement of shape is not very obligatory. For canning, small tubers of round to oval shape are suitable. Medium to large-sized tubers with shallow eyes are preferred for most of the processed products as these results in lower peeling losses. The colour of the finished product is also one of the most important attributes determining the quality of the finished product. For the processing varieties with white or light and golden yellow colour are more preferred.

Tuber dry matter content

The dry matter content of tubers determines the quality and yield of fried and dehydrated products. The higher dry matter results in higher recovery and crispy texture of finished products. Moreover high dry matter reduces oil absorption and energy consumption during frying or dehydration. The reduced oil content in the fried products results in shelf life enhancement of the product. On the other hand, for canning the tubers with low dry matter are more preferred as higher dry matter content results in sloughing of tubers. The specific gravity of potatoes is highly correlated with the dry matter of the potato and used as an indirect quick tool for estimation of dry matter content. It has been established that the specific gravity of potatoes is directly proportional to their dry matter content and increases with an increase in their specific gravity. For chips, French fries and dehydrated products, tubers with more than 20% dry matter or more than 1.080 specific gravity is preferred whereas for canning dry matter content of 18–20% is considered acceptable.

Reducing sugar content

Reducing sugars (glucose and fructose) play a critical role in determining the colour of fried products during deep frying at high temperatures by the ‘Maillard reaction’ between reducing sugars and free amino acids (asparagine) present in the tubers. Excessive amounts of reducing sugars in potato tubers result in unacceptably dark colour and bitter taste in fried products. Potatoes contain an appreciable amount of sucrose (~50%), glucose and fructose as well as many other sugars in small quantities. For making good quality fried (chips, French fries) or dehydrated (flakes, granules, powder) products, potatoes should have low reducing sugars (0.1–0.15% on a fresh weight basis). Besides affecting the colour and flavour of fried products, Maillard reaction has also been related to the formation of acrylamide, which is considered a potentially toxic compound having carcinogenic properties, therefore, its concentration is of high concern for processed potato products. All the Indian varieties have been profiled for the formation of acrylamide in the chips and French fries and it is well established that the processing varieties having low reducing sugars also produce less acrylamide in the products and hence, it is recommended that for processing of potatoes, only processing varieties must be utilized.

Phenolic compounds

Enzymatic discoloration and after-cooking discoloration are caused by phenolic compounds present in the tubers. Enzymatic discoloration occurs when the potatoes are peeled, cut or injured. Some of the constituents like tyrosine and ortho-dihydric phenols present in the tubers react with oxygen in the presence of polyphenol oxidase enzyme and tuber flesh turns brown. This type of discoloration can be prevented by reducing the exposure of peeled and cut potatoes to air by keeping them immersed in water and also by blanching treatments to some extent. After-cooking discoloration develops upon cooking and exposure to air which is the matter of concern for potato canners.

Glycoalkaloids

Potato tubers contain small quantities of naturally occurring steroidal glycoalkaloids, potentially toxic compounds. Approximately 95% of the total glycoalkaloids present in potatoes are -solanine and -chaconine. The distribution of glycoalkaloids in the tubers is not uniform. Periderm and cortex have higher concentrations than the pith. Varieties differ with respect to their inherent glycoalkaloid content; at lower levels, it is suggested that they may enhance potato flavour, but at higher concentration (more than 15 mg/100 g fresh weight) these causes bitterness and levels above 20 mg/100 g fresh weight are considered unsuitable for human consumption, typically associated with food poisoning. A number of factors can influence the level of glycoalkaloids in potato tubers, including variety, climate, storage environment, maturity, damage, temperature and exposure to light. The Indian potato varieties contain glycoalkaloids within the permissible limit and meet human food safety limits. Besides, the requirement of above morphological and biochemical traits, the tubers of processing varieties should not show more than 3% greening and the total tuber defects such as growth cracks, hollow heart, internal brown spots, and secondary growth should not exceed 15%.

Table 1: Tuber quality requirement for some popular potato-based products

Product	**Shape**	**Size (Diameter)**	**Dry matter (%)**	**Reducing sugars (mg/ 100g FW)**
Chips	Round	45-80 mm	> 20	<150
French Fries	Oblong	>76 mm	> 20	<150
Potato flakes	Any shape	Not specific	> 20	<100
Canning	Any shape	20-40 mm	<18	Not specific
Starch	Any shape	Not specific	22-24	Not specific
Dehydrated products (Cubes, shreds, sticks)	Any shape	>30 mm	22-25	<150
Porridge and semolina	Any shape	Not specific	>20	Not specific
Flour and bakery products	Any shape	Not specific	>20	Not specific

Storage requirements

Colour is one of the most important aspects of quality for processors as well as consumers. Therefore, proper storage conditions are very critical for the potato to be used for processing. As a living organism, potatoes continue to respire in storage. During respiration, simple sugars are formed from starch hydrolysis. During starch hydrolysis, loss of dry matter also occurs, resulting in weight loss. The respiration rate is highly influenced by temperature hence will vary depending on storage conditions.

Table 2: Indian potato varieties for processing

Variety	Crop Duration (days)	Shape/Size	Dry matter (%)	Reducing sugars (mg/100g FW)	Acrylamide (µg/Kg FW)
Kufri Chipsona-1	100-110	Oval/Large	21-24	45-100	< 100
K. Chipsona-2	100-110	Round/Large	21-25	44-93	<100
K. Chipsona-3	90-110	Round-Oval/ Medium	22-24	30-50	< 100
K. Chipsona-4	90-110	Round	21-23	60-140	< 100
K. Frysona	90-110	Oblong/ Large	22-23	<100	< 100
K. Himsona	110-120	Oval/ Medium	20-25	<50	< 100
K. Jyoti	90-100	Oval/Large	18-21	106-275	< 800
K. Lauvkar	80-85	Round/Large	18-20	200-250	< 300
K. Chandramukhi	80-85	Oval/large	18-20	250-324	< 500

Potato tubers stored at temperatures below 9–10 °C results in accumulation of high concentrations of reducing sugars such as glucose and fructose, known as low-temperature sweetening (LTS) or cold-induced sweetening. These reducing sugars participate in the Maillard browning reaction with free amino acids during frying, resulting in dark brown fries and chips. After harvest, low-temperature storage between 4 and 7 °C can prolong dormancy and reduce shrinkage and diseases; however, temperatures below 9 °C can cause LTS, an often reversible accumulation of reducing sugars. Sprouting increases at storage temperatures above 4–5 °C. Hence, at temperatures above 4 °C, tubers need to be treated for sprout suppression. Isopropyl N-(3-chlorophenyl) carbamate (CIPC) is the most commonly used sprout suppressant for the potatoes. Storage at 10-11°C along with CIPC treatment is the most ideal storage conditions for the potatoes to be used for processing. Beside this, for short term (2-3 months) CIPC, treated potatoes can also be stored in heaps.

Opportunities with novel value-added products

It is well established that reducing sugar content, tuber shape, size and dry matter content have a very important role for fried products particularly chips, French fries, lachha and other fried products. But for some products such as cookies, sweets and preserve there is greater flexibility for these parameters (Table 1). Even partially damaged tubers can also be utilized for the production of these novel products. Recently ICAR-CPRI has developed the process for the production of gluten-free potato cookies which are made from whole potato tuber. These cookies can be prepared from fresh as well as cold-stored potatoes of any shape and size. Similarly, such type of potatoes can be utilized for the production of potato porridge and semolina. Potato porridge and semolina are gluten-free alternatives of wheat-based porridge and semolina. Tubers having high sugar concentration and irregular shape can be used for the preparation of sweets such as lactose-free potato burfi and petha. As these products are sweet and contain added sugar therefore, the sugar present in the tuber has no harmful effect on the taste, texture and colour of the finished products. High sugar-containing tubers of more than 20 mm diameter can be utilized for the canning after suitable pre-treatment. These tubers can also be converted into the flour which can be used for the preparation of soups and thickeners.

Points to be remember

- Therefore, for the preparation of chips, French fries and other fried products only processing varieties of potatoes should be used.
- The knowledge of various biochemical and morphological parameters, the effect of various intrinsic, extrinsic factors and storage conditions affecting the processing quality is essential.
- Potato suitable for processing is not available throughout the year.
- Potatoes having medium sugar content, they can be processed into porridge and semolina.
- Potatoes having sugar medium to high sugar levels, can be processed for the production of cookies, sweets and preserve.

Nutritional and associated processing quality of potato: Recent approaches for their improvement

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1. Introduction

Having achieved the food sufficiency in almost all parts of the world, provides us the leverage to have a paradigm shift in our approach from "quantity increase" to "quality improvement" of crops. Improvement of quality also becomes essential as in future, it is expected that there will be significant reduction in land available to agriculture as compared to that is available today. This suggests that in the less land availability for agriculture we shall have to produce higher nutrients. Agricultural innovation has always involved new, science-based products and processes that have contributed reliable methods for increasing productivity and sustainability. Biotechnology has introduced a new dimension to such innovations, offering efficient and cost-effective means to produce a diverse array of novel, value-added products and tools. Globally, plant products comprise the vast majority of human food intake, irrespective of location or financial status. Therefore, it is to be expected that nutritional improvement can be achieved via modifications of staple crops. Further, it has been suggested that food components can influence physiological processes at all stages of human life. For example inverse relationships have been observed between carotenoid-rich foods and certain cancers. Other nutrient-related correlations link dietary fat and fibre to the prevention of colon cancer, folate to the prevention of neural tube defects, calcium to the prevention of osteoporosis, antioxidant nutrients to the scavenging of reactive oxidant species and protection against oxidative damage of cells etc.

Potato has a definite place in the diet and is associated with good nutrition and health. Potatoes are uniquely positioned to be a valuable source of dietary vitamins, minerals, and phytonutrients because of their high per capita consumption. In most of the developed world, potatoes are by far the most eaten vegetable. Because of this high consumption, the vitamin and phytonutrient content of potato will have much more dietary relevance and impact than food eaten in sparse quantities. Potatoes yield more calories per acre than any other major crop, a criterion that becomes even more important in light of the planet's ever-increasing population, food shortages, price spikes, and the recent trend of utilizing farmland for other commercial purposes. Collectively, these facts emphasize the impact potatoes can have on global nutrition in the future. These facts imply that any significant improvement in nutritional quality of potato will have even more than significant impact on human health and nutrition. Here we have described the biotechnology based approaches for improving the quality traits of potato. World-wide conventional breeding technologies have given the mankind a large number of varieties having improved traits as compared to their predecessors. However, the long breeding cycles, high heterozygosities, lack of various degrees of preciseness in hybridization, low frequencies of desirable mutations and limit of using the genetic resources of primary and secondary gene pool have made new varietal development highly resource-demanding. Recent advancements in the field of agricultural biotechnology have created a new domain to complement the methods of plant breeding. These biotechnolological approaches are also being used/ can be used for improving the nutritional quality as well as the processing attributes of potato.

2. Tuber composition and dietary importance of potato

Nutrition is the processes by which we take in and utilize food substances. Nutrition is essential for growth and development, health and wellbeing. Essential nutrients include carbohydrate, protein, fat, vitamins, minerals and electrolytes. Recommended dietary allowances (RDA) of these important nutrients have been defined world-wide and is revised/ updated from time to time. RDA for these nutrients in India is presented in (Table 1).

Table 1: Recommended dietary allowances (Adapted from Dietary guidilines for Indians- A manual, National Institution of Nutrition, Indian Council of Medical Research, Hyderabad, Second Edition, 2011).

Nutrient	**Man**	**Woman**	**Pregnant woman**	**Children (1-9 yrs)**	**Girls (10-17 yrs)**	**Boys (10-17 yrs)**
Protein (g/d)	60	55	78	16.7 – 29.5	35- 40	35- 50
Calcium (mg/d)	600	600	1200	600	800	800
Iron (mg/d)	17	21	35	9 - 16	27	32
Vitamin A (b-carotene) (µg/d)	4800	4800	6400	3200 - 4800	4800	4800
Thiamin (mg/d)	1.2- 1.7	1.0 – 1.4	1.6	0.5 – 0.8	1.0 – 1.2	1.1 – 1.5
Riboflavin (mg/d)	1.4 – 2.1	1.1 – 1.7	2.0	0.6 – 1.0	1.2 – 1.4	1.3 – 1.8
Niacin equivalent (mg/d)	16-21	12 - 16	18	8 - 13	13-14	15 - 17
Pyridoxin (mg/d)	2.0	2.0	2.5	0.9 – 1.6	1.6 – 2.0	1.6 – 2.0
Ascorbic acid (mg/d)	40	40	60	40	40	40
Dietary Folate (µg/d)	200	200	500	80 - 120	140 - 200	140 - 200
Vit. B12 (µg/d)	1	1	1.2	0.2 -1.0	0.2 -1.0	0.2 -1.0
Magnesium (mg/d)	340	310	310	50- 100	160 -235	120 - 195
Zinc (mg/d)	12	10	12	5-8	9-12	9-12

Potatoes are approximately 80% water and 20 % solids, although it can vary widely from cultivar to cultivar (Fig. 1). Of the 20 g of solids in a 100 g tuber, about 17 g are carbohydrate and 2 g protein. In addition to carbohydrates and proteins potatoes are a good source of many vitamins and minerals (Fig.1). According to the USDA nutrient database, 100 grams of potatoes contains 4% of the RDA calorie intake, 33% of the RDA of Vitamin C, the most abundant vitamin in potatoes and 12 %

of the RDA for potassium. Also, potato tubers contain an array of other small molecules, many of which are phytonutrients. These include polyphenols, flavonols, anthocyanins, phenolic compounds, carotenoids, polyamines, tocopherols etc. These phytonutrients play various important roles as improving immune system, antioxidant activities and health promoting activities, thus are considered as important nutritional quality constituents of potato. Because of the presence of these important nutritional constituents in potato, potato is sometimes referred to as a wholesome food, though levels of these important nutrients are invariably quite low with reference to the RDA values for these nutrients. Therefore, there exists ample scope to further improve the nutritional value of potato and make it a truly wholesome food.

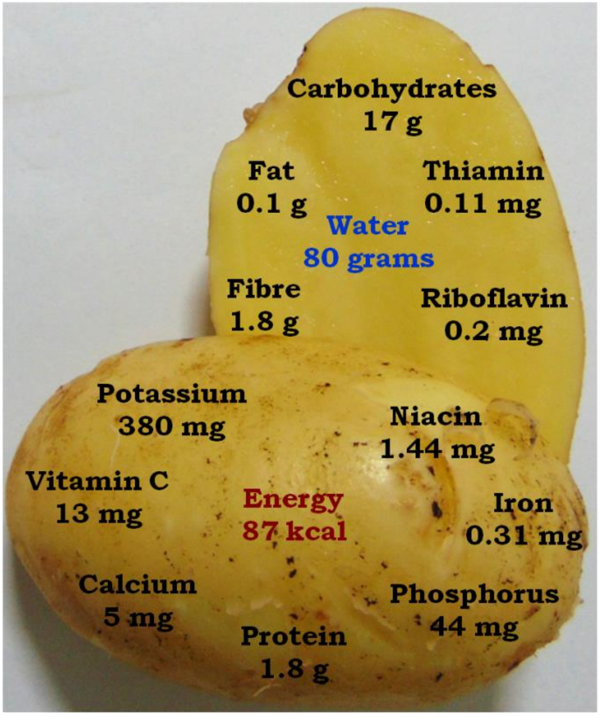


Figure 1. Nutrient contents of potato (in 100 g after boiling in skin and peeling before consumption. Partially adapted from www.fao.org/potato-2008.

3. Biotechnological tools for assisting conventional plant breeding

Recent advancements in the field of agricultural biotechnology have created a new domain to complement the methods of plant breeding. Genetic improvement can be achieved through conventional as well as non-conventional approaches. There are broadly three benefits to agriculture and crop improvement programs from use of biotechnology. These are: (i) reduction of the duration of the breeding programmes, (ii) to develop and multiply the healthy planting material, and (iii) genetically engineering the crop plants for trait improvement. The first two benefits hold true for all kinds of crop improvement and breeding programs. The third area i.e. genetic engineering or recombinant DNA technology is target trait specific.

From consumer point of view the main quality traits in potato are nutrient content of the potato tubers, organoleptic characteristics including taste, flavour, appearance etc. Therefore, for researchers improving the quality traits means improving any one, two or all of these three characteristics of potatoes. Worldwide efforts are going on to develop the cultivars of potato with improved quality characteristics. Biotechnological tools are being continuously enriched and improved. Potatoes being one of the most important commodities for processing sector, its processing attributes are also crucial for determining their suitability for processing purposes (e.g. making chips, French fries, dehydrated products etc.). This chapter is restricted to nutritional and processing trait improvement in potato using biotechnological approaches.

Genomic resources for biotechnological applications in potato: The generation of huge volume of the datasets of DNA sequences has gone much beyond everyone's imaginations. This has been mainly possible due to tremendous advancements in highthroughputness of DNA sequencing technologies and the parallel development of sequencing storage servers and bioinformatics tools employed for DNA sequence assembly and annotations. Even in case of vegetable crops, the genome of the vegetables (including potato) belonging to more than 15 groups (tomato, potato, sweet potato, pepper, carrot, cabbage, turnip, radish brinjal, cucumber, chenopodium, bitter gourd yam, beans, lettuce spinach etc.) have been sequenced and the genome sequence database is available in public domain (Table 2). This list of genome sequences of vegetable crops has expanded very rapidly**.** The assembly of these sequenced genomes are at different levels of assembly (chromosomes, scaffolds/contigs) (Table 2). Availability of genome sequences (including those of other vegetable crops) can be of great as a source of efficient gene isoforms for improving quality traits of potato through biotechnological approaches.

Genome resequencing, single nucleotide polymorphism (SNP) discovery through genotypic sequencing will be very useful in deciphering the genetic diversity at nucleotide sequence levels. This information inturn can be used for establishing the association between DNA/ nucleotide variation and phenotypic/ trait variability. The availability of genome sequences of various species within a clad/ group may be very useful in performing genome-wide association mapping (GWAS) for various quality traits which will be vital for developing effective breeding strategies aiming at targeted quality trait(s) improvement. This may further help in identifying the more efficient alleles associated with desirable quality traits. However, this may need additional information about comparative kinetics of the enzymes encoded by these isoforms/ alleles.

Table 2: Published sequenced genomes of vegetable crops (available in public domain database-NCBI)

SN.	Organism/Name	Common name	BioProject	Size (Mb)	Scaffolds	Genes	Level of assembly
1.	*Solanum lycopersicum*	tomato	PRJNA119	824	3224	30336	Chromosome
2.	*Solanum pennellii*	wild tomato	PRJEB5228	720	57205	-	Contig
3.	*Solanum pennellii*	wild tomato	PRJNA256426	926	12	32519	Chromosome
4.	*Solanum arcanum*	wild tomato	PRJEB5226	665	46594	-	Contig
5.	*Solanum lycopersicum*	tomato	PRJEB6302	760	13	-	Chromosome
6.	*Solanum lycopersicum, Heinz 1760*	tomato	PRJNA41343	541	100783	-	Scaffold
7.	*Solanum pimpinellifolium*	wild tomato	PRJNA72351	688	309180	-	Contig

8.	*Solanum melongena*	egg plant	PRJDB1505	833	33873	-	Scaffold
9.	*Capsicum annuum*	pepper	PRJNA186921	2936	6478	41504	Chromosome
10.	*Capsicum annuum*	pepper	PRJNA223222	3064	35797	35845	Chromosome
11.	*Capsicum annuum var. glabriusculum*	pepper	PRJNA193661	2768	16998	-	Chromosome
12.	*Capsicum chinense*	pepper	PRJNA331024	3071	87978	34974	Chromosome
13.	*Capsicum baccatum*	hot pepper	PRJNA308879	3216	23260	35853	Chromosome
14.	*Solanum commersonii*	wild potato	PRJNA269007	730	63664	-	Scaffold
15.	*Solanum tuberosum*	potato	PRJNA63145	706	14854	33410	Scaffold
16.	*Brassica oleracea var. oleracea*	wild cabbage	PRJNA293438	489	32886	53670	Chromosome
17.	*Brassica oleracea var. capitata*	cabbage	PRJNA174731	514	1816	-	Scaffold
18.	*Brassica juncea var. tumida*	mustard	PRJNA285130	955	9746	-	Chromosome
19.	*Brassica napus*	turnip	PRJEB5043	848	20899	61153	Scaffold
20.	*Spinacia oleracea*	spinach	PRJNA396054	870	78263	30973	Scaffold
21.	*Spinacia oleracea*	spinach	PRJNA41497	494	103502	21539	Scaffold
22.	*Cucumis sativus*	cucumber	PRJNA33619	196	190	20396	Chromosome
23.	*Cucumis sativus*	cucumber	PRJNA40333	324	13113	-	Scaffold
24.	*Cucumis sativus*	cucumber	PRJNA296786	343	8035	-	Contig
25.	*Chenopodium quinoa*	chenopodium	PRJNA394242	1334	3487	58734	Scaffold
26.	*Chenopodium suecicum*	chenopodium	PRJNA326219	537	11198	-	Scaffold
27.	*Chenopodium pallidicaule*	chenopodium	PRJNA326220	337	3013	-	Scaffold
28.	*Raphanus sativus*	radish	PRJNA344915	427	10676	58031	Scaffold

29.	*Raphanus sativus*	radish	PRJNA259311	383	44239	-	Chromosome
30.	*Raphanus sativus*	radish	PRJDB1517	402	76592	-	Scaffold
31.	*Raphanus sativus*	radish	PRJDB707	383	40123	-	Scaffold
32.	*Raphanus raphanistrum subsp. raphanistrum*	wild radish	PRJNA209513	254	64732	-	Contig
33.	*Dioscorea rotundata*	white yam	PRJDB3383	457	21	-	Chromosome
34.	*Manihot esculenta*	cassava	PRJNA394209	582	2020	31881	Chromosome
35.	*Manihot esculenta subsp. flabellifolia*	cassava	PRJNA236442	391	54016	-	Scaffold
36.	*Ipomoea batatas*	sweet potato	PRJNA301667	837	28461	-	Chromosome
37.	*Ipomoea trifida*	wild sweet potato	PRJDB3230	513	77400	-	Scaffold
38.	*Beta vulgaris subsp. vulgaris*	sugarbeet	PRJNA41497	540	84234	-	Scaffold
39.	*Daucus carota subsp. sativus*	carrot	PRJNA326436	422	4826	36299	Chromosome
40.	*Amaranthus hypochondriacus*	grain amaranth	PRJNA214803	502	117340	-	Scaffold
41.	*Asparagus officinalis*	garden asparagus	PRJNA376608	1188	11792	32073	Chromosome
42.	*Vicia faba*	faba bean	PRJEB8906	80	74659	-	Contig
43.	*Momordica charantia, OHB3-1*	bitter gourd	PRJDB4642	286	1052	21623	Scaffold
44.	*Phaseolus vulgaris*	french bean	PRJNA221782	550	68335	-	Chromosome
45.	*Lactuca sativa*	lettuce	PRJNA68025	1134	876110	-	Contig

Transgenic based tools for quality improvement of potato: Genetic engineering has the application in introducing the specific traits into plants. It does not replace conventional breeding but add to the efficiency of crop improvement. It is possible due to the fact that plants are totipotent, enabling regeneration of a new plant from an isolated cell, tissue or organ. Genetic engineering is the purposeful addition of a foreign gene or genes to the genome of an organism with the aim to transfer the desired trait to the target plant. Genetic engineering physically removes the DNA from one organism and transfers the gene(s) for one or a few traits into another. Genetic engineering is mainly focussed on the central dogma of biology. The components of central dogma i.e. DNA, RNA and proteins are manipulated to influence the targeted biological process, metabolic pathway or the trait. However, to do this we need quite a bit of information about the molecular, genetic and biochemical basis of the target trait(s). Establishing the correlation between the gene (DNA) and the targeted trait is very crucial in achieving the success in genetic engineering. That is to identify the gene (s) which should/ can be used for improving the quality trait in question. Once the genes have been identified, then the second question comes to search for the availability of the isoforms of the gene which are more efficient in improving the targeted trait. These information are very vital. Hence the availability of genomic resources is proving to be very useful for genetic engineering.

Through transgenic based approaches the desired traits can be manipulated by two methods. These are over-expression of the specific gene(s), and repression or inhibition of the specific gene, or both these together. Various tools and constructs have been developed in order to perform these gene over-expression mediated or gene repression (silencing) mediated genetic engineering for improvement of the targeted trait. These aspects of the genetic engineering have been extensively described in various literatures. The employed tools/ approaches are continuously being improved for their efficiency, precision and biosafety. The transgenic technology has achieved great success in supplementing crop breeding.

Genome editing based tools for crop improvement: Genome editing biotechnological approach is the latest edition to the list of biotechnological approaches for crop improvement. Genome-editing technologies rely on engineered endonucleases (EENs) that cleave DNA in a sequence-specific manner due to the presence of a sequence-specific DNA-binding domain or RNA sequence. Through recognition of the specific DNA sequence, these nucleases can efficiently and precisely cleave the targeted genes. The double-strand breaks (DSBs) of DNA consequently result in cellular DNA repair mechanisms, including homology-directed repair (HDR) and error-prone non-homologous end joining breaks (NHEJ), leading to gene modification at the target sites. There are various kinds of engineered endonucleases systems (e.g. Zinc finger nucleases system, Transcription activator-like effector nucleases system, Clustered regularly interspaced short palindromic repeats/CRISPR-associated 9 system etc) used for genome-editing and can be very useful in improving quality traits of potato

4. Quality traits of potato targeted through biotechnological interventions

In additional to have nutritional importance of potato as a staple food/vegetable, potatoes are also one of the most widely used food commodities for a wide-range of processed products. Hence their processing attributes may also be considered as quality traits. Potatoes do contain some anti-nutritional factors, and thus reducing levels of these anti-nutritional factors also becomes improvement in quality. Improvement in these quality traits of potato employing biotechnological approaches will be described below.

4.1 Nutritional quality improvement

4.1.1 Phenolic compounds

Phenolics are a diverse group of tens of thousands of different compounds. Many phenolics occur as derivatives formed by condensation or addition reactions. Chemically, a phenolic is a compound characterized by atleast one aromatic ring (C6) bearing one or more hydroxyl groups. Some phenolics compounds are effective against diseases or have other health-promoting qualities including effects on longevity, mental acuity, cardiovascular disease, and eye health. Phenolics are the most abundant antioxidants in the diet. Potatoes are an important source of dietary phenolics. Phenolic compounds belonging to various classes are present in potato. These include: phenolic acids (chlorogenic acid, caffeic acid, coumaric acid, protocatechuic acid, vanillic acid, ferulic acid, cryptochlorogenic acid, neochlorogenic acid, gallic acid, p-hydroxybenzoic acid etc), flavonols (rutin, kaempferol rutinose, quercetin-3-o-glu-rut), flavan-3-ols (catechin, epicatechin), anthocyanidins (delphinidin, cyanidin, pelargonidin,peonidin, malvidin, anthocyanins). Variations in these phenolic compounds in potato genotypes have been reported by several studies . Although majority of phenolic compounds are found in greater concentrations in the skin, but significant quantities are also present in the flesh, yet overall the flesh typically contains more phenolics than the skin on a per tuber basis because majority of the fresh weight of a mature potato is contributed by the flesh. These main phenolic compounds found in potato have been briefly described as follows.

Phenolic acids: Phenolic acids and their derivatives are a diverse class of phenolic compounds made by plants. Phenolic acids are derivatives of benzoic and cinnamic acids. Phenolic acids are produced in plants via shikimic acid through the phenylpropanoid pathway. The most abundant phenolics in tubers are caffeoyl-esters. Of the caffeoyl-esters, chlorogenic acid (CGA) comprises over 90 % of a tuber's total phenolics. CGA acid is known to provide protection against degenerative, age-related diseases, may reduce the risk of some cancers and heart disease, and have anti-hypersensitive anti-viral & anti-bacterial properties. The biosynthetic pathway of CGA in plants is depicted in **Fig 2.** This CGA biosynthetic pathway can thus be engineered for increasing the CGA content in potato.

Flavons and flavan-3-ols: Potatoes contain flavonols such as rutin, kaempferol rutinose and quercetin-3-o-glu-rut, but have not been thought to be important source of dietary flavonols. Numerous studies have suggested flavons having multiple health-promoting effects, including reduced risk of heart disease, lowered risk of certain respiratory diseases, such as asthma, bronchitis, and emphysema, and reduced risk of some cancers including prostate and lung cancer. One group showed that flavonols increased in fresh-cut tubers, observing concentrations up to 14 mg/100 g FW and suggested that because of the large amount of potatoes consumed, they can be valuable dietary source. Various studies have reported the presence of variations in the levels of these flavons in various potato genotypes.

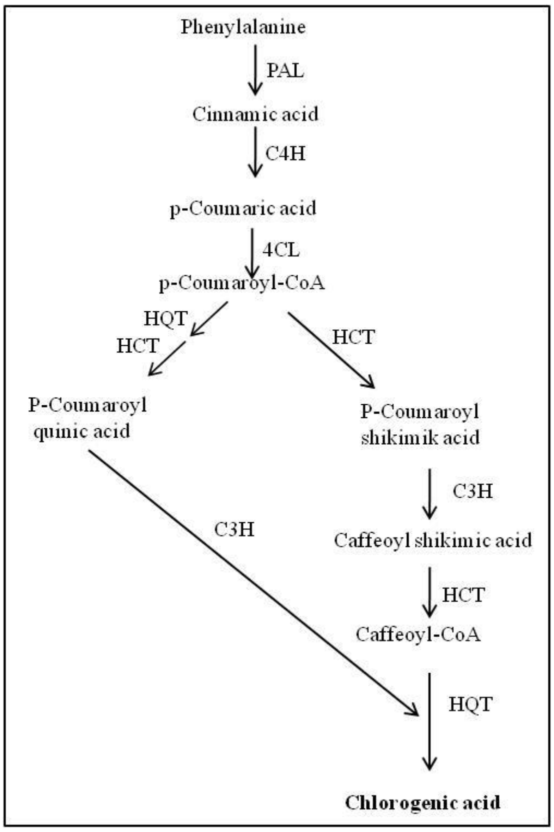


Figure 2: Biosynthesis of chlorogenic acid in potato**.** PAL: phenylalanine ammonia-lyase; C4H: cinnamate 4-hydroxylase; 4CL: 4-coumaroyl:CoA-ligase; HCT: hydroxycinnamoyl CoA shikimate/quinate hydroxycinnamoyl transferase; C3H: p-coumarate 3-hydroxylase; C4H: cinnamate 4-hydroxylase; HQT: hydroxycinnamoyl CoA quinate hydroxycinnamoyl transferase

Flavan-3-ols (sometimes referred to as flavanols) are derivatives of flavans and include catechin, epicatechin gallate, epigallocatechin, epigallocatechin gallate, proanthocyanidins, theaflavins, thearubigins etc. Biosynthetic pathway of flavons and flavan-3-ols in plant is depicted as Fig 3.

Anthocyanins: Potatoes, particularly colored-fleshed cultivars can contain substantial amounts of anthocyanins, compounds that can function as antioxidants and have other health-promoting effects. Anthocyanins from potatoes have been found to have anti-cancer properties. A wide range of variations in anthocyanin content in potato have been reported. Biosynthetic pathway of anthocyanins in plant is depicted as Fig 3. It has been demonstrated that tuber-specific expression of the native and slightly modified MYB transcription factor gene StMtf1(M) activates the phenylpropanoid biosynthetic pathway. Compared with untransformed controls, transgenic tubers contained four-fold increased levels of caffeoylquinates, including CGA (1.80 mg/g dry weight), whilst also accumulating various flavonols and anthocyanins. Subsequent impairment of anthocyanin biosynthesis through silencing of the flavonoid-3',5'-hydroxylase (F3'5'h) gene resulted in the accumulation of kaempferol-rut (KAR) to levels that were approximately 100-fold higher than in controls (0.12 mg/g dry weight).

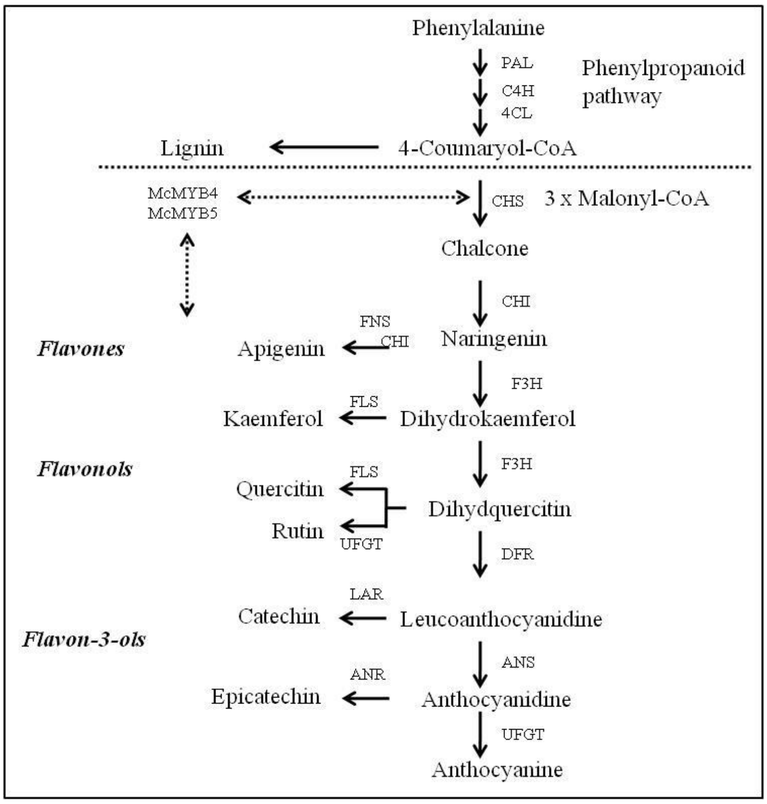


Figure 3: Biosynthesis of flavons, flavan-3-ols and anthocyanins in potato. PAL: phenylalanine ammonia-lyase; C4H: cinnamate 4-hydroxylase; 4CL, 4-coumarate-CoA ligase; CHS: chalcone synthase; CHI: chalcone isomerise; F3H: flavanone 3-hydroxylase; F3 9 H: flavonoid 3 9–hydroxylase; DFR: dihydro-flavonol 4-reductase; FNS: flavone synthase; FLS: flavonol synthase; LAR: leucoanthocyanidin reductase; ANS: anthocyanidin synthase; UFGT:UDP-glucose: flavonoid-3-O-glycosyltransferase.

4.1.2 Carotenoids

Carotenoids are the second most abundant naturally occurring pigments on earth, with more than 750 members. Carotenoid pigments are mainly C40 lipophilic isoprenoids and synthesized in all photosynthetic organisms (bacteria, algae, and plants) and range from colorless to yellow, orange, red, with different degree of variations. Carotenoids have numerous health-promoting properties. Some carotenoids are precursors of vitamin A, and prevent human age-related macular degeneration, and some are potent antioxidant and are considered to prevent prostate cancer and cardiovascular disease. In humans, carotenoids also serve as antioxidants and reduce age-related macular degeneration of the eye, the leading cause of blindness in the elderly worldwide. An increasing interest in carotenoids as nutritional sources of provitamin A and health-promoting compounds has prompted a significant effort in metabolic engineering of carotenoid content and composition in food crops. Potatoes also contain lipophilic compounds such as carotenoids, though in lesser amount. The yellow/orange flesh color found in some potatoes is due to carotenoids. The carotenoids content of tubers in most potato cultivars ranges between 0.2 and 36 µg/ g FW. This variation in carotenoids concentrations has been suggested to be regulated mainly at the transcriptional levels.The most abundant potato carotenoids are composed mainly of the xanthophylls lutein, antheraxanthin, violaxanthin, and of xanthophyll esters. Carotenoids are synthesized in plastids from isoprenoid pathway (Fig 4), and are accumulated in most plant organs.

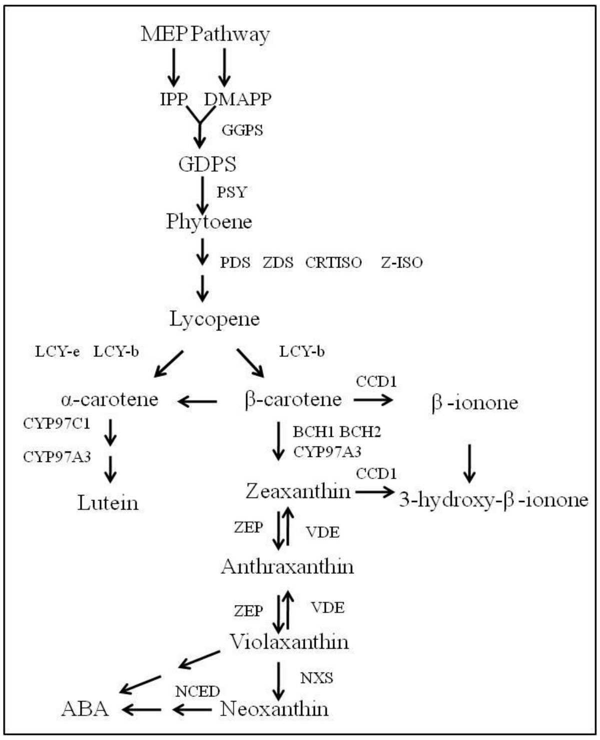


Figure 4: Biosynthesis of carotenoids in potato. GGPS: geranylgeranyl pyrophosphate synthase; PSY: phytoene synthase; PDS: phytoene desaturase;ZDS: f-carotene desaturase; CRTISO: carotenoid isomerise; LCY-ε: lycopene ε-cyclase; LCY β, lycopene β-cyclase; CHY-ε, ε-ring hydroxylase; CHY-β, β-carotene hydroxylase; VDE, violaxanthin de-epoxidase; ZEP, zeaxanthin epoxidase; NXS, neoxanthin synthase; CCD, carotenoid cleavage dioxygenase; NCED, 9-cisepoxycarotenoids dioxygenase

Various genes of these pathways have been characterized in a range of organisms and understanding of the regulation of the carotenoids pathway has led to devising strategies for manipulating this pathway. Numerous groups have attempted to increase potato carotenoids using transgenic strategies. The strategy commonly used in plants is to increase the biosynthetic capacity by altering the carotenogenic enzyme activities. Overexpressing a bacterial phytoene synthase in tuber of the cultivar *Desiree* increased carotenoids from 5.6 to 35 ug/g DW and changed the ratios of individual carotenoids. Beta-carotene concentrations increased from trace amounts to 11 ug/g DW and lutein levels increased 19-fold. Carotenoids have also been increased by the approaches that do not directly involve use of carotenoids biosynthesis genes, as shown by overexpression of the cauliflower *Or* gene in Desiree resulting in a 6-fold increase in tuber carotenoids to about 20-25 ug/g DW. A two-fold increase in carotenoids was observed in tubers overexpressing *Or* after six months of cold storage but no such increase was observed in wild-type or empty-vector transformed plants.

Both *Solanum tuberosum* and *Solanum phureja* transgenic lines have been produced that expressed an algal bkt1 gene, encoding a beta-ketolase, and accumulated ketocarotenoids. Similarly, expression of *Erwinia uredovora* crtB gene encoding phytoene synthase in potato resulted in increased levels of carotenoids. The tuber of *Solanum tuberosum* L. cultivar Desiree normally produces tubers containing 5.6 µg carotenoid /g DW and tubers of *S. phureja* cultivar "*Mayan Gold*" contain carotenoid content of typically 20 µg carotenoid /g DW. In developing tubers of transgenic crtB Desiree lines, carotenoid levels reached 35 µg carotenoid /g DW and the balance of carotenoids changed radically compared with controls. Beta-carotene levels in the transgenic tubers reached 11 µg carotenoid /g DW, whereas control tubers contained negligible amounts and lutein accumulated to a level 19-fold higher than empty-vector transformed controls. The crtB gene was also transformed into *S. phureja*, again resulting in an increase in total carotenoid content to 78 µg /g DW in the most affected transgenic line.

4.1.3 Vitamins

Vitamins are a class of organic compounds, absolutely required for the maintenance of healthy life processes. Role of vitamins in maintaining human health via regulating metabolism and supporting the biochemical process related to the energy released from food or other sources in living organisms is well established. Vitamins are also important in the synthesis of hormones, enzyme activity, red blood cells, genetic materials and neurotransmitters. Although vitamins are required in small amounts, their capability of sustenance and their ability to perform biochemical functions is remarkable. Based on the solubility, vitamins have been grouped into water soluble vitamins and fat soluble vitamins. Fat soluble vitamins are A, D, E and K and the rest are water soluble. Most of the vitamins have been found to act as coenzymes, some act as growth regulators and most of them as antioxidants. Well known human vitamin related disorders include blindness (Vitamin A), beriberi (Vitamin B1), pellagra (Vitamin B3), anemia (Vitamin B6), neural defects in infants (Vitamin B9), scurvy (Vitamin C), sterility related diseases (Vitamin E), and ricketsia (Vitamin D). In potato, predominant vitamin is vitamin C. Potato also contains several B vitamins (Folic acid, niacin, pyridoxine, riboflavin and thiamin). Vitamin in potatoes can be increased through fortification in processed foods, conventional breeding or through use of transgenic techniques, a process known as biofortification.

Vitamin C: Predominant vitamin in potatoes is vitamin C (also known as L-ascorbic acid), which ranges from 84 to 145 mg/ 100g DW depending on cultivar and soil composition. A medium red-skinned potato (173 grams) provides about 36% vitamin C of the RDA according to the USDA database. Vitamin C is an important component in nutrition with the property of antioxidant, immuno-protection, cardiovascular function improvement, prevention of ailments associated with connective tissues, and help in iron metabolism. Vitamin C is a cofactor for numerous enzymes, functioning as an electron donor. The best known symptom of vitamin C deficiency is scurvy, which in severe cases is typified by loss of teeth, liver spots, and bleeding. More than 90% of vitamin C in human diets is supplied by fruits and vegetables. It has been suggested that 100-200 mg vitamin C should be supplied by human diets and this quantity is expected to be increasing because of increasing stress in modern life. Therefore, it is valuable to increase vitamin C content in edible products of plant. In India the available supply of vitamin C is 43 mg/ capita/day, and in the different states of India it ranges from 27 to 66mg/day which is far below the recommended dose of 400 mg/day by ICMR (National Institute of Nutrition 2011). Plants may have multiple vitamin C biosynthetic pathways; with all of the enzymes of the L-galactose pathway have been characterized. Extensive research work has been undertaken at molecular levels of vitamin C biosynthetic pathway in plants. An outline of plant vitamin C biosynthesis pathway is represented in (Fig 5). This knowledge has made it possible to manipulate vitamin C content in several crops (including potato) using various approaches including genetic engineering based. Transfer of L-gulone-γ-lactone oxidase gene from rat to potato resulted in 40 % increase in vitamin C.

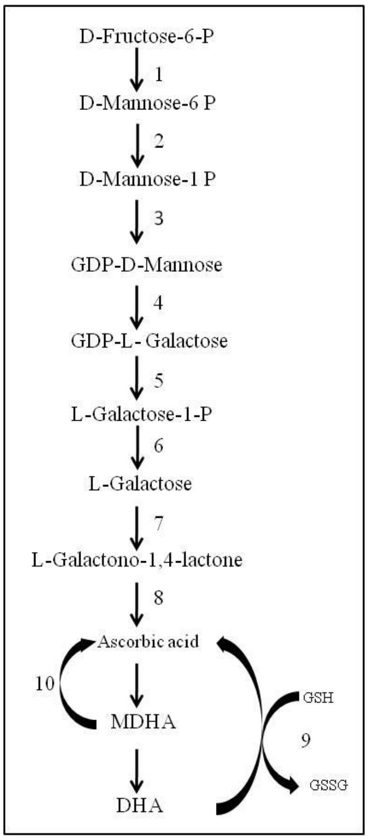


Figure 5: Ascorbic acid biosynthesis and recycling pathways in plants. 1: mannose-6-phosphate isomerase; 2: phosphomannomutase; 3: GDP-mannose pyrophosphorylase (mannose-1-phosphate guanylyltransferase); 4: GDP-mannose-3′,5′-epimerase; 5: phosphodiesterase; 6: sugar phosphatase; 7: L-galactose dehydrogenase; 8: L-galactono-1,4-lactone dehydrogenase; 9: dehydroascorbate reductase; 10: mono-dehydro-ascorbate reductase.

Vitamin A: Vitamin A deficiency is one of the most prevalent nutrient deficiencies in many underdeveloped regions of the world, where it affects an approximately 250 million children under 5 years of age. Beta-carotene is the primary substrate for synthesis of vitamin A in humans. Plant provitamin A carotenoids are the primary dietary precursors of vitamin A. While many fruits and vegetables have high levels of provitamin A carotenoids, staple crops contain low levels of these compounds, which contributes to the global prevalence of vitamin A deficiency. Vitamin A deficiency (VAD) is the leading cause of preventable blindness in children and increases the risk of disease and death from severe infections. To help combat vitamin A deficiency, a global effort is underway to increase provitamin A content in major food crops including potato. Cultivated potato is extremely poor in pro-vitamin i.e. β-carotene. However, metabolic engineering efforts to accumulate high levels of β-carotene in potato tubers proved successful. Ducreux and his group worked on two potato cultivars to increase the carotenoid content of potato tubers. *S. tuberosum* cv Desiree, which typically accumulates 5.6 µg / g DW carotenoids with negligible β-carotene content and *S. Phureja* cv. Mayan Gold which typically accumulates 20 µg / g DW carotenoids. Both cultivars were transformed with the phytoene synthase gene (crtB) (for place of this enzyme in carotenoid biosynthetic pathway from *Erwinia uredovora*. Transgenic potato showed an accumulation of 35 total carotenoids and 11 µg / g DW β-carotene in developing tubers of Desiree and 78 µg per g DW in Mayan Gold tubers.

Vitamin E: Vitamin E (also known as tocopherols) is another essential nutrient for human health, but is consumed at suboptimal levels. The importance of vitamin E for reproductive health was recognized as early as 1922. Humans and other animals are not capable of synthesizing tocopherol (vitamin E) autonomously and must be obtained from their diet. The vitamin E (α-tocopherol) is only synthesized by photosynthetic organisms which show potent antioxidant activity and vital for human health, however, consumed at the sub-optimal level. The metabolic pathways involved in tocopherol biosynthesis in plants have been deciphered to a greater extent. A generalized pathway of the vitamin E metabolic biosynthesis in plants is represented in (Fig 6). In 2008, Crowell et al. reported the development of transgenic tuber over accumulating vitamin E where the transgenic potato lines developed via *Agrobacterium* mediated transformation using two vitamin-E biosynthetic genes, p-hydroxyphenylpyruvate dioxygenase (At-HPPD) and homogentisate phytyl transferase (At-HPT), isolated from *Arabidopsis thaliana*. Biochemical and molecular analysis revealed that the over-expression of At-HPPD and At-HPT resulted in a maximum 266% and 106 % increase in alpha-tocopherol respectively.

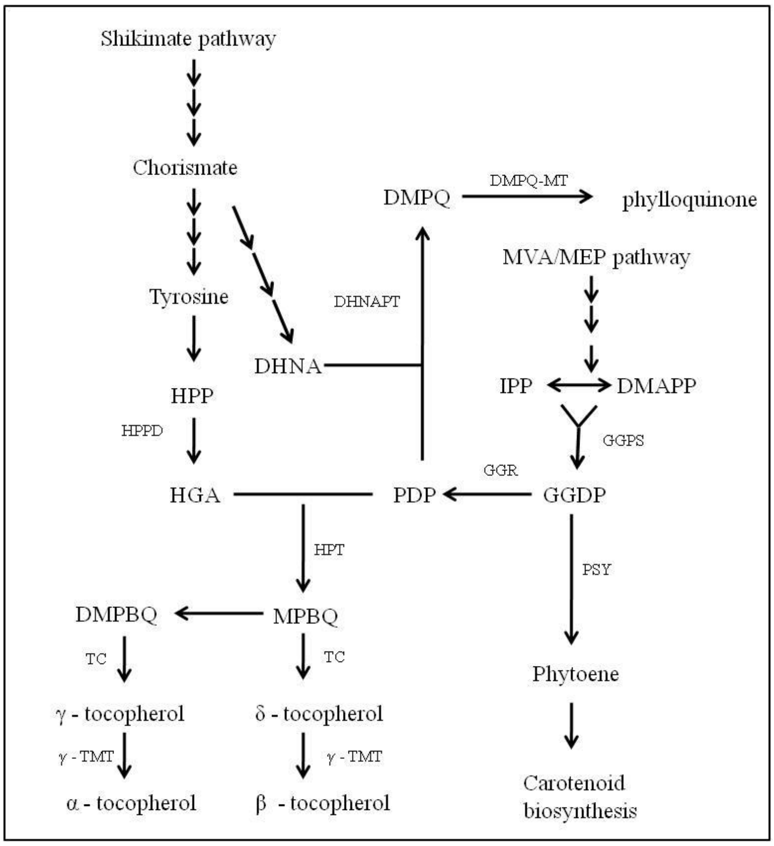


Figure 6: Biosynthesis of tocopherols in plants. HPPD: p-hydroxyphenyl-pyruvate dioxygenase; HPT: homogentisate phytyltransferase; MPBQ: methylphytylbenzoquinone; MT: methyltransferase; γ-TMT: γ-tocopherol methyltransferase.

Vitamin B9: Vitamin B9, also known folates and is used as generic name to designate tetrahydrofolate (THF) and its on-carbon (C1) unit derivatives. Folates are essential micronutrients in the human diet. Folates are important cofactors involved in C1 unit transfer reactions. Folates exist in various forms. Folate deficiency is associated with the increase risk of neural tube defects, cardiovascular diseases, megaloblastic anemia, and some cancers. Unfortunately, folate intake is suboptimal in most of the world's populations, even in developed countries. Therefore there is an urgent need to increase folate content and bioavailability in staple foods. Because of its large consumption worldwide, potato is an appealing target for enrichment. Importance of folates in human diets urges to increase the folate levels in potato. Humans are not capable of synthesizing folates and thus require dietary supply. Plants represent the major source of folate in the diet. As such Potato is in the lower range of folate contents among plant foods, even then potato is a well-known significant source of folates in the diet due to its high level of consumption more so that for its endogenous content. Values for folate concentrations in mature raw potato vary between 12 and 37 ug/ 100 g FW . As folate biosynthesis has been fairly delineated in recent years, metabolic engineering of the pathway is feasible. Recent studies have provided a proof of concept that additional introduction of HPPK/DHPS and/or FPGS, downstream genes in mitochondrial folate biosynthesis, enable augmentation of folates to satisfactory levels (12-fold) and observed folate stability upon long-term storage of tubers. This engineering strategy can serve as a model in the creation of folate-accumulating potato cultivars, readily applicable in potato-consuming populations suffering from folate deficiency.

Vitamin B6: Vitamin B6 (chemically know as pyroxidine) is water soluble and like folate has several vitamins. Vitamin B6 may be involved in more bodily functions than any other nutrient, is a cofactor for many enzymes, especially those involved in protein metabolism, and is also a cofactor for folate metabolism. Vitamin B6 has anti-cancer activity, is a strong antioxidant, is involved in hemoglobin biosynthesis, lipid and glucose metabolism, and immune and nervous system function Possible consequences of deficiency include anemia, impaired immune function, depression, confusion, and dermatitis. The most significant sources of Vitamin B6 are animal proteins, starchy vegetables (potatoes), bananas, avocados, walnuts, peanuts, legumes. Potatoes are an important source of dietary vitamin B6 with a medium baked potato (173 grams) providing about 26% of the. Very little research has been conducted on this vitamin in potato, thus little is known about how much its concentrations vary among genotypes. Vitamin B6 in potato has been reported in the range of 0.26-0.82 mg/ 200 g FW. Vitamin B6 content varies substantially among the potato genotypes. There is thus great potential for improving potato further through increasing the content of this specific phytonutrient, by either breeding or genetic manipulation to fortify the B6 vitamin as a healthy food resource for human nutrition.

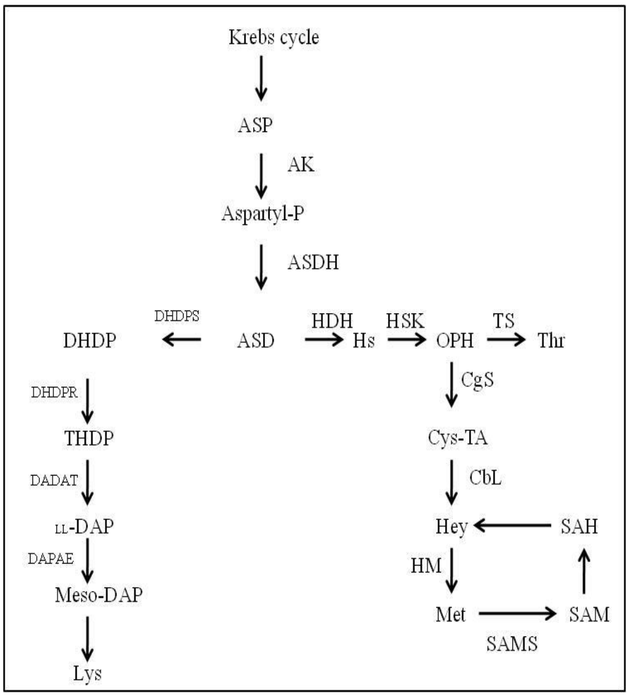
4.1.4 Protein and essential amino acids

Origin of name "Protein" (derived from the Greek word "*proteios"* means primary) itself justifies it as one of the primary components of the living cells and is the most important nutrient for humans. Lack of sufficient proteins in diet leads to deleterious effects on growth and development in human beings. Lack of sufficient protein in diet is known as Protein energy malnutrition (PEM) and this is the most lethal form of malnutrition and affects every fourth child worldwide. Building blocks of proteins are twenty common amino acids. Humans like other animals, can only produce about half of the 20 common amino acids needed for life, the rest amino acids must be obtained via diet and these amino acids are referred to as essential amino acids. Plant proteins contribute about 65% of the per capita supply of protein on worldwide basis. Among plants, cereal grains, tubers and food legumes as the most important suppliers of proteins. As the world population increases (and with it the load on our agricultural resources), the need to make good-quality protein available efficiently and economically becomes increasingly important. The importance and urgency of providing humans with quality proteins are reflected in the growing scientific and industrial interest in augmenting the nutritive value of the world's protein sources. Major efforts have been made to enhance the overall protein content and /or to improve the essential amino acid composition of plant protein. The later may be considered as improving the quality of the targeted protein(s). Because of the importance of dietary protein and the fact that plants are its major source, development of strategies to increase protein levels and the concentration of essential amino acids in food crops is of primary importance in a crop improvement program.

In potato, protein content ranges from 1 to 2.0 % of tuber fresh weight. Compared with other, it is negligible a source, potatoes are not typically considered to be good dietary protein sources due to their low overall protein content although it has excellent biological value of 90-100. Keeping these facts in view, genetic engineering based strategies and the efforts to enhance the protein quality/quantity and essential amino acids (specifically methionine, lysine and tryptophan) in various crop plants including potato have been targeted world-wide.

Lysine and methionine are synthesized by aspartate pathway within the chloroplast (Fig. 7). The major genetic engineering based strategies for improving protein quantity/quality can be broadly grouped into three categories. These three groups are: (1) Genetic engineering of essential amino acids. (2) Genetic engineering to enhance the levels of natural high quality proteins within the plant tissue. (3) Improving the nutritional quality of protein plant synthesises, through protein engineering and/or design. Efforts are being on for increasing content of various essential amino acids (methionine, lysine, tryptophan, threonine etc.) in potato. Advances in biotechnology allowed the use of transgenic approach to increase the content of specific essential amino acids in a target plant. Chakraborty et al. (2000) developed transgenic potato over-expressing the sunflower albumin or an amaranth seed albumin (*AmA1*), driven under the constitutive promoters, which resulted in five to seven folds increase in total methionine level in tubers. Further analysis of transgenic potato lines with enhanced methionine amino acid via tuber-specific expression of a seed protein, *AmA1* (*Amaranth albumin* 1) revealed an increase in total protein contents up to 60% in comparison to the transformed potato.

Figure 7: The Aspartate pathway leading to the biosynsthesis of Met and Lys. Asp: Aspatate, AK: Aspartate kinase, ASD:aspartatesemialdehyde, ASDH: aspartic semialdehyde dehydrogenase, DHDP: dihydrodipicolinate, DHDPS: dihydrodipicolinate synthase, HS: homoserine, HDH: homoserine dehydrogenase, OPH: Ophosphohomoserine, HSK: homoserine kinase, Thr: Threonine, TS: Thr synthase, CysTA: cystathionine, CgS: cystathionine -synthase, HcY: Homocysteine, CbL: cystathionine -lyase, SAH: Sadenosylhomocysteine, HM: homocysteine methyltransferase, SAM: S-adenosyl-methionine, SAMS: S-adenosyl-methionine synthetase, THDP: tetrahydro-dipicolinate, DAPAE: DAP epimerase, DAP: diaminopimelate, DAPAT: DAP-aminotransferase.



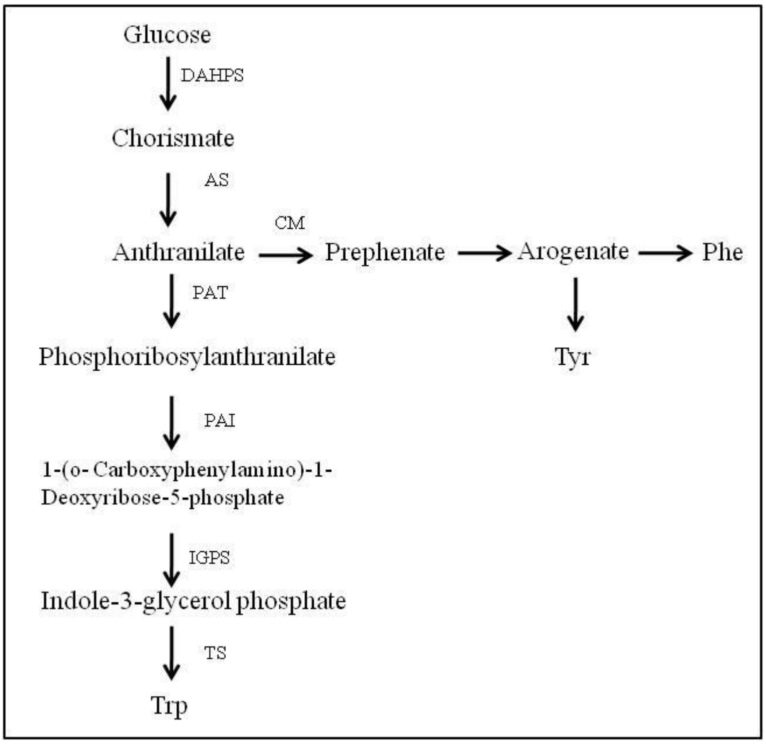


Figure 8: Tryptophan biosynthesis pathway. AS: Anthranilate synthase; PAT: Phosphoribosylanthranilate transferase; PAI: Phosphoribosyl anthranilate isomerase; IGPS: Indole-3-glycerol phosphate synthase; Trp: Tryptophan; TS: Trp Synthase; Tyr: Tyrosine; Ser: Serine; IAA: Indole-3-acetic acid; Phe: Phenylalanine; AH: Arogenate dehydro; DAHPS: DAHP Synthase.

4.1.5 Minerals

Humans require various minerals to maintain health and for proper growth, and plants are essential source of such minerals (Welch 2002). Minerals can generally be classified as (a) major minerals [such as calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P), cobalt (Co), manganese (Mn), nitrogen (N), chlorine (Cl)], and (b) minor / trace minerals [such as iron (Fe), copper (Cu), selenium (Se), nickel (Ni), lead (Pb), sulfur (S), boron (B), iodine (I), silicon (Si), bromine (Br)]. Importance of optimal intake of these minerals to maintain good health has been universally recognized. Potatoes are an important source of different dietary minerals. However, there are significant differences in major and trace mineral contents among different genotypes of potato. In addition to genetic factors, many other factors affect the mineral composition of potatoes, these include: location, stage of development, soil type, soil pH, soil organic matter, fertilization, irrigation, weather etc. Therefore, the same genotype grown in different locations may have different mineral concentration due these environmental factors.

In terms of mineral content, potato is best known as an important source of dietary potassium. Potassium plays a fundamental role in acid-base regulation, fluid balance, required for optimal functioning of the heart, kidneys, muscles, nerves, and digestive systems. Health benefits of sufficient potassium intake include reduced risk of hypokalemia, osteoporosis, high blood pressure, stroke, inflammatory bowl disease, kidney stones, and asthma. Potato is listed as providing 18% of the RDA of potassium. Potato qualifies for a health claim approved by the US. Food and Drug Administration, which states: ‘Diets containing foods that are good source of potassium and that are low in sodium may reduce the risk of high blood pressure and stroke.' Potassium varies from 3550- 8234 ug/gFW. The dietary reference intake of potassium for adult men and women is 3000-6000 mg per day. The US National academy of Sciences has recently increased the recommended intake for potassium from 3500 mg to atleast 4700 mg per day. Besides potassium, phosphorus is the main mineral in potato tubers. It has many roles in the human body and is a key player for healthy cells, teeth, and bones. Inadequate phosphorus intake results in abnormally low serum phosphate levels, which affect loss of apetite, anemia, muscle weakness, bonepain, rickets osteomalacia, susceptibility to infection, numbness and tingling of the extremities, and difficulty in walking. In potatoes phosphorus ranges from ~1300-6000 ug/ g DW. Daily requirement of phosphorus is 800-1000 mg. Potato is listed as providing 6% of the RDA of phosphorus. Calcium is important for bone and tooth structure, blood clotting, and nerve transmission. Deficiencies are associated with skeletal malformation and blood pressure abnormalities. The RDA for calcium is is 600-1200 mg (Table 1). Potatoes are a significant source of calcium and has been shown to provide 2% of the RDA of calcium. Magnesium is required for normal functioning of muscles, heart, and immune system. Magnesium also helps maintain normal blood sugar levels and blood pressure. Potato magnesium levels range from 142 to 359 ug/g FW and provides 6% of the RDA of magnesium. Manganese has a role in blood sugar regulation, metabolism, and thyroid hormone function. RDA for manganese is 2-10 mg. The range of potato manganese content has been reported from 0.73 - 3.62 ug/gFW to 9 - 13 ug/g DW. Copper is needed for synthesis of hemoglobin, proper ion metabolism, and maintenance of blood vessels. The RDA for copper is 1.5 – 3.0 mg. Copper in potatoes varies from 0.23 to 11.9 mg/kg FW. Copper is high in yellow–fleshed potatoes.

Iron deficiency affects more than 1.7 billion people worldwide and has been called the most widespread health problem in the world by the World Health Organization. Dietary iron requirements depend on numerous factors, for example, age, sex, and diet composition. Potato is a modest source of iron. Potato is listed as providing 6% of the RDA of iron. Iron content in cultivated potato tubers have been found in the range of 0.3 - 2.3 mg 100 g FW or 6 to 158 ug/g DW. Potato iron has been suggested to be quite bioavailable because it has very low levels of phytic acid unlike the cereals. Zinc is needed for body's immune system to properly work and is involved in cell division, cell growth, and wound healing. Iron and Zinc deficiencies result in decreased immune function and can interfere with growth and development. The RDA for zinc is 15-20 mg and potato is listed as providing 2% of the RDA of zinc. The zinc content ranges from 1.8 to 10.2 ug/g FW. Yellow-fleshed potatoes from different cultivars contain zinc in 0.5 0 4.6 ug/ g FW.

Very few reports are there about research attempts improving mineral content in potato through biofortification. Because plants cannot synthesize these minerals, they must be acquired from soil. As a result, engineering of plant mineral content is quite different from modifications of improving other nutrition associated constituents such as proteins, vitamins etc. that the plant itself synthesizes. There are four main strategies which can be employed for improving the mineral contents in potatoes (Fig. 9), these are: (i) improving minerals uptake from soil, (ii) increasing transport to storage organ. (iii) increasing storage capacity of sink, (iv) decreasing anti-nutrient (phytic acid, phytase etc.) components which reduce availability of the minerals. Research to improve the mineral composition of crop plants has mostly focused on Iron content. Several reports exist in this particular area, most of which describe research that was performed on Iron biofortification in rice crop. However, very less research in this regard in potato has been carried out worldwide.

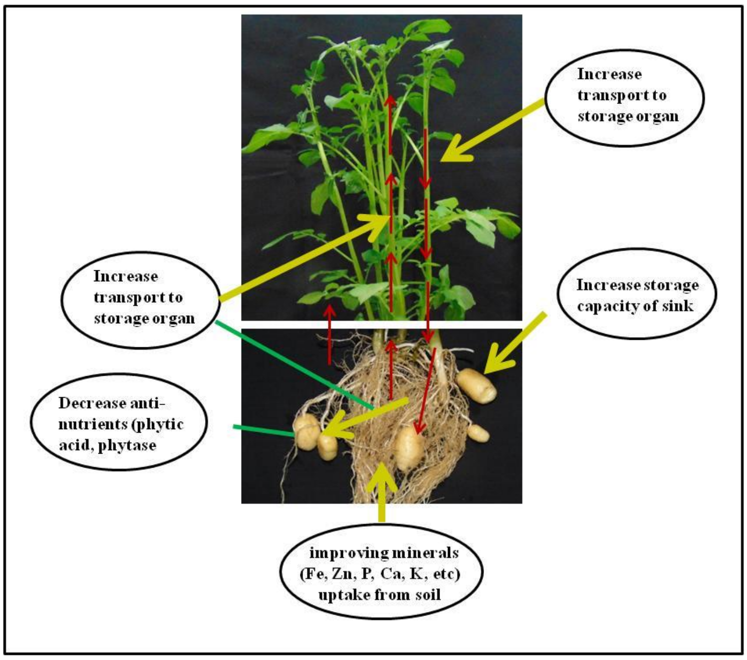


Figure 9. Approaches for improving mineral content in potato. The four main strategies includes: (i). Improving minerals uptake from soil. (ii) Increasing transport to storage organ. (iii) Increasing storage capacity of sink, (iv). Decreasing anti-nutrient (phytic acid, phytase etc.) components which reduce availability of the minerals.

4.2. Reducing anti-nutritional factors

Glycoalkaloids: Steroidal alkaloids (SAs) and their glycosylated forms i.e. steroidal glycosylated alkaloids (SGAs) are toxic compounds mainly produced by members of the Solanaceae and Liliaceae plant families. In humans and animals, steroidal alkaloids are considered anti-nutritional factors because they affect the digestion and absorption of nutrients from food and might even cause poisoning. Presence of SGAs in potatoes, have been of a particular concern due to their toxicity to humans. In potatoes SGAs are found in every plant organs (roots, tubers, stolans, stems, foliage, flowers and fruits) with fresh weight concentrations ranging from 10 mg per kg (fresh weight) in tubers to 5,000 mg per kg (fresh weight) in the flowers . Solanine and chaconine, derived from the aglycone solanidine are the most prevalent glycoalkaloids found in cultivated potato. Elimination of solanidine glycosylation have been found to decrease toxicity of edible tuber. Antisense DNA constructs of *SGT1* coding for solanidine galactosyl transferase involved in α-solanine biosynthsis, *SGT2* coding for solanidine glucosyltransferase involved in α-chaconine biosynthesis, or *SGT3* coding for sterol rhamnosyl transferase, the last step in the triose formation of α-chaconine and α-solanine, reduced the corresponding glycoalkaloids in transgenic potato plants. Antisense silencing of a potato gene encoding a sterol alkaloid glycosyl transferase (*sgt1*) resulted in complete inhibition of α-solanine accumulation. But this decrease was compensated by elevated levels of α-chaconine and resulted in wild type total steroidal glycoalkalids (SGA) levels in transgenic lines.

Acrylamide and allergins: Acrylamide, has been classified as probable carcinogen in humans and has neurological and reproductive effects. It is formed from free asparagine and reducing sugars during high-temperature cooking and processing of common foods. Potato and cereal products are major contributors to dietary exposure to acrylamide. One of the promising approaches to reduce the acrylamide formation in plant based processed products is to develop crop varieties with lower concentrations of free asparagine and/or reducing sugars, and of best agronomic practice to ensure that concentrations are kept as low as possible. Allergies to potatoes appear to be relatively uncommon. Patatin the primary storage protein in potato, unfortunately has also been suggested to be major allergen in potato. Patatin may be cross reactive for persons with allergy to latex, and children with atopic dermatitis appear to have increased sensitivity to this potato protein. However, boiling of potatoes reduce or nullify the allergic reaction.

4.3 Improving carbohydrates quality

After cellulose, starch is the second most abundant compound produced in higher plants. Starch represents the most important carbohydrate used for food and feed. purposes. While cellulose is a structural component of plants, starch mainly serves as a compound to temporarily store energy that can be accessed at a later time point. Chemically, starch is an alpha-glucan (α-glucan) and composed of two types of polysaccharides: amylose and amylopectin (Fig. 10). Amylopectin is highly branched, leaving more surface area available for digestion. It is broken down quickly, and thus produces a larger rise in blood glucose. On the other hand a**mylose** is a straight chain, which limits the amount of surface area exposed for digestion. Therefore digestion of amylose is slow than that of amylopectin and hence is responsible for resistant nature of starch. Thus, improving the resistant starch content refers to increasing the amylose content of the target crop. Resistant starch provides health benefits such as glycaemic control, control of fasting plasma triglyceride and cholesterol levels and absorption of minerals. In view of the industrial application and the nutritional benefits of resistant starch, researchers around the globe have been working to increase the RS content of the plants. The approaches for increasing the RS content in plants includes natural selection, conventional breading as well as transgenic. All these approaches are based on biosynthetic pathways of starch metabolism. As potato contains high starch, they have been genetically modified for increasing the resistant starch content (i.e. amylose content).

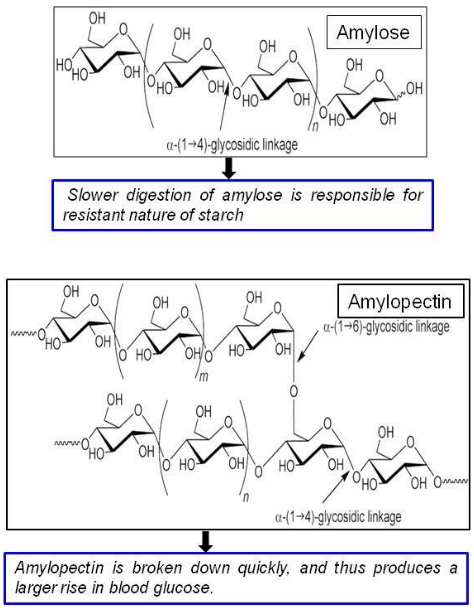


Figure 10. Starch components in potato. Starch has two components viz: amylose and amylopectin. Amylose is considered as resistant starch.

4.4 Improving processing attributes

Accumulation of reducing sugars (primarily glucose and fructose) in cold-stored potato tubers is referred to as "cold-induced sweetening" (CIS). CIS makes the cold-stored potatoes unfit for processing purposes such as chips and French-fries making (Fig 11). Two separate metabolic events are critical in determining a potato tuber's ability to produce sugars in the cold storage: the ability to form sucrose and the ability to hydrolyze sucrose to the reducing sugars glucose and fructose. The control of sucrose synthesis is controlled by several related enzymes while reducing sugar formation is more specifically related to level of vacuolar acid invertase activity. Role of vacuolar acid invertase in cold induced sweetening has been demonstrated by various researchers (Fig 12). Silencing the potato vacuolar acid invertase gene (VInv) has been shown to prevent reducing sugar accumulation in cold-stored tubers.

Processed potato tuber texture is an important trait that influences consumer preference, a detailed understanding of tuber textural properties at the molecular level is lacking. Tuber pectin methyl esterase activity is a potential factor impacting on textural properties. Expression of a gene encoding an isoform of pectin methyl esterase (PEST1) was associated with cooked tuber textural properties. Potato polyphenol oxidases are the enzymes responsible for enzymatic browning reaction observed in impacted, damaged or sliced tubers. These oxidative deterioration reactions alter the organoleptic properties of food and greatly affect potato tuber quality. Silencing of the *PPO* gene in transgenic potato has exhibited reduction in the enzymatic browning and enhanced the shelf life of potato.

Figure 11. Chips prepared from potatoes having high glucose content due to cold induced sweetening a); and from potatoes having low glucose content (b).

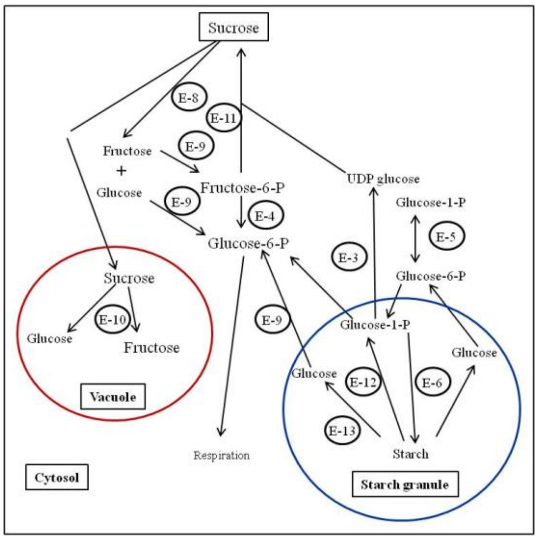


Figure 12. Carbohydrate metabolism in stored potato tubers. Enzymes: (E1) sucrose synthase; (E2) fructokinase; (E3) UDP glucose pyrophosphorylase; (E4) phosphohexose isomerase; (E5) phosphoglucomutase;(E6) ADP glucose pyrophosphorylase; (E7) starch synthases, branching enzymes;

(E8) neutral invertase; (E9) hexokinase; (E10) acid invertase; (E11) sucrose phosphate synthase; (E12) starch phosphorylase; (E13) amylases, debranching enzymes. (Partially adapted from Dale and Bradshaw 2003).

5. Conclusion

Malnutrition is a pressing agricultural and human health problem of the 21st century. Potato being an important constituent of our diets is expected to play vital role in tackling this serious malnutrition problem. The genomic resources need to be continuously enriched to have deeper insights for identifying key molecular regulators which can be utilized through biotechnological approaches in potato with the aim of developing nutritionally superior cultivars.

Potato Value Chain – Scope and Opportunities

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Executive Summary

Potato is among the most important food crop globally, its demand is rising rapidly in India, the second largest producer of potato in the world, next to China. Apart from consumption as vegetable potatoes are used for a variety of purposes as chips, french fries, baked, boiled, mashed and using flour to make a cake, pancake, re-casted potato chips etc. Processing potatoes is an effective way of adding value to the final product. Food processing is often called the sunrise sector of India. The importance of this industry is not only limited to the simple addition to the GDP, but it also provides many other desirable socio-economic benefits such as increased employment opportunities; improvement in income & lifestyle of the rural people leading to reduction of migration of rural masses to cities; and mitigation of huge post-harvest & storage losses. India possesses wide agro-climatic conditions suitable for adequate and round the year supply of processing quality potatoes. The potato processing shall provide a permanent solution to avoid glut like situations.

The demand for the processed potato products are continuously increasing due to number of factors like increased purchasing power, change in preferences for fast foods, urbanization, expanding globalization and increased number of working woman preferring ready to eat / cooked foods (Singh et.al, 2016). In spite of this recent spurt, both organized and unorganized Indian processing industries presently consume less than 10% of the total potato produce in the country as compared to about 30–67% in developed European countries and North America. According to data analytics firm Global data, India's potato chips/crisps market was worth US$2.59bn in 2017, growing at an annual rate of 18.7%, and is expected to further expand to a value of $5.5bn in 2022. The sale of branded chips sold by manufacturers across India is dominated by a handful of big companies viz., PepsiCo, Balaji, ITC, Haldirams and Parle.

Though the consumption of these products is increasing, there are still some bottlenecks in this sector. One of the major issues is the availability of quality raw material at competitive cost. The focus should be made to make provision of a year-round supply of processing potatoes by identifying the hotspots for production of such potatoes and extension of research activities in identifying more suitable varieties. Further, development of low-cost improved storage chambers for long term storage of raw materials, development of novel varieties with desirable characteristics like early maturing, temperature insensitive, resistance to cold sweetening, etc., should be strengthened. There is also an immediate need to identify value added or bio-fortified varieties with high antioxidants, anthocyanin's, low sugar, low calorie and other health benefits or nutrients. Similarly, there is a high potential for the development of processing industry at the farm level as these do not involve higher investment. These value-added processed products will open up new possibilities to make the potato agriculture sector highly remunerative and can take the rural agriculture to the national and international markets.

I. INTRODUCTION

Potato (*Solanum tuberosum* L.) popularly known as **'The king of vegetables'**, has emerged as fourth most important food crop in India after rice, wheat and maize. Indian vegetable basket is incomplete without Potato. Being a short duration crop, it produces more quantity of dry matter, edible energy and edible protein in lesser duration of time than cereals like rice and wheat. It is very strategic crop from value addition point of view in our country. Indian potato meets the international quality in terms of disease freeness, shape, size, skin, colour etc. (Marwaha et al., 2010). A processed potato is of more economic value than the raw, unprocessed one; the increased economic value has a positive effect as the farmer gets a better price due to increased demand, the processing companies realises decent profit margins from a better quality processed potato food product. Potato contributes around 2.86% of the agricultural GDP of the country (*Vision 2050*, 2015) with agriculture sector contributing about 15.87% in the nation's GDP (Madhusudhan L, 2015).

The demand for processed potato products like chips, french fries, flakes etc., is increasing continuously in the present liberalized economy mainly due to improved living standard, increased urbanization, preference for fast foods, rise in per capita income, increase in the number of working women preferring ready cooked food and expanding tourist trade. To meet this demand potato processing industry is emerging as a fast growing industry with more entrepreneurs joining and existing ones increasing their capacity of processing units. Hence, there is a strong need for creating awareness, imparting knowledge, skills and motivating the farmers to increase their income through the adoption of value addition methods as v**alue addition is an important technology, which increases shelf-life of storage, nutritional value and market price of potato.**

II. POTATO UTILIZATION PATTERN

a). Potato production in India

In India, more than 80% of the potato crop is raised in the winter season (*rabi*) under assured irrigation during short winter days from October to March. About 8% area lies in the hills during long summer days from April to October. Rainy season (*Kharif*) potato production is taken mainly in Karnataka, Maharashtra, HP, J&K and Uttrakhand. Plateau regions of south-eastern, central and peninsular India, constitute about 6 per cent area where potatoes are grown as a rainfed crop during rainy season (July to October). In a small area covering mainly the Nilgiri and Palni hills of Tamilnadu, the crop is grown round the year both as irrigated and rainfed crop.

The potato production during the year 2018-19 is estimated to be around 529 lakh MT from the area of 21.67 lakh ha in the country (Table 1). Potato production in India is highly concentrated in Indo-Gangetic plains as three largest potato producing states, viz. Uttar Pradesh (32.32% of national production), West Bengal (26.91% of national production) and Bihar (15.09% of national production), collectively contribute about 74% to the national production.

Table : 1 Area, Production and Productivity of Potato in India (1950-51 to 2018-19)

Year	Area (In ' 000 Hectare)	Production (In ' 000 MT)	Productivity (In MT/Hectare)
1950-1951	240	1660	6.90
1951-1952	250	1712	6.80
1952-1953	255	1992	7.80
1953-1954	257	1956	7.60
1954-1955	266	1764	6.60
1955-1956	280	1859	6.60
1956-1957	286	1724	6.00
1957-1958	321	2004	6.20
1958-1959	338	2348	6.90
1959-1960	362	2733	7.50
1960-1961	375	2719	7.30
1961-1962	365	2447	6.70
1962-1963	413	3365	8.10
1963-1964	415	2593	6.20
1964-1965	429	3605	8.40
1965-1966	479	4076	8.50
1966-1967	473	3522	7.40
1967-1968	501	4232	8.40
1968-1969	524	4726	9.00
1969-1970	496	3913	7.90
1970-1971	482	4807	10.00
1971-1972	492	4826	9.80
1972-1973	505	4451	8.80
1973-1974	543	4861	9.00
1974-1975	587	6225	10.60
1975-1976	622	7306	11.70
1976-1977	620	7171	11.60
1977-1978	665	8135	12.20
1978-1979	807	10133	12.60
1979-1980	685	8327	12.20
1980-1981	729	9668	13.30
1981-1982	763	9912	13.00
1982-1983	735	9956	13.50
1983-1984	794	12152	15.30
1984-1985	849	12571	14.80
1985-1986	843	10423	12.40
1986-1987	832	12740	15.30
1987-1988	885	14138	16.00
1988-1989	933	14857	15.90
1989-1990	940	14771	15.70
1990-1991	936	15206	16.30
1991-1992	1030	16388	15.90

1992-1993	1054	15230	14.40
1993-1994	1047	17392	16.60
1994-1995	1069	17401	16.30
1995-1996	1109	18843	17.00
1996-1997	1249	24216	19.40
1997-1998	1206	17648	14.60
1998-1999	1321	23611	17.90
1999-2000	1340	24713	18.40
2000-2001	1211	22143	18.30
2001-2002	1102	24456	22.20
2002-2003	1325	23269	17.60
2003-2004	1289	23060	17.90
2004-2005	1319	23631	17.90
2005-2006	1401	23905	17.10
2006-2007	1482	28600	19.30
2007-2008	1795	34658	19.30
2008-2009	1828	34391	18.80
2009-2010	1835	36577	19.90
2010-2011	1863	42339	22.70
2011-2012	1907	41483	21.80
2012-2013	1992	45344	22.80
2013-2014	1973	41555	21.10
2014-2015	2076	48009	23.10
2015-2016	2117	43417	20.50
2016-2017	2179	48605	22.30
2017-2018	2142	51310	24.00
2018-2019 (2nd Advance Estimates)	2167	52959	24.40

Source: Indiastat, 2019

Table : 2. State-wise Area, Production and Productivity of Potato in India (2017-2018)

States	**Area (In ' 000 Hectare)**	**Production (In ' 000 MT)**	**Productivity (In MT/Hectare)**
Andhra Pradesh	3.93	68.29	17.36
Assam	102.87	720.97	7.01
Bihar	304.78	7740.79	25.40
Chhattisgarh	44.87	694.61	15.48
Gujarat	133.29	3806.95	28.56
Haryana	34.72	897.58	25.85
Himachal Pradesh	15.88	198.66	12.51
Jammu and Kashmir	5.17	110.24	21.32
Jharkhand	48.21	690.23	14.32
Karnataka	35.53	509.48	14.34
Kerala	0.50	7.50	15.01
Madhya Pradesh	136.29	3144.64	23.07

Maharashtra	11.09	259.22	23.38
Meghalaya	18.92	187.95	9.93
Mizoram	0.09	0.93	10.33
Nagaland	4.92	65.02	13.23
Odisha	25.09	298.06	11.88
Punjab	98.52	2571.04	26.10
Rajasthan	13.82	278.52	20.15
Sikkim	19.14	89.91	4.70
Tamil Nadu	3.51	67.66	19.30
Telangana	3.35	42.44	12.66
Tripura	7.99	144.53	18.10
Uttar Pradesh	614.78	15555.53	25.30
Uttarakhand	26.31	362.16	13.76
West Bengal	427.50	12782.50	29.90
Others	0.67	14.61	21.84
India	**2141.72**	**51310.01**	**23.96**

Source:(*Horticultural Statistics at a Glance 2017*), Government of India

Table : 3 Top Potato producing countries (2017)

Sl. no.	Country	Potato production (Million tonnes)
1	China	99.2
2	India	48.6
3	Russian federation	29.6
4	Ukraine	22.2
5	United States	20.0
6	Germany	11.7
7	Bangladesh	10.2
8	Poland	9.1
9	Netherland	7.7
10	France	7.3

Source: FAOSTAT,2017

b. Consumption pattern of potato produced in India

Apart from consumption as vegetable, potatoes are used for a variety of purposes as chips, French fries, baked, boiled, mashed and using flour to make a cake, pancake, re-casted potato chips etc. (Zaheer & Akhtar, 2016). Cooked or processed potatoes are more digestible than raw potatoes since raw potatoes contain starch in β-crystalline structure that is resistant to amylase digestion (Englyst *et.al*, 1992). Potato processing industries are highly advanced in developed countries like USA, Canada, and other European countries (Pandey *et. al*, 2009). In fact, it has been found that in developed nations, as high as 60% of total production is consumed in processed form.

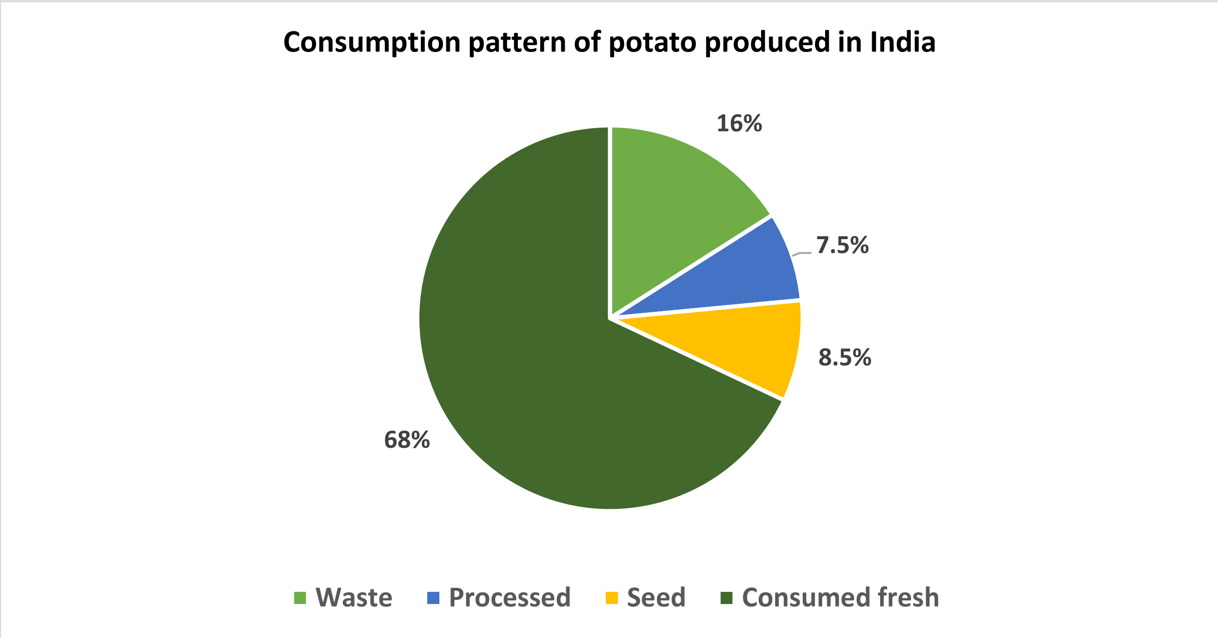


Fig 1. Consumption pattern of potato produced in India

III. STATUS OF INDIAN POTATO PROCESSING MARKET

a) Potato processing segments and status in India

Potato processing industry mainly comprises four segments: potato chips, French fries, potato flakes/powder and other processed products such as dehydrated chips, Alu Bhujia, Samosa, and Tikkis. However, potato chips still continue to be the most common and popular processed product.
Although the country stands second in global production the level of processing is mere 7.5% with per capita consumption of mere 365g which is very poor when compared to USA (37 kg), Canada (35.8 kg) and Germany (30.4 kg) (Rana et. al, 2017). Since the majority of potato growing regions fall under tropics and sub-tropics, there are high post-harvest losses up to 12.5% and it has been found that more than one-eighth of the production is retained as seed (Rana, 2011). The per capita processing of potato in India is 365g out of 1.475 kg potatoes per capita. Out of which the potato chips contribute the major portion (around 89.69%) followed by potato powder/ flakes contributing 9.28% and French fries 1.03%. (Rana, 2011).

The processed potato products are classified as follows:

- **Fried Products**: Potato chips, Frozen French Fries, other frozen fries.
- **Dehydrated Products**: Dehydrated chips, dices, flakes, granules, flour, starch, potato powder soup or gravy thickner and potato biscuits.
- **Non-Fried Products:** Potato jam, Potato murraba, Potato candy, Potato biscuits, Potato cakes.
- **Canned Products**

b). Indian potato processing market size

According to data analytics firm Global data, India's potato chips/crisps market was worth US$2.59bn in 2017, growing at an annual rate of 18.7%, and is expected to further expand to a value of $5.5bn in 2022. The sale of branded chips sold by manufacturers across India is

dominated by a handful of big companies viz., Pepsico, Balaji, ITC and Haldirams (Srirama Chaitanya Manyam, 2019).

c). Potato processing - sector wise operator in India

A lot of national and multinational companies are working in the processing sector of the country (Thapa and Thapa, 2019). List of potato sector wise processor operating in India are presented in the below table 4.

Table 4: List of sector wise processors operating in India

Manufacturer	Location	Product
Ace Foods	Mangalore	Chips
A-One Wafers	Mumbai	Wafers
Arumugam Industries	Coimbatore	Chips
Balaji Wafers	Rajkot	Chips
Bikano Namkeen	Delhi	Potato products
Budhari Brothers	Pune	Chips
Merino Industries Ltd	Hapur	Flakes
Golden Fries	Coimbatore	French fries
Faber Leather	Kolkata	Flakes
GP Foods	Kolkata	Chips
PepsiCo (Frito Lay)	Channo, Pune, Noida & Kolkata	Chips
Haldiram	Delhi, Kolkata, Nagpur & Bikaner	Chips
ITC	Haridwar, Pune, Kolahpur, Hyderabad, Coimbatore, Mysore, Trcichy.	Chips
Janata Wafers	Mumbai	Wafers
Kakaji Namkeen	Delhi	Potato products
Kishlay Foods	Guwahati	Chips
Little Bee Products	Ludhiana	Chips
McCains Foods	Gujarat	French fries & Flakes
Mota Chips	Mumbai	Wafers
MTR Foods	Bangalore	Chips
Potato King	Kolkata	Flakes
Satnam Agri. Prod Ltd	Jalandhar	French fries & flakes
Shivdeep Foods	Bikaner	Chips
Twinkle chips	Faridabad	Chips
Vista Foods	Mumbai	French fries
Welcome Wafers	Mumbai	Wafers
Welga Foods	Badayun	French fries
Wimpy's	Delhi	French fries

d). Major potato processors and their approximate quantity processed in India

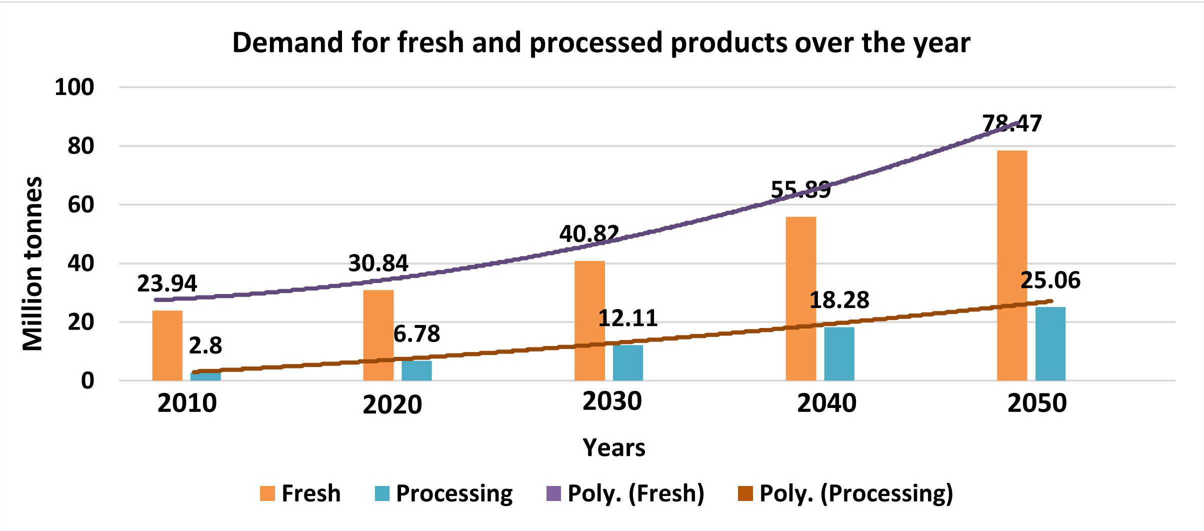
Although, there are several domestic and multi-national companies are operating in Indian potato processing industry, the sale of branded chips sold by manufacturers across India is dominated by a handful of big companies viz., PepsiCo, Balaji, ITC, Haldirams and Parle.

Table 5. Top 6 Potato chips processors in India (2019)

Sl no	Company	Quantity ('000 MT)
1	PepsiCo (Frito Lay)	350
2	Balaji	174
3	ITC	100
4	Haldiram	90
5	Pratap	68
6	Parle	30

e). Demand for fresh and processed products over the year

The demand for the processed potato products are continuously increasing due to number of factors like increased purchasing power, change in preferences for fast foods, urbanization, expanding globalization and increased number of working woman preferring ready cooked foods (Singh et.al, 2016). These value-added processed products are opening up new possibilities to make the agriculture sector highly remunerative and taking the rural agriculture in the national and international markets (Pandey et al 2009). The demand for fresh and processed potatoes in million tonnes by 2050 is depicted in graph 2.

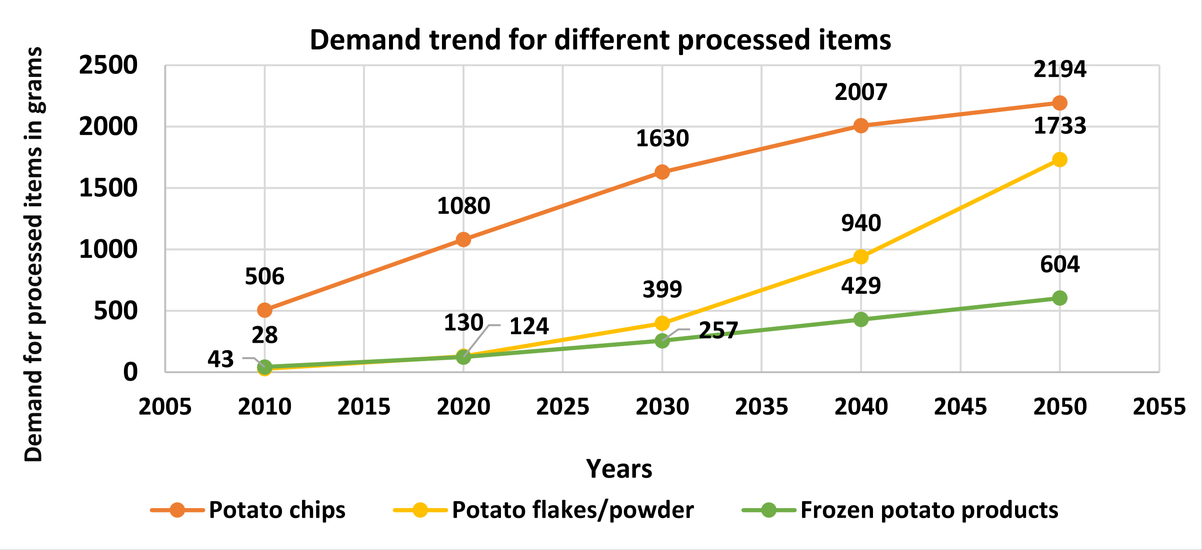


(Source; *Vision 2050*, 2015)

Graph 2: Demand for fresh and processed products over the year

f). Demand trend for different processed items

The demand trend of the various processed products is also changing. The demand for chips remains high and interestingly the demand for potato flakes / powder and French fries are in increasing trend. The per capita consumption for potato chips which was 506 g in 2010 is expected to reach 2194 g by 2050. Similarly, other processed items under various years are illustrated in graph -3.



Graph -3: Demand trend for different processed items

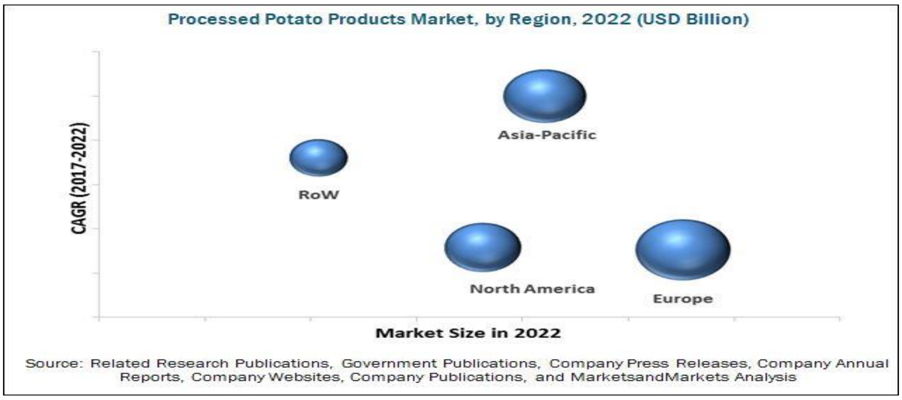
IV. Global scenario

a). Global potato processing market size

The global potato chips market size was worth US$ 29 Billion in 2018. The market is further projected to reach a value of US$ 35 Billion by 2024, growing at a CAGR of 3.3% during 2019-2024. Easy availability, convenient packaging, rapid urbanization, change in eating habits, and improvement in the standard of living are the major factors that have driven the global market in recent years. Other factors such as the growth in consumer preferences for convenience foods to save time and efforts, coupled with the rise in demand for applications such as snack foods and prepared ready meals, are expected to drive the growth of this market. (Imarc, 2019).

b). Processed potato products market by region (USD billion)

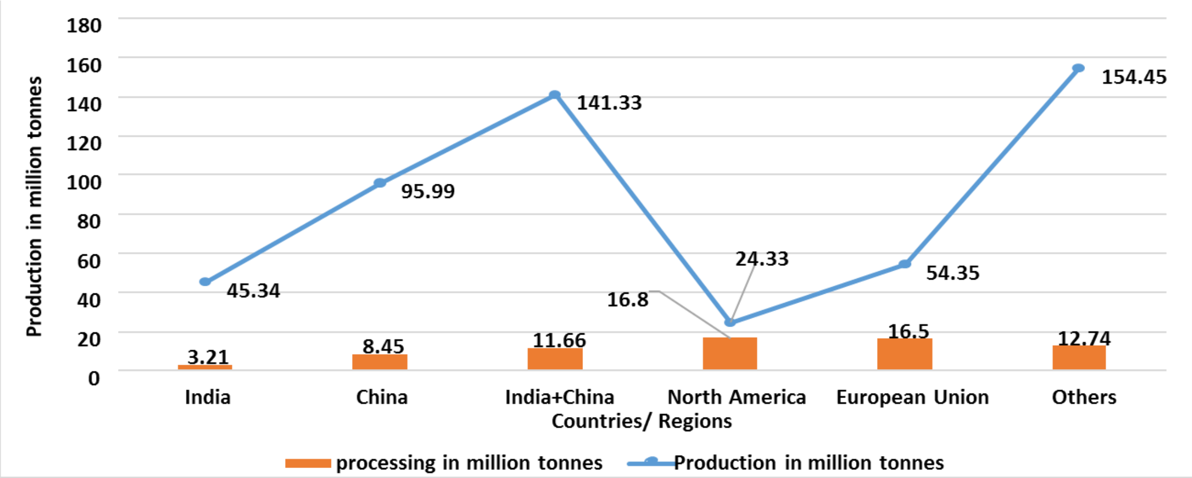
Europe is estimated to occupy the largest share in the global potato processing market, in terms of value and volume, in 2017, owing to the booming food processing industry and presence of major companies in these countries such as the Germany, The U.K., France, The Netherlands, and Belgium. The Asia-Pacific region is projected to be the fastest-growing during the forecast period. Key players in Europe and the U.S. focus on tapping the potato processing market in Asia-Pacific, owing to which Asia-Pacific is expected to witness high growth in the coming years (Graph-4).



Graph 4: Processed potato products market by region, 2022 (USD billion)

c). Total processed product in different countries

The total production and total processing of potatoes in different countries and regions for 2013 are shown in below graph 5 (R. Rana *et al.*, 2017).



Graph 5: Total processed product in different countries

d). Global trend based on type, application and distribution

On the basis of type, the market has been segmented into frozen, chips & snack pellets, dehydrated, and others (canned potato, potato granules, flour, and starch). The frozen segment dominated the global potato processing market, and this trend is expected to continue through the forecast period. Frozen potato products are highly consumed owing to the increase in demand for french fries, served in restaurants and fast food chains, worldwide. The expansion of Quick Service Restaurants (QSRs) such as KFC, Pizza Hut, and McDonald's in countries such as India and China, is expected to fuel the demand for frozen potato products during the forecast period. The chips & snack pellets segment was the second-largest due to the growing popularity of potato chips among young population and ease of availability. (Food dive, 2019).

Based on application, the market is segmented into snacks, ready-to-cook & prepared meals, and others (food additives in soups, gravies, bakery, and desserts). The consumption of processed potato products in ready-to-cook & prepared meals application is estimated to account for the largest market share in 2017. Processed potato products used in ready-to-cook & prepared meals are a booming market due to the increase in consumer preference for convenience food products, busy work schedules, and on-the-go consumption habits. Apart from ready-to-cook & prepared meals, processed potato products also find applications in the snacks segment, such as potato-based snacks with low carbs, low salt, air-dried, baked products with a number of flavours, which also drives the demand for potato processing market.

The global market has been segmented on the basis of distribution channel into foodservice and retail. Potato processing have been gaining importance in the foodservice segment due to the growth of food delivery channels and increase in demand for fast food. Apart from the demand from full-service and quick service restaurants, increase in the number of national and international brands in the hotel industry is expected to drive the demand for potato products in the foodservice industry.

V. Attributes of potatoes for processing purpose

Selection of suitable potato varieties and its growing region is the most important criteria for success in the processing industries. Various morphological and biochemical characteristics are judged for the selection of suitable varieties. Though morphological attributes like shape, size, physical and biological damage are not very important they affect the appearance and consumer acceptability. The most important factors like dry matter, reducing sugar, free amino acids, phenol content comes under bio-chemical attributes which determine the quality and recovery of the processed materials (Gupta et. al, 2014). We also need to identify the variety specific geographies or growing regions which can produce the desired quality traits for processing. The quality requirements of the potatoes for the different processing purposes is given in below Table 6.

Table 6. Attributes of potatoes for processing purpose

Qualities	Dehydrated	French fries	Chips	Canned
Tuber Shape	Round to oval	Oblong	Round to oval	Round to oval
Tuber size(mm)	>30	>75	45-80	25-35
Eyes	Shallow	Shallow	Shallow	Shallow
Specific gravity	1.080	1.080	>1.080	<1.070
Dry matter(%)	>20	>20	>20	<18
Reducing sugar(%)	0.25	0.15	<0.1	0.5
After cooking discoloration	Slight	Slight	-	Nil
Texture	Firm to mealy	Fairly firm	Firm to mealy	Waxy

VI. Potato value addition options

There are two value addition options exists in Potato viz., i. Farm level value addition by growers and ii. Industrial value addition by individuals/companies.

i). Farm level value addition - Grow speciality potatoes - *Low calories, low sugar, high anti-oxidant & high anthocyanin potatoes:*

Food consumed by people can have two functions, first to meet the nutritional need and second to maintain the health and fitness of the body, improves physiological function or eliminate the negative effects of certain diseases. Foods which are having the second function is called functional foods and contains natural substances called bioactive compounds. Bioactive compounds functioned as antioxidants which can react with free radicals and form a more stable free radical (not reactive). Antioxidants react with free radicals thereby reducing the capacity of free radicals to cause damage. Therefore, antioxidants can prevent cell damage due to free radicals so that the body can be protected from the generative diseases such as coronary heart disease, cancer, diabetes, cataracts, and others. Based on its source, antioxidants are grouped into synthetic antioxidants and natural antioxidants. The use of synthetic antioxidants is decreasing because it can cause negative health effects (liver damage) and may pose a carcinogenic substance, so its use is replaced by natural antioxidants. The sources of natural antioxidants are fruits, vegetables, grains and tubers.

One example of a natural source of antioxidants is purple potato.

Similarly, there are potato varieties with intrinsically low calories, low sugar, high anti-oxidant and high anthocyanin content, which can be exploited for commercial production and value addition by farmers for realising higher farm income. Example, there are potato varieties which are naturally low in sugar level below 1%.

ii). Industrial value addition

There are several value added options are available in potatoes (Singh et al., 2016) and the popular value added products are a. Potato chips, b. French fries, c. Shreds/ Lachcha, d. Potato flakes, e. flour f. Starch, g. Canned potatoes, h. Dehydrated potato products, i. Pringles, j. Microwave-Ready Fingerling Potatoes and k. Convenience Potatoes.

a) Potato chips

Potato chips are thin, fried, baked popular ready to eat snacks used both in domestic as well as in fast food centre and restaurants. As per "Potato Chips – India, Statista Market Forecast," 2019, the revenue of potato chips in India is US$ 70m in 2019 i.e. US$ 0.3 per person which is expected to grow annually by 9.7%. Some popular varieties suitable for chips preparation are Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Chipsona-4, Kufri Himsona, Kufri Jyoti, Kufri Lauvkar and Kufri Chandramukhi. Potato chips preparation includes the following steps: Fresh potatoes free from any deformities are peeled, sliced of approximately 1.5 to 2.0 mm, rinsed in water to remove surface starch, blanched in hot water at 60-80^{o}C for 2-3 minutes, dried, fried at 180^{o}C till the chips turn golden and uniformly salted or spiced and packed in bags in the presence of nitrogen.

b). French fries

French fries are turning into the fastest growing snack food and is growing in India at an annual rate of more than 30%. Kufri Frysona is the popular variety for French fry's production. French fry's preparation includes the following steps: Fresh healthy potatoes are selected and washed, peeled and cut into sticks of dimension 10x10 mm, rinsed in water to remove the surface starch, blanched in hot water at 60-80^{o}C for about 5 minutes, dried, fried at 180-190^{o}C for about 2 minutes, cool down to room temperature and frozen at -20^{o}C and fries are fried at 180-190^{o}C at the time of serving and salt and spices are added as per the taste.

c). Shreds/ Lachcha

Shreds are prepared from fresh potatoes of any shape and size containing 20% or more dry matter and low reducing sugars less than 150mg/100g by fresh weight. Preparation of shreds/ lachcha includes following steps: Fresh healthy potatoes are taken, washed, peeled, passed through the shredder to make thin and short shreds, washed with water to remove the surface starch, blanched in hot water at 60- 80^{o}C for about 1-2 minutes, dried, fried at 180-190^{0}C till the bubbling ceases.

d). Potato Flakes

Potato flakes are prepared by drying of potato slurry used for stuffing. Flakes preparation includes the following steps: Fresh healthy potato tubers are washed, peeled, sliced into small slices of 1-2 mm, washed in water to remove liberated starch, slices are cooked in two stages i.e. first at 70^{o}C for 20 minutes and second at 100^{o}C for 30 minutes after cooling for 15 minutes at 12^{o}C in between, mashed and passed through perforated mash which then is dried on roller drier which is removed as a sheet and broken into flakes.

e). Potato flour

Potato flour used as a thickener & flavoring agent. Potato flour preparation includes the following steps: Peeled potatoes is cooked, potassium Metabisulphite (5g) is added to reduce browning and boiled, mashed, spread on a tray in a thin layer, dried, grind the mash get the powder and sieve the flour.

f). Potato Starch:

Having high swelling power and high viscosity it is superior to other starch sources. Potato starch is characterized by their larger granule size long with low glass transition temperature, paste clarity along with neutral taste (Tigabu & Abebe Desta, 2018). Potato starch manufacture process involves the following steps: Fresh potato tubers are peeled, cut into small pieces, ground to get slurry, sieve through muslin cloth with the help of water, starch gets accumulated on the bottom of the tub, starch is dried in a hot air oven at 60°C or in sunlight, ground to get the powder and sieved and packed in an airtight container.

g). Canned Potatoes:

Mostly preferred immature and small potatoes. Canning of potatoes include following steps: Fresh potato tubers are washed, peeled, blanched in hot water for 4-5 minutes, filled in the can at the rate of 500g per A21/2 size can along with 2% brine leaving about 0.8 cm, exhausted by heating till the temperature reaches 80°C which results in complete removal of air, cans are sealed, sterilized at 10 psi for 45 minutes and cooled.

h). Dehydrated potato products:

Lowering the moisture content by drying to lessen the chances of microbial growth and prolong the shelf life. They are cheaper, easier to prepare, do not require sophisticated machinery. Dehydrated products preparation includes the following steps: Fresh healthy potato tubers are washed, peeled, slice of 1.5 to 2mm is made, rinsed to remove surface starch, blanched in hot water at 60-80°C for 1-2 minutes, dried, packed.

i). Pringles:

Pringles have about 42% potato content, the remainder being wheat starch and flours (potato, corn, and rice) combined with vegetable oils, an emulsifier, salt, and seasoning. Snack dough is prepared with slurry of rice, wheat, corn, and potato flakes and presses them into shape. The snack-dough is then rolled out like a sheet of ultra-thin and cut into chip-cookies. The chips move forward on a conveyor belt until they're pressed onto molds, which give them the curve that makes them fit into one another. Those molds move through boiling oil and fry for a few seconds. Then they're blown dry, sprayed with powdered flavors, and at last, flipped onto a slower-moving conveyor belt in a way that allows them to stack.

j). Microwave-Ready Fingerling Potatoes:

Growers, packers and shippers are responding to the changing consumer taste and preferences by introducing value-added potato products to provide consumers with ready-to-serve healthy potato offerings to meet the growing trends for fast fresh foods. In this context Alsum Farms & Produce Friesland, WI, USA has created **Microwave-Ready Creamer and Fingerling Potatoes that come in a pre-packaged steam tray with spice and olive oil packets that allow consumers to take these fresh potatoes from the microwave to the dinner table in 6 minutes or less.**

k). Convenience Potatoes: As an example few companies like Side Delights® fresh potatoes are offering convenience potatoes in steamables, bakeables and grillables forms. **Steamables:** Smaller-sized potatoes that are triple washed, packed in microwave bag and ready to eat in 8 minutes. **Bakeables:** Single-serve, light, fluffy, delicious baked potatoes, triple-washed, to microwave right in its wrapper and ready to eat in just 8 minutes.
Grillables: Triple-washed russet potatoes, wrapped in foil and ready to grill.

VII. Efficient harvest and post- harvest management for better value addition

Proper harvest and post - harvest care is very critical to get quality raw material or better value addition. (Ezekiel, R et al., 2003).

a). Harvesting care: Follow the practice of Dehaulming [cutting of haulms / aerial parts by sickle or killing by chemicals (e.g. Gramoxone) or destroying by machines] when the crop attains 80-90 days and when the aerial part of the plant turns yellow. Always harvest in dry weather. Stop irrigation about two weeks before dehaulming. Harvest the crop after 10-15 days of haulm cutting.

b). Drying and Curing care: Always dry the harvested tuber quickly to remove excess moisture from the surface of tubers for improving their keeping quality. Do not store the tubers immediately if they are exposed to rain after harvest. Always follow the curing process at 25 degrees centigrade with a 95 per cent relative humidity.

c). Grading care: Grading is an important factor in the marketing process of potato. Grade as per the uses viz., small to medium sized tubers are prepared for 'seed tubers' and large sized tubers (45 to 80 mm size) are preferred for processing purpose.

d). Packaging care: Heaped potatoes must be graded again for separating the diseased and cut tubers. The sound tubers alone to be packed in hessian cloth bags or nettlon bags.

e). Storage care: Storing potatoes for longer period in normal temperature is not possible as it is a living material and through respiration, the changes occurs due to heat, resulting in loss of dry matter and ultimate deterioration of quality of tubers. Sprouting in stored potato is always a serious problem. To avoid sprout inhibition, suppressant like Isopropyl N-Chlorophenyl Carbamate (CPIC), TNCB, MH are used. The irradiation process has also been found effective for sprout inhibition. The best temperature and humidity condition for storage of potatoes are as follows:

Table 7. Storage condition for different potato USE

Intended Use	Temp (in ^{0}C)	RH (in per cent)
Seed purpose	2-4	95
Table purpose	7	98
Processing purpose	8-12	95

VIII. SWOT Analysis – INDIAN POTATO PROCESSING INDUSTRY

Strength	Weakness
o Diverse production environments o High domestic demand due to improved living standard, increased urbanization, preference for fast foods, rise in per capita income, increase in the number of working women preferring ready cooked food and expanding tourist trade.	o Small operational holdings o Non-availability of processing varietal option for different production environment.
Opportunity	**Threat**

o Suitable location for export of potato products.	o High transportation cost o High cold storage cost

IX. THRUST AREAS FOR BETTER GROWTH

Indian food sector has one of the strongest growth fundamentals of any industry owing to the growing population and rising income levels. For packaged snack foods these fundamentals are complemented by two further growth drivers; convenience and the nation's eating habits. With smaller families leading busier urban lives, the time and resources for regular home cooking are rapidly declining. At the same time, longer working hours and lengthy commutes leave less time for regular sit-down meals. Snack foods have been a long-time favourite in the Indian diet and now packaged and branded variants have become the natural solution to the culinary cravings induced by the modern Indian lifestyle. Although the market is large and diverse enough to accommodate a broad range of both existing players and new entrants, there are still some bottlenecks in this sector which needs to be address for making it more sustainable business (Gehan Wanduragala, 2015).

Rising Input Costs: Input costs are a critical factor in the potato processing industry and commodity prices have been rising at record rates in recent years. In India, the vagaries of the monsoon have a major effect on the price of snack food staples like potato, even small price movements can have a major effect on demand. This needs concentrated research attention to develop region specific superior varieties and variety specific production practices for different agro-ecological situations of India.

High transportation cost: The cost of land transportation of goods in India is high. Currently, Indian railways have a very low priority for potato transportation. However, substantial planned expenditure on dedicated rail freight corridors and express highways across the country is likely to bring a permanent solution to this problem.

Costly cold chain: In tropical countries, the unit cost of cold chain facilities is many times that in temperate zones, and the shortage of these facilities in India makes the service still costlier. However, with the anticipated focus on road infrastructure and increasing economies of scale, one can expect much cheaper and more easily available cold chain facilities in the near future.

Diverging Consumer Trends: In a large market like India, with such extremes in income levels and lifestyles, consumer trends can seem to move in conflicting directions at the same time, posing a major challenge to strategic planning. In response to a wave of media concern about rising obesity and diabetes in recent years, leading snack food players began offering health-oriented products advertised as low fat, low sugar and low salt.

Closely monitor micro as well as macro trends: Snack foods manufacturers must balance the urge to respond to prevailing trends in the broader market place with a constant focus on their target customers. Whilst innovation is an integral part of success in fast-moving consumer goods, if it is not driven by customer needs it will result in alienation rather than improved brand loyalty. To counter this risk of misreading the market, snack food companies should closely monitor the micro trends occurring within their target customer group as well as tracking the macro trends affecting the sector as a whole. Such an approach will give companies the confidence to take a divergent view from the competition wherever it better serves their customers.

Export of potato products: At present India exports a sizeable quantity of processing quality potato to Mauritius and Middle Eastern countries. Further widening of these options to other nearby countries would make much better business opportunity.

X. SUMMARY

Potato is a wholesome food containing carbohydrates, proteins, minerals and vitamins. The potato has been widely grown and consumed in the country. The net returns from the produce can be increased through value addition. It is utilized in variety of ways such as dehydrated potato products like chips, dice, flakes, granules, flour, starch, potato powder and potato biscuits. It is also used to prepare frozen foods like potato patties, puffs, wedges, pancake, dehydrated mashed potatoes etc. to enhance the market value, marketability, and desirability of the product.

There is a huge scope for value addition and processing in potato crop. Processed value-added products have the huge market demand with enhanced market value which can improve the income of the farmer and uplift the living standard and can definitely be the important milestone in the endeavour of doubling the farmer's income. The Indian processed product market is nominal compared to developed countries like the US. But the trend is continuously shifting forward triggered by the increased income and globalization. Still, there is much scope in quality up gradation and product diversification to bridge customer requirements. Thus, value addition in potatoes is definitely going to occupy a larger share in the Indian GDP in the days to come and there is a huge potential considering the present national and international trade scenario.

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PepsiCo potato value chain and partnership with farmers

Santosh Tiwari, PepsiCo.

At PepsiCo India, we see ourselves as an agriculture company. Since our entry into India in 1989, we have worked closely with farmers to help improve both their livelihoods and agricultural yield. Our journey began with our successful introduction of a high-yielding variety of tomato, and we went on to help paddy farmers increase their crop. Today our ventures into crop diversification and the farming of high-quality potatoes and other edibles have transformed the lives of thousands of Indian farmers.
We continue to strengthen our partnerships with farmers across the country to boost their productivity and income. We plan to strengthen farmer connect from 10,000 in 2009 to 25,000 by 2020.

Helping farmers improve yield and income

The company's vision is to create a cost-effective, localized agri-supply chain for its business by:

- Building PepsiCo's stature as a development partner by helping farmers grow more and earn more.
- Introducing new high-yielding varieties of potato.
- Introducing sustainable farming methods and practicing contact farming.
- Making world-class agricultural practices available to farmers and helping them raise farm productivity.
- Working closely with farmers, central & state governments to improve agri-sustainability and crop diversification.
- Providing customized solutions to suit specific geographies and locations.
- Facilitating financial and insurance services in order to de-risk farming.

The journey so far

Where we stand today, at a glimpse

- Today PepsiCo India's potato farming programme reaches out to more than 22,000 farmer families across 12 states. We provide farmers with superior seeds, timely agricultural inputs.
- We have an assured buy-back mechanism at a prefixed rate with farmers. This insulates them from market price fluctuations.
- Through our tie-up with State Bank of India, we help farmers get credit at a lower rate of interest.
- We have arranged weather insurance for farmers through our tie-up with ICICI Lombard.
- We have a retention ratio of over 90%, which reveals the depth and success of our partnership.

Contact farming

PepsiCo pioneered contact farming in India in 1989, when in order to improve the performance of a tomato processing plant in Punjab, it imported and tested high-yielding varieties that thrived best in India. Consequently, yield improved by over 300% and the length of the tomato season more than doubled, resulting in a substantial increase of farmer incomes. Today, the success of contact farming has spread and PepsiCo engages with over 22,000 farmers across the country to grow a variety of crops. Through this partnership, PepsiCo has transformed the lives of thousands of farmers by helping them refine their farming techniques and raise farm productivity.

Our high-quality seed programme

- In order to provide our farmers the 'best quality potato seeds', PepsiCo invested in a world-class potato mini-tuber facility at Zahura in Punjab which helps getting robust and disease-free seeds to our company's contact farmers.
- In order to fulfill the demand of quality seeds, PepsiCo collaborated with the Thapar Institute of Technology to develop quality potato mini-tubers under net tunnels.

Potato farming

- PepsiCo India has introduced world-class, top-quality, high-yielding potato varieties.
- High-yielding potato seeds have allowed farmers to produce world-class potatoes and obtain higher returns.
- We have partnered with more than 22,000 farmers working across Punjab, Uttar Pradesh, Bihar, West Bengal, Gujarat, Madhya Pradesh, Rajasthan, Maharashtra & Karnataka for the supply of quality chip-grade potatoes.
- We have partnered with State Bank of India to get soft loans to all our contact farmers, thus reducing their cost of cultivation and saving them from the clutches of moneylenders (higher interest rates).

Farmers' friend

Over the last 25 years, PepsiCo India has been combining deep insights into Indian farming with its global technological expertise to transform the lives of farmers.
PepsiCo India established a model of partnership with farmers and currently works with over 22,000 happy farmers across twelve states through the crop lifecycle by providing new varieties, technologies and sustainable farming practices. In PepsiCo, farmers truly have a friend and development partner. The association with PepsiCo India has not only raised the incomes of small and marginal farmers, but also their social standing.

Collaborative farming – potato

PepsiCo's 360-degree farmer connect program has transformed the lives of small and marginal farmers across India.
PepsiCo India was the first corporate to introduce collaborative farming of process-grade potatoes in India in 2004-05. PepsiCo presently works with farmers, spread across West Bengal, Maharashtra, Punjab, Gujarat, UP, Karnataka, Bihar, Haryana and Chattisgarh. More than 45 percent of these are small and marginal farmers with a land holding of one acre or less. PepsiCo India has helped improve their incomes through a 360-degree farmer connect program that includes:

- Assured buy-back of produce at pre-agreed prices, which insulates farmers from open market price fluctuations.
- Supply of high quality planting material, including its proprietary advanced seed varieties.
- Offering advanced plant protection program and technical know-how developed in collaboration with leading agri-input companies like Bayer, DuPont, Syngenta and BASF.
- Soft loans through a national level tie-up with State Bank of India.
- Facilitation of crop/weather risk insurance in partnership with leading insurance companies to protect farm incomes.

Micro irrigation

PepsiCo is also helping farmers in water-scarce areas in Maharashtra, Gujarat, Karnataka and Haryana and promoting drip irrigation in over 5000 acres. PepsiCo's initiatives include:

- Helping raise money for the assets through banks.
- Incentivizing the farmers for the adoption of drip irrigation through a buy-back mechanism.
- Providing help to design agricultural equipment to make drip irrigation commercially viable for farmers

PepsiCo potato operations

PepsiCo has three potato processing plants in India located in Punjab (Sangrur), West Bengal (Sankrail near Kolkata) and Ranjangaon near Pune in Maharashtra. The production capacity at these three plants is approximately 34,000 tons for Channo in Punjab, 23,000 tons for Pune and 34,000 tons for Kolkata. Potatoes are currently procured from West Bengal, Gujarat, Punjab, Uttar Pradesh, Madhya Pradesh, Rajasthan during winter season and from Karnataka and Maharashtra during the rainy season. The quantity of potatoes sourced under contract farming has risen from 2920 tons in 2002 to 3, 50,000 tons in 2018. Potatoes sourced under contract farming account roughly 40-43 percent of PepsiCo's total requirement.

Processing and quality requirements

The quality parameters set in place through the chain are driven by the buyer requirements and specific requirements for processing. Potatoes grown in India for traditional use have high sugar content and low dry matter. Processing requires potatoes with no or very low sugar content and high dry matters (>18 to upto 25 percent). Apart from these requirements, the company is HACCP- and ISO certified, which requires stringent quality control at all levels in the chain. Specific requirements are met by ensuring quality compliance at every stage, research and development, farming, storing, processing, and packaging. This section describes in detail the steps taken to

PepsiCo ensure quality at every stage of potato supply chain:

Farm inputs

The company ensures the availability of inputs to farmers working in the area under contract. The vendor in the region ensures that the farmers falling under his or her supervision have all the required inputs at the right time.

Farm production

In order to produce a specific variety of potato and to enhance productivity PepsiCo is very closely involved with its potato contract farmers. The company has employed a team of agricultural scientists & graduates, who work with the farmers to provide technical input and to monitor the production of the farmers in their specified area.

Grading and sorting

At the company's unloading dock, the potatoes are mechanically graded for size. Potatoes that are too small for processing are separated. There is also visual inspection for damaged potatoes. Test for sugar content is undertaken by YSI & frying a small sample from this lot. Potatoes that do not meet the requirements are rejected.

Storage

Critical factors in successful storage include variety, methods of culture, harvest, field curing, temperature and humidity control, storage and sprouting inhibition. Potatoes are stored at 10-12°C to control conversion of starch into sugar. At this temperature potatoes can be stored up to >7 months.

Processing centre

The selected produce is taken to the processing plant and is subjected to washing and peeling. Peeled potatoes are subject to metal detection and inspection for physical damages and discoloration. Following this, the potatoes are run through rotating slicers and are subjected to deep frying. The fried crisps undergo optical testing for colour. As mentioned earlier, rice bran oil is used for frying which significantly reduces saturated fat content. At the last stage the crisps are mixed with spices and packed. Thorough testing of inputs and packaging materials is also conducted. The plant has a well-equipped quality testing lab.

Mechanization in potato cultivation

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For any crop to be successful, all the input factors carry certain weightage. These factors can be type of cultivars, field growing agronomic practices, plant protection chemicals and their method of application, harvesting time and method and post harvest practices. Besides all these, another factor for any crop's successful growing is timely and in an appropriate manner completeing all the pre and post harvest operations. For this, efficient machines, equipment and tools need to be designed. When it is crop like potato, which is perishable, bulky and has limited time available for planting, in-field crop management, harvesting, sorting & storage, importance of efficient machineries becomes all the more important. Luckily, for potato a number of machineries have been developed for fertilizer application, seed treatment, planting, weeding, harvesting, grading, sorting, storage and on-farm processing of potato.

Field preparation

After burying green manure crop (usually *dhaincha*) with disc plow, mould board plow or disc harrow (Fig.1) or rotavator followed by one planking makes field conditions favorable for decomposition of green manure. Potato requires good tilth soils to ensure covering of stolons/tubers and also to provide adequate aeration for respiration of roots and tubers. To get the good yield, soil should be loose and friable with good drainage and aeration. Subsoiler is an important primary tillage implement. It breaks the hard pan below the soil surface and provides good drainage environment. Pre-sowing irrigation has to be done before field preparation to have uniform germination. After 5-7 days of pre-sowing irrigation, 2-3 cross harrowing or 3-4 tiller operations followed by two planking make the required seedbed for a good crop of potato. Among the primary and secondary tillage implements, the rotavator is most popular for preparation of field which provides fine level of soil tilth. All these implements are easily available in the market and are being used for other crops also.

Fig. 1. Green manuring with disc harrow, deep tillage with subsoiler improves infiltration and final field prepration with rotavator.

Fertilizer application

Fertilizer type, quantity and placement are the important factors for good production of potato crop. Precise and judicious use of fertilizer is of prime importance to ensure its efficient utilization and to reduce the cost of farm input and environmental risk. After seed bed preparation, a fertilizer drill-cum-marker (Fig. 2) or fertilizer broadcaster can be used for fertilizer application. Fertilizer drill –cum-line marker is a machine which ensures uniform placement of fertilizer in furrows and marks the line impressions at 600 or 650 mm fixed row spacings for tuber placement. With this machine fertilizer rate can be adjusted between 50-300 kg/ha with a field capacity of 4.0 ha/day. In case, fertilizer unit is attached with the planter than the use of fertilizer drill can be avoided. In potato crop, fertilizer should be placed 5-7 cms below the seed tubers and should not come in direct contact with the seed. Band placement helps in improving efficient utilization of fertilizer which results in improved production. Genrally fertilizers are hygroscopic in nature, hance it is recommended to properly clean the applicator after use.

Fig. 2. Fertilizer applicator cum marker

Seed tuber planting

About 80-85 thousand seed potato has to be planted per hectare for good yield of the crop. This can be achieved by planting 35-55 gm of seed potato tubers per hectare. Uniform placement of tubers in prepared soil bed at specified spacing and depth is also important for better emergence as well as production of the crop. Uniform plant emergence can be achieved by planting of seed material with tractor operated potato planters (Fig. 3). Function of the planter is to open a furrow, meter the seed tubers with a suitable metering mechanism, place the tubers in to the furrow and cover them by a soil layer of about 6-8 cm. These machines maintain uniformity of planting in terms of row to row (60 cms), plant to plant spacing and depth (6-8 cms) of planting. Various types of machinery are available in India for planting of potato viz.

(A) Rotating drum type
(B) Revolving magazine type
(C) Belt and cup type and
(D) Picker wheel type

First two are semi-automatic type planters in which one person per row puts seed tubers in to the seed metering cells of the machines. Function of these machines is to open a furrows drop the seeds in to the soil through seed delivery tubes. Seed tubers are dropped in lines and a ridge of soil mass is formed over the tubers. Automatic planters are becoming popular nowadays due to their distinct advantages over the other types. In this type of machine labour is required only for filling of hopper. All other activities like lifting individual tubers, dropping them into rows and than covering with soil mass are carried out by the machine itself.

Fig. 3. Potato planting with semi automatic and automatic planters

Weeding, top dressing and earthing

Mechanical and chemical weed control methods are used in most of the crops. Potato being a tuber crop, is highly responsive to inter-row-cultivation. Three row tractor operated inter-row-cultivator is operated in 22-25 day crop when plant height is 8-10 cms. After operating this weeding machine, three or five row ridger (Fig. 4) is used for earthing up and remaking the ridges. Ridger makes uniform ridges and accumulates sufficient soil mass around the plants. For light soils and low weed intensity areas another multipurpose machine is available which perform weeding, furrow opening, fertilizer application and re-earthing operation simultaneously. For chemical weed control, tractor operated multi-nozzle sprayer or spray gun are used to achieve fast and uniform coverage.

Fig. 4. Interculturing and fertilizer top dressing before earthing operations in potato crop

Plant protection

Potato crop needs to be protected from different disease carriers, insects and pests by applying respective chemical formulations. Commonly the liquid chemicals are sprayed on crop canopy to protect the crop. Many times delay in chemical spray can cause huge crop losses. Particularly, in case of late blight disease. Delay of 1-2 days can result in total loss of crop. Therefore, timely and uniform application of plant protection chemicals is important, which is possible with high capacity tractor operated sprayers. Multinozzle boom sprayer, having 12-16 nozzles, is also useful for potato crop. However, spray gun is especially effective in case of late blight in potato plants as it covers lower surface of leaves more effectively (Fig. 5). For small holdings, manually or battery operated knapsack sprayer can be used which has field capacity of 0.5 ha/hr.

Fig. 5. A view of spraying operation with power sprayers

Potato digging

Before starting harvesting operation haulms are removed manually sickles or with chemical methods. Potato digging is a cumbersome process and involves a lot of manpower. About 600-700 man-hours/ha are required for manual digging of 300-400 quintals of potato from huge soil mass of around 10,000 quintals. In manual harvesting spade or *khurpa* is used which results up to 10% tuber cut or bruise which is a huge loss to the farmers and nation. In manual harvesting some portion is always left behind in the field. Animal drawn plow is another tool for potato digging. This method is faster as compared to manual digging but in case of large scale farming with this method harvesting is delayed and fields become dry. Tractor operated diggers are fast, economical and cause least damage to the produce (Fig. 6).

Fig. 6. Potato harvesting with tractor operated digger elevator

Digger elevator is an efficient machine which exposes 90-95% tubers in optimum field conditions. This machine has to be maintained properly as there are many parts which move in soil and cause more wear and tear. Multipurpose passive blade potato digger (Fig.7) is another less expensive equipment. It exposes about 80-85% potatoes and is easy to maintain. It can be used in early crop (60 days without cutting haulms) and also can successfully work in dry field conditions.

Fig. 7. Low cost blade type digger

Potato combine harvester

A two row potato combine harvesters has been developed at CRPI to perform potato digging and picking operation combinely (Fig. 8). Some other firms have also developed single and two row potato combine harvesters in recent years. Functions of the combine harvester machine are to dig the potato tubers from 15-20 cm deep soil, separate the tubers from soil clods, convey the tubers to the sorting platform and collect them in to a hopper. Further it can be unloaded in to a transporting trolley or on a heap. Four workers have to be employed with these machines to sort the rotten tubers or soil clods passing over the sorting table. These machines are usually powered by a 50 to 60 hp tractor.

Fig. 8. Two row Potato combine harvester

Grading

Graded, sorted and properly packed potatoes always fetch good price in the market. Manual grading is not uniform and it requires a lot of time and energy which bring down the overall returns.

Various manual as well as power operated graders have been developed for size grading of the potato tubers. Rubber belts having different size of round or square shaped perforation are generally used in the grading system (Fig. 9). Lot of labour have to be still required in these high capacity graders for feeding sorting and packaging of the potatoes.

Fig. 9 Rubber belt sreen type potato sorting and grading machine

Seed treatment

Disease free seed is the most important requirement to grow healthy potato crop. Seed potatoes needs to be treated before stroge to protect agrainst diseases. For controlling tuber and soil born diseases viz. common scab, black scurf and powdery scab, 3% boric acid treatment can be given with the help of an electric powered seed treatment machine. In this machine boric acid is sprayed on the potatoes moving and rolling over a conveyor. All the surfaces are coated with the chemical and the used solution is re-circulated. This machine can treat about 300-350 quintals of potatoes per day.

Summary

Machines are avaialbe for all the field and post harvest operations for potato in India. Now it is the duty of extension workers to hand hold farmeres to identify right machines, of right size for different oprations. If any machine is unaffordable for individual farmers, they can be encouraged to buy in groups so that these are affordable to more number of farmers. Adopting these machines will definitely help in completing field operations timely with lesser cost which will enable them timely sowing of subsequent crops. All this, will surely help in reducing input costs and increasing their income.

Protected cultivation technologies for potato

JS Minhas

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Introduction

Agriculture is highly dependent on environment, and it's very difficult to get favourable climatic conditions for crop growth and development as per crop need. Agriculture is basically climate/season based, a hot and humid climatic conditions characterized in rainy and post rainy season is most favourable for both crop and crop enemies. To raise a healthy dis- ease free crop spring-summer seasons was counted as most suitable. But, fast climatic changes happening across the globe has changed climatic characteristics of a season, which has resulted in untimely rains and other fluctuations in the spring-summer season, raising the challenge to develop climate resilient technologies. Not even that, with time extreme hot and cold temperature stresses have been noticed in geographically varied locations where it was not supposed to be earlier based on various geographi- cal factors deciding the climatic conditions of that area. Therefore, there is need to develop suitable varieties and technologies to sustain these challenges which may come up in form of various biotic and abiotic factors. Vegetable cultivation is an awesome business in India, but under open field conditions by following traditional cultivation practices it is difficult to manage various abiotic and biotic stresses. These stresses not only reduce productivity levels but they are also responsible for poor quality specifically during rainy and post rainy season. Mostly to manage biotic stresses farmers spray large amount of different chemicals, this not only enhances the cost of cultivation but it also increases residual toxicity in the freshly produced vegetables, which is ultimately hazardous to human health.

How to address these issues, can we manipulate the climatic conditions or can we provide protection to the crops against climatic fluctuations and various other related stresses. Yes, protected cultivation technology has the answer to this but, it's a tricky technology highly depending upon intelligent implementation of protected structures for vegetable cultivation by having a knowhow on "*What, When, Where and Why*" *to* implement. Every protected structure has its own limitations and advantages, but the basic benefit is its extra protective shelter restricting or minimizing the exposure of the crops to various adverse factors, which are high in open conditions. Even though the application of chemicals for controlling biotic stresses is also low under protected structures which gives a high quality safe vegetables for human consumption. By using protected structures, it is also possible to raise an offseason and long duration vegetables crop of high quality. Vegetable farming in agri-entrepreneurial models targeting various niche markets of the big cities is inviting regular attention of the vegetable growers for diversification from traditional ways of vegetable cultivation to the modern methods. Production of vegetable crops under protected conditions provides high water and nutrient use efficiency under varied agro climatic conditions of the country. This technology has very good potential especially in peri-urban areas adjoining to the major cities which is a fast growing markets of the country, since it can be profitably used for growing high value vegetable crops like, tomato, cheery tomato, colored peppers, parthenocarpic cucumber, healthy and virus free seedlings in agri-entrepreneurial models. But protected cultivation technology requires careful planning, attention and details about timing of production and moreover, harvest time to coincide with high market prices, choice of varieties adopted to the off season environments, and able to produce economical yields of high quality produce, etc.

Protected cultivation is expensive and is profitable only for high value and exotic vegetable crops, but why do we want to cultivate potato under protected environment? Potato is a vegetatively propagated crop and its quality degenerates due to virus accumulation generation after generation. Since insects are the major vectors for virus transmission, growing potato seed crop under protected environment protects it from virus infection. Therefore high value virus free mother plants are grown under protected cultivation for production and maintenance of high value early generation potato seed crops.

Various kind of protective structures are available for seed potato cultivation. Virus free minitubers or virus free tissue culture plants van be successfully grown in these structures. Potato is a short duration crop (3-4 months) and these structures can be used for other vegetable crop production during rest of the year.

Virus free potato micro-plants can also be multiplied using aeroponics technology. Aeroponics technology consists of a grow box where potato micro-plants are grown. Nutrients are sprayed onto the roots at regular interval. Potato tubers can be picked by lifting the top cover at regular intervals. In this way 40-60 minitubers can be harvested from each plant during the crop season. Aeroponics structures are usually set up in protected structures for virus free minitubers production.

Walk in tunnels

Walk in tunnels are temporary structures erected by using G.I. pipes and transparent plastic. The ideal size of a walk in tunnel can be of 4.0 m width and 30 m length (120 m^2) and cost of fabrication may range from Rs.160–180 per m^2. The ideal size has been standardized for optimum cross ventilation, to have a single piece coverage of above sized structure with plastic commonly manufactured by firms of dimension 7 □□30 m or 7 □□36 m. Walk-in-tunnel technology is a simple and profitable technology for potato seed multiplication as well as crops like summer squash can be grown as a complete off-season crop, whereas other cucurbits like muskmelon, round melon, bottle gourd, cucumber, bitter gourd, watermelon are mainly grown during off-season. Basically these are temporary and really low cost structures since the fixed investment made on plastic can last for 5–6 years and the investment made on GI pipes can last for more than 20 years if proper care is taken.

Insect proof net houses

Insect proof net house is ideal for potato seed multiplication from mini-tubers as well as micro-plants. Net house minimizes the use of pesticides in fresh vegetable cultivation for producing safe vegetables and for production of quality seeds either of the seasons. Nethouse cane be used during hot humid conditions of rainy and post rainy season. For high quality vegetable crops like tomato, chili, sweet pepper, okra which are highly affected by viruses and other pests like borers and fruit-flies under open fields during rainy and post rainy season The farmers are using several insecticides for several sprays to control these vectors, even though they could not effectively control these vectors. Huge amount of insecticidal spray increases the residual toxicity which can be minimized by using insect proof net houses of 40 or 50 meshes covered walk in tunnels. These structures can be fabricated with a cost of Rs.350–400/m^2 having 40–50% shading net covering during critical summer months (April–June) and with transparent plastic covering during critical winter months (Dec–Feb) under arid and semiarid climatic conditions.

Zero energy naturally ventilated greenhouses

Naturally ventilated greenhouses are the protected structures where no heating or cooling devices are provided for climate control. They are simple and medium cost greenhouses which are erected with a cost of Rs.700–800 per sq. mt. Potato crop using microplants can be grown in these structures. Aeroponics structures can also be setup in these greenhouses. They can be also be used successfully and efficiently for growing summer parthenocarpic slicing cucumber. These structures are having a manually operated natural ventilation system, as and when required..

The basic prerequisite of implementing the technology is to depending upon selection of appropriate design based on the climatic conditions, market available and the type of vegetable crop. Under arid and semi arid conditions maximum ventilation up to 40–50% is required to make the structure efficient and successful to raise vegetable crops. Under extreme hot periods (May–July) rooftops of the greenhouses should be covered with shade nets (preferably with black color) allowing a space between the shade net and roof surface for air movement. Such greenhouses can be equipped with low-pressure drip irrigation system to make them energy efficient ecofriendly model.

Temperature controlled greenhouses

These greenhouses are the protected structures where heating or cooling devices are provided for climate control. These structures cost 1000-1500 per m2 and are ideal for setting up aeroponics technology for potato minitubers production. Two potato crops can be taken in these grwwn houses by extending the growing season both pre and post optimum season by providing cooling. One high value summer vegetable crop having short duration cab ne grown in these structures.

Conclusion

With climate change and change in insect dynamics it has become imperative to produce high value potato basic seed using protective structures. Virus free potato micro plants can be grown in these structures using soil or soil less systems including aeroponics technology. In the off seasons these structures can be used for cultivation other high value vegetable crops.

Potato seed production and technological development – India

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Potato is the 4th largest crop in India after wheat, rice and Maize. It produces the highest food energy per unit of land i.e. 216 MJ/Ha/day. India is the 2nd largest producer of potato after China. This crop is going to play a very important role in ensuring the food security of our country in the future. In spite of these facts, the availability of quality seed in India is still less which results in a gap in current & potential per capita yield in the country. According to the forecast, in 2030, our population may touch to 1.6 billion and during that time potato will be one of the imperative crops to provide sufficient food to peoples of India. The Central Potato Research Institute (CPRI) also sets 70 Mln tons potato production target for the Country in 2030. But the way the potato seed industry is developing in India, this target can be achieved even earlier as there is tremendous technological development in this sector in last almost 15 years. In 2019, production already crossed to 50 mln tons.

Till 1980, the world was mostly dependent on the old selection method of seed production which is a very slow system and was incapable to cater to the increasing global requirement of seed potato. But in between 1980-1990 there are some technological development and the world has moved towards micro and minituber production technology. The capacity was limited till 1990 and only about <10 million minitubers were available in the global market. India was hardly done any progress in this direction. But from 1990 to 2000 India had also taken this challenge & started work toward the production of minitubers/ micro tubers. The founder organization was TERI, CPRI, etc. But after 2000, there is tremendous development in this direction and Technico has emerged as strong player in fast multiplication of minituber seed through hydroponics technology, and given its trade name "Technituber". Simultaneously some other private organizations have also ventured in minituber production. In 2000, the world minituber production was about 50 million which later on goes fast and currently reached about >.125 million minitubers globally.

Till 2000, global seed potato generation was 10+ and India was 15+. But due to technological development in India along with global progress, today's world average potato seed generation is +8 and India has come down to about 10th generation. This is another green revolution in potato seed production sector in the country. Today if we see the total capacity of minituber production in India is about 35 million minitubers and another about two lakhs tons of early generation seed produced largely by private sectors. However, apart from this CPRI is also produced about 3000 tons' breeder seed which goes to next multiplications and finally produce about one lakh tons of F2 seed. So there is huge progress in quality seed production in the country in last almost 10 years which resulted in a considerable increase in the average per capita yield of potato production in the country, especially in the northern, central and eastern part of the country. But still there is a gap in the requirement and availability of good quality seed in India and hopefully, it should be fulfilling incoming 5-10 years.

Apart from technological development, there is another development of the availability of new varieties in India. CPRI has already developed & released about 51 varieties. Apart from them, there are a lot of other varieties imported in India by various corporates involved in potato processing sector or in the potato seed business. In India, there is a huge shortage of processing varieties till 2000. But CPRI has released Chipsona-1 in 1998 and later on other variants of Chipsona. In the meantime, there are some other varieties imported in the country like Lady Rosetta, Atlantic etc. in crisping sector and Shepody & Kennebec etc in frying sector. But after 2010 there are a lot of varieties had imported to the country from Europe, US & New Zealand etc. for evaluation purpose in various category and some of them are doing well in their respective fields like Santana in French Fries. In the meantime, the "Plant Variety & Farmer Right" act has enacted in the country in 2001. This act gives protection to all the global private and domestic breeders to register their varieties for their protection. This act has encouraged the global breeder's companies to enter in Indian market and promote their varieties. Thus a combination of seed potato production technology and availability of domestic & global varieties in India market has resulted in tremendous development in processing Industry in the country in the last almost 10 years. It has also resulted the substantial per capita yield increase in potato crop which can be seen as overproduction in last three years in row, especially in table potato portfolio. The farmers are generally of the opinion that there is no considerable increase in potato planting area in last 3-4 years and they thought going forward market should be alright but only limited % of farmers could realize that due to tremendous improvement in availability of quality seed in the last 10 years and change in climate, the yield of potato has increased substantially and the market has gone to low sentiments in last three years. So there is excellent transformation in overall potato portfolio across the sectors in the country and farmers need to rationalize their production as per the requirement of various categories of potato.

Use of Information Technology for Potato Research & Development

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Information Technology (IT) is the mantra of modern world. Today IT has pervaded each and every field of human endeavor including agriculture. Unlike medicine, engineering and commerce, its application in agriculture is much slower primarily due to paucity of IT trained manpower in this sector. The institute has so far developed many decision support systems, some are Indo-Blightcast, The Potato Pest Manager (PPM), Potato Growing Season Descriptor, Potato growing period and yield calculator, Computer Aided Advisory System for Potato Crop Scheduling (CAASPS), Potato Weed Manager, VarTRAC, etc. An EBook on potato and a potato photographic database are also developed at ICAR-Central Potato Research Institute Shimla.

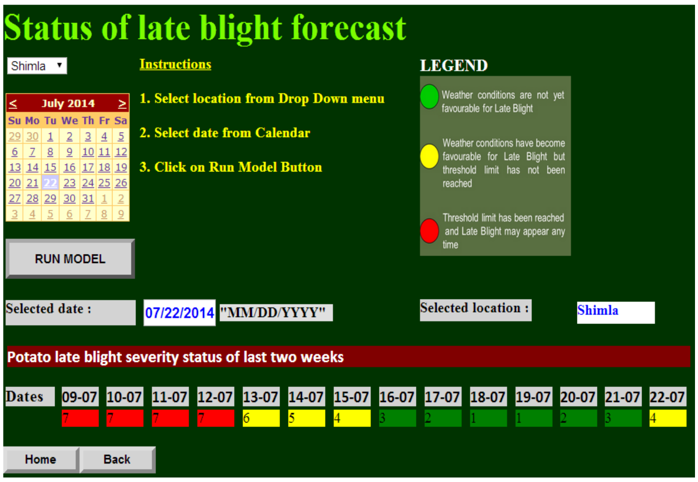
Decision support systems:

1. INDO-BLIGHTCAST- A web based Pan India Model for forecasting potato late blight

Late blight is the most dreaded disease of potato causing annual crop loss of about 12 billion € globally. Its appearance and spread is highly dependent on environmental factors. Under favourable conditions its spread is so fast that it can wipe out the crop within a weeks' time. In India it is very serious in the hills where it occurs regularly but in the plains it may or may not appear and even if it appears its time of occurrence would vary. The time of its occurrence and severity determines the yield loss which may exceed 40% country wide in some years. Prevention through prophylactic sprays of recommended chemicals is the best option since once it appears it is very difficult to control. This, however, requires information on the likely time of appearance of the disease and hence the importance of disease forecasting.

INDO-BLIGHTCAST- is a web based forecasting model (http://cpri.icar.gov.in) developed to predict the first appearance of late blight disease using daily weather data of meteorological stations. This is an improvement over the JHULSACAST model, which requires hourly data of temperature, relative humidity and daily rainfall. The intensive data requirement as well as location specific calibration of JHULSACAST was a serious impediment to its wide spread use. The INDO-BLIGHTCAST, however, is applicable pan India, since, it is web based, it requires only daily weather and does not need local calibration for different regions. Hence it is more robust and its predictions are broader based.

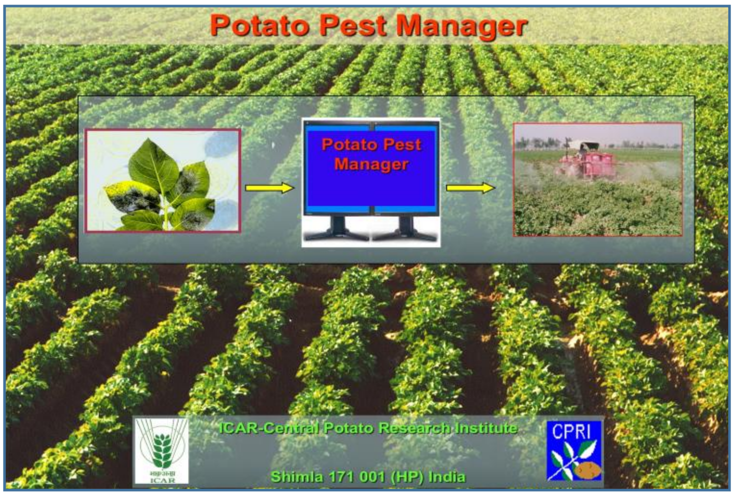
INDO-BLIGHTCAST has two modules one for data entry and the other for the general users to see the status of late blight forecast.



Data entry: The data entry module is user and password protected. The registered users can "Load data"(for viewing already entered data), "Add data" (to save entered data), "Edit data" (to change entered data values) and “Delete data" (to remove data) if required, in addition to running the model. Check late blight appearance status: Through this button, any user (requires no registration) can select any location which would lead to another window with a calendar and map showing the location with default state map. The user can select a date in the calendar and click on the "Run model" button which would then display the status of late blight in a circle through colour. Green colour indicates that late blight is not likely to appear soon; yellow colour indicates that late blight would appear very soon; and red colour indicates that the weather conditions have become suitable for late blight and it can appear any time within fifteen days. Thus depending upon the time required for taking control m easures, the user may start preventive measures at yellow or red colour indication. The model has been developed and tested using the data on late blight appearance monitored at ICAR-CPRI regional stations and AICRP centres over the past several years.

2. Potato Pest Manager (PPM)

For the management of diseases and pests two aspects are involved. The first is to establish the identity of the disease/pest and second is to recommend appropriate preventive and management practices to control them. These objectives are achieved in a sequence of steps as discussed below



Step 1: The photographs showing the symptoms of the diseases/pests are arranged in a photo gallery and displayed in sequence. The user is asked to match the symptoms in the photographs with those he has seen in the field and select the most closely matching one.

Step 2: The appropriateness of the selected photograph needs to be confirmed, because the user may not be fully conversant with the symptoms of different diseases or damage by pests. Information about the biotic/a biotic factors prevailing, together with the symptoms, are necessary for a correct diagnosis. This is done through a set of confirmatory questions.

These are questions about the symptoms of the disease/damage by the pest, or conditions which need to be satisfied for the disease/pest occurrence. This information is arranged in a linear fashion. This arrangement allows insertion/deletion of questions/an option to a question at any level without disturbing the overall structure. Furthermore, this information is presented in a format of questions/statements to the user, while answers are given as options to these questions/statements.

Step 3: Once all the confirmatory questions are answered, the name of the disease/pest corresponding to the photograph selected is displayed along with confidence percentage. The confidence percentage is calculated based on answers given to the confirmatory questions relevant to disease symptoms/pest damage. Each confirmatory question/statement is assigned a certain value such that for all the questions if the option corroborating the disease/pest whose photograph is selected is chosen as the answer, the value adds up to 100.

However, the value allotted to each question may vary depending upon its significance.

Step 4: Many potato diseases/pests can only be controlled through preventive measures taken over a period of time before planting the crop and control is not possible once the disease/pest appears. This is especially the case with diseases/pests where symptoms are seen at/after harvest. Therefore, the preventive measure applicable to the disease/pest identified is displayed in this step. The preventive measures are the set of practices, which would have prevented/mitigated the disease/pest occurrence.

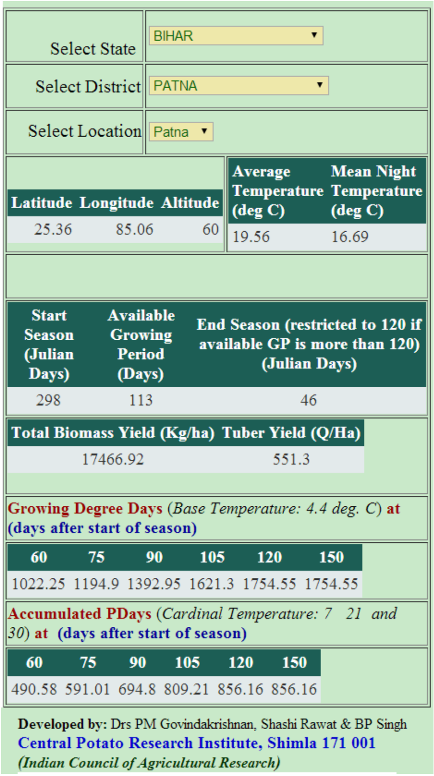
Step 5: In this step information required for suggesting control measures on the standing crop is obtained through a further series of questions. For example, information regarding severity of disease/pest damage, age of the crop, *etc*. is invariably required for deciding the chemicals to be used, their dosage, number of sprays *etc*. This information is again obtained from the user by presenting the questions or statements with various options. The questions or statements are arranged in tree structure and depending upon the answers given to each question a path is followed leading to a recommendation which is attached at the end node.

Step 6: This step displays the recommendation based on the options chosen.

This tool/DSS is web based and is developed in ASP.NET and the database is developed in Microsoft SQL. It can be accessed from ICAR-CPRI website (http://cpri.icar.gov.in).

3. Potato Growing Season Descriptor (PGSD)

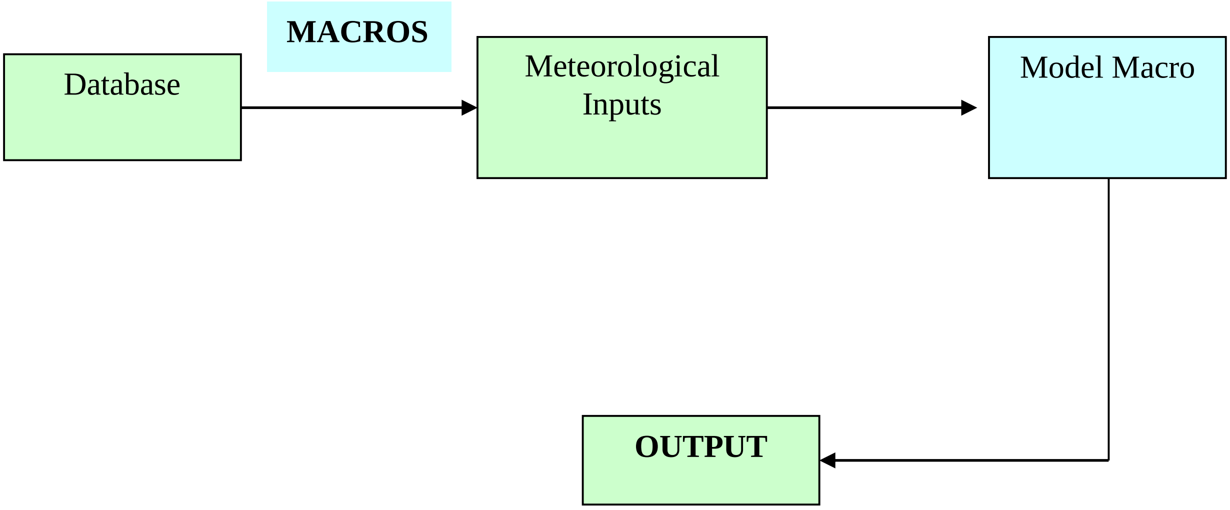
Potato is one of the most sensitive crops to the environment. It has specific temperature and photoperiod requirements for growth and development. Apart from the phenology and growth and yield, the weather conditions during the growing season also affect the size of the tubers as well as its quality. There is also a wide variation in the pest and disease scenario affecting potato primarily due to differences in the in growing season environmental factors in different locations/seasons in which potato is grown in India. Moreover, potato has been adapted to be grown under subtropical conditions in India. This has been possible by the development of resource intensive production technologies. Therefore there is need for careful planning of the production strategy by analyzing the growing season.



The PGSD consists of a database of daily meteorological data generated by MARKSIM weather generator for many locations. The daily meteorological data is analyzed using algorithms to determine the length of the plausible growing season, mean daily temperature, mean night temperature, accumulated growing degree days and accumulated P days during the autumn growing season. The tool also gives the expected yield calculated using a summary model of the autumn crop under constraint free situation. It is expected that these information would be useful for production managers, extension workers and farmers in planning their production strategy. It can be accessed from ICAR-CPRI website (http://cpri.icar.gov.in).

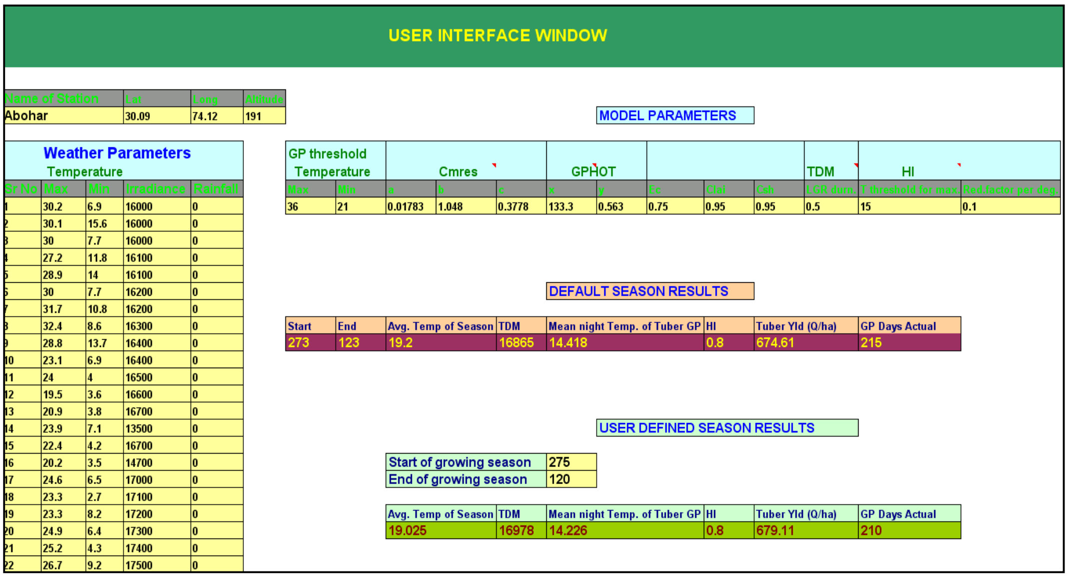
4. Potato Growing Period & Yield Calculator

Potato is a short duration crop grown under diverse growing conditions. It is highly flexible in terms of time of planting as it can be planted early, at optimum time or late in the season. Similarly, as regards harvest time it can be harvested at any time after about 3 quarters of the growing season by which time economic yields are realized. Such flexibility makes it an ideal choice to fit in multiple cropping systems. To exploit this flexibility at any given location there is need to identify the growing season/s and the length of each growing season/s. Temperature is the primary determinant for potato under sub-tropical conditions of India. The temperature suitability criteria are that the maximum temperature should be less than 35 ºC, minimum temperature should be less than 21 ºC at least 3 weeks after the maximum temperature suitability criteria is met and it should also be more than 2 ºC to ensure frost free season. Identifying the suitable growing period based on these criteria is difficult and there is also a need to know the expected yield in the different season. A PC based tool was developed for delineating the potato growing seasons and the expected yield of any given season for any location as given in the flow chart below.



A spreadsheet with macros was created to process the raw data and extract the information required by the model. Four fields each with 365 records were created in spreadsheet and macros for screening the day as suitable or unsuitable for potato based on threshold limits for maximum and minimum temperature was written. The starting day number, ending day number and the total number of suitable days of the longest period, where more than two growing seasons were obtained, were derived as outputs. Further the meteorological variables required by the model *viz*. mean temperature and mean irradiance of the growing season were derived from the data of the thermally suitable days for potato.

Macros for estimation of gross photosynthesis (GPHOT), maintenance respiration, linear growth rate *etc*. (Versteeg & vanKeulen, 1986) utilizing the outputs of the database screening macros were written to derive the expected potential yield.



A Graphical User Interface (GUI) was designed in MS Access/Visual Basic. Fields were created for display of location and its spatial features and also for display of the various outputs as shown below.

5. COMPUTER AIDED ADVISORY SYSTEM FOR POTATO CROP SCHEDULING (CAASPS)

The optimum time of planting, the most suitable variety and the expected yield at different dates of harvest are vital information required by farmers for scheduling their planting and harvesting times as well as for choosing the variety to be grown. Obtaining such information through field experimentation in the diverse agro-climatic conditions in which potato is grown in India is an uphill task, but this information can be derived from crop models which can simulate crop growth, development and yield with reasonable accuracy under diverse situations.

However, use of crop models requires extensive data inputs as well as technical expertise to handle the model. Therefore, world over, models are handled by researchers and off take of models by field level workers is not very satisfactory. Decision Support Systems (DSS) on the other hand provide a method for delivery of information in a user friendly and simple way. Therefore, this DSS "Computer Aided Advisory System for Potato Crop Scheduling (CAASPS)" has been developed with the following purposes:

a) To provide information on the expected yields of different varieties planted at different times to enable farmers to decide on the most suitable one for their respective locations.
b) To help decide the time of harvest based on yield accrued at 60, 70, 80 and 90 days after planting.
c) To indicate the varietal performance under different dates of planting and crop durations and thus help choose the appropriate variety.

This DSS consists of a database and a user interface. The database consists of state, district and location names along with Infocrop-potato model derived yield outputs.

The model outputs were derived as follows:

1) Weather database were created for important locations in India using MARKSIM weather generator.
2) Suitable thermal window were delineated for each location by defining screening rules for maximum temperature (< 35^0C) and minimum temperature (< 21^0C).
3) Infocrop-potato model was run for 5 planting situations starting from ten days earlier to the beginning of the suitable thermal window identified by the screening rules and staggered at 10 days interval.
4) For each date of planting, the model was run for 10 varieties under potential situations and 80% of the potential yield was taken as attainable yield.
5) Yield output of each variety at 60,70,80 and 90 days after planting were linked to corresponding spatial attributes *viz.* state, district and location names in MS Access.

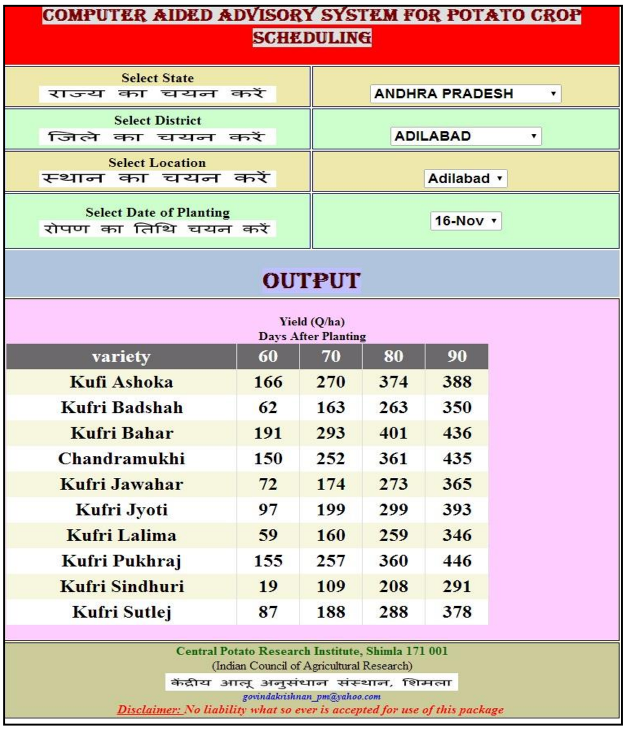
User interface: A simple query system was designed for querying the database.

The user first selects the State, and then the Districts of the state. The locations within the district for which information is available are then displayed for selection of one of them.

Once the location is selected, the five dates of planting for which model has been run for the selected location is displayed and the user is required to select one of them.

When any of the dates is selected, the attainable yield data for all the ten varieties at five durations, corresponding to 60, 70, 80 and 90 days after start is displayed in tabular format.

This tool/DSS is web based and is developed in ASP.NET and the database is developed in Microsoft SQL. It can be accessed from ICAR-CPRI website (http://cpri.icar.gov.in).


COMPUTER AIDED ADVISORY SYSTEM FOR POTATO CROP SCHEDULING

Select State राज्य का चयन करें	ANDHRA PRADESH
Select District जिले का चयन करें	ADILABAD
Select Location स्थान का चयन करें	Adilabad
Select Date of Planting रोपण का तिथि चयन करें	16-Nov

OUTPUT

Yield (Q/ha)
Days After Planting

variety	60	70	80	90
Kufi Ashoka	166	270	374	388
Kufri Badshah	62	163	263	350
Kufri Bahar	191	293	401	436
Chandramukhi	150	252	361	435
Kufri Jawahar	72	174	273	365
Kufri Jyoti	97	199	299	393
Kufri Lalima	59	160	259	346
Kufri Pukhraj	155	257	360	446
Kufri Sindhuri	19	109	208	291
Kufri Sutlej	87	188	288	378

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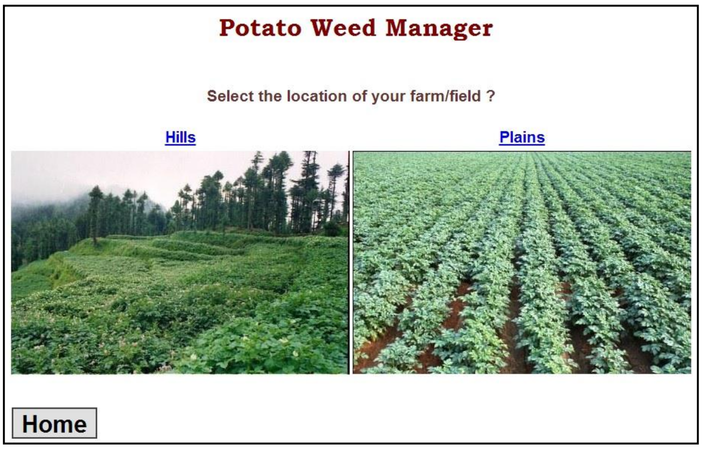
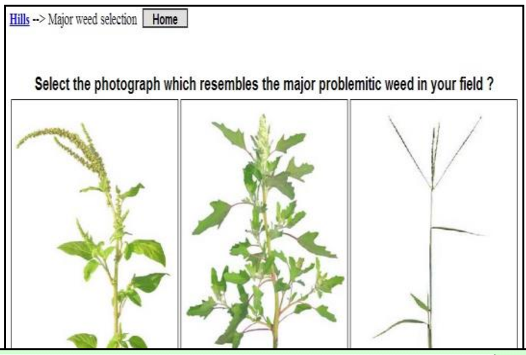
6. **Potato Weed Manager (PWM):** Weeds cause enormous loss in potato production. Weeds in potato not only compete for moisture, nutrients, space and light but also harbour several pests and diseases as alternate hosts. Up to 80% reduction in the productivity of potatoes due to weeds is reported. A number of cultural, mechanical as well as chemicals methods are available for controlling weeds in potato crop. Herbicides are available for control of different types of weeds at different stages. The selection of proper herbicide depends upon the type of weed flora and the stage of crop growth. However, weeds prevalent in potato crop vary from region to region and season to season and in the absence of

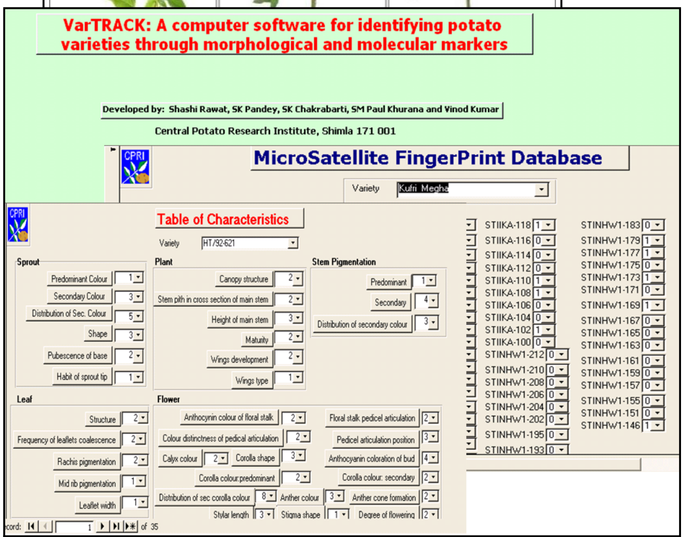


knowledge about weed flora, it is difficult to give precise recommendation for their control. The knowledge of farmer about the weeds is limited only up to its local name and the extent of damage it may cause. Moreover, availability of proper guidance about weed control in the absence of technical advice may lead to improper control method leading to inefficient weed control. To alleviate this problem, a decision support tool "Potato Weed Manager" has been developed. The software is developed in DOT NET technology and the database used is SQL. This software is hosted on CPRI application server and is connected to CPRI website. This software incorporates the photographs of the weeds for identification by the user. This software gives the recommendation for weed control on the basis of situation of potato field, type of weed flora (major and secondary/associated weeds) and the stage of the potato crop. Thus the software provide proper guidance to the farmer about the weed control method to be adopted and dispense with the need of technical knowledge. It can be accessed from ICAR-CPRI website (http://cpri.icar.gov.in)

7. VarTRAC: BIOINFORMATICS-TOOL FOR IDENTIFYING POTATO VARIETIES

Authentic identification of potato cultivars is important for plant breeders, the variety registration and certification agencies, seed producers, merchants, farmers, growers, processors, and other end-users. Currently morphological descriptors are being used internationally for variety identification. However, there is a possibility of utilizing DNA fingerprint data to supplement morphological characters in near future. Central Potato Research Institute, Shimla is, therefore, developing both morphological and DNA fingerprint databases for potato cultivars' identification.





A combined view of different windows of the "VarTRAC"

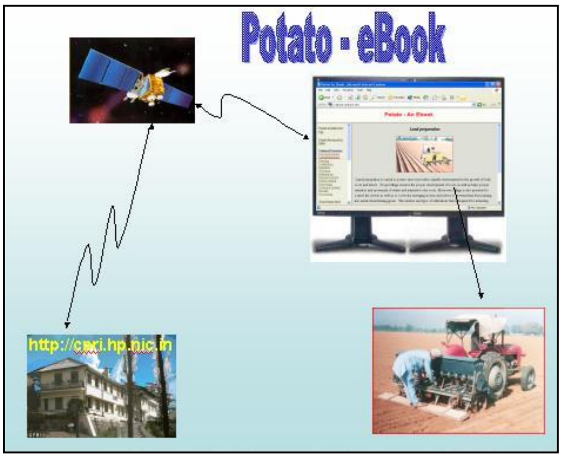
Data on 50 different morphological attributes and DNA fingerprints based on 127 alleles from 4 micro-satellite markers are currently being used at CPRI for varietal identification. Manual analysis of such huge data is not easy. Therefore, a computer software named "VarTRAC" was developed at CPRI for speedy identification of a variety based on the morphological and DNA fingerprint data.

The database was created in MS Access with each morphological character taken as a field. All the characters necessary for the identification of a potato variety have been included. Scores are given for each character in a drop-down menu format and the users have only to select the appropriate score for each character. Further the help has also been provided for proper scoring. As regards DNA fingerprints, the data on 127 alleles have been recorded by giving a score of one for those alleles, which are present while zero for the absent ones.

The software can make generalized abstraction even from the minimum available information. For example, if only 5 morphological attributes of any unknown variety are known, the software can identify the group of varieties having similarity in respect of those 5 attributes.

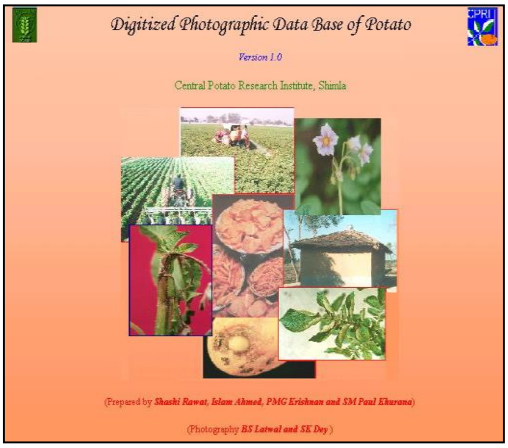
8. E-BOOK ON POTATO

E-book on the Potato is meant to give a bird's eye view of practical knowledge about the potato production, utilization, *etc*. in India. It is aimed at providing appropriate information for all those interested in knowing about the ways potato is cultivated in different regions in India, the reasons for the adoption of the various agro techniques and the major abiotic and biotic stresses. This is expected to provide insights about the scientific cultivation and utilization of potato. This e-book is also meant to be a supplement to many excellent publications on potato, which could not be fully illustrated with photographs due to limitation of cost of printing. This lacuna is overcome in this e-book since cost factors are minimum in this case. Thus, this e-book apart from being used as a book *per se* would also be a pictorial supplement to other publications available in print. Through this e-book, it is hoped to further strengthen the cause of potato R&D in India using the electronic media, the use of which is becoming rampant. It can be accessed from ICAR-CPRI website (http://cpri.icar.gov.in).



9. DIGITIZED PHOTOGRAPHIC DATABASE OF POTATO

The creation of photographic database is a very important activity because information can be presented very easily and concisely through photograph rather than text. Therefore, a digitized photographic database was developed. It can be used by professional s in their presentations, extension lectures to the farmers/industry entrepreneurs, in publication of scientific books, technical bulletin *etc*. The database contains more than 600 photographs pertaining to all aspects of potato research and development. The use of this database does not require any specialized skill.



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