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REVIEW

Potato processing scenario in India: Industrial constraints, future projections, challenges ahead and remedies – A review

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Abstract Indian potato (*Solanum tuberosum* L.) processing industry has emerged fast due to economic liberalization coupled with growing urbanization, expanding market options and development of indegenous processing varieties. India's first potato processing varieties 'Kufri Chipsona-1' and 'Kufri Chipsona-2' were developed in 1998, followed by an improved processing variety 'Kufri Chipsona-3' in 2005 for the Indian plains and first chipping variety 'Kufri Himsona' for the hills. These varieties have >21% tuber dry matter content, contain low reducing sugars (<0.1% on fresh wt) and are most suitable for producing chips, French fries and dehydrated products. The availability of these 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 within a short span of 10 years. Currently about 4% of total potato produce is being processed in organized and unorganized sector. Potato processing industry mainly comprises 4 segments: potato chips, French fries, potato flakes/powder and other processed products. However, potato chips still continue to be the most popular processed product. The major challenge facing the industries lies in arranging round the year supply of processing varieties at reasonable price for their uninterrupted operation, besides several others which have been discussed at length and addressed with concrete solutions.

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Introduction

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 world (Swaminathan 2001, Naik 2005). The crop has the capacity to produce more food per unit time and area and has high nutritional value to sustain burgeoning population. It produces 47.6 kg of food/ha/day whereas wheat, rice and maize produce 18.1, 12.4 and 9.1 kg food/ha/day, respectively (Kumar and Pandey 2008). 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. Potatoes can be served in any course of a meal from salads, snacks and soups to the main course in which they can figure either as an accompanying side dish, or as the main dish itself. There has been a sustained change in potato consumption pattern in most of the developing countries. This is due to increasing population pressure, growing urbanization and fast changing consumer and market preferences (Pandey et al. 2005a). Till date, the Central Potato Research Institute, Shimla has released 44 high yielding potato varieties including 4 'Kufri Chipsona-1', 'Kufri Chipsona-2', 'Kufri Chipsona-3' and 'Kufri Himsona', which have been specifically bred for catering to the needs of processing industries.

Need for processing

India produced 26 million MT of potato during 2007-08 that made it the third largest producer in the world after China (75 million MT) and Russian Federation (37 million MT) (Eijck 2008b). The average productivity of potato in India is 20 t/ha which is more than the world average (17.2 t/ha). The per capita availability of potato has gone up to 23.5 kg/year from 5 kg/year in 1952, however, it is still far behind China (35.3 kg/year) and Russian Federation (122.0 kg/year) (Pandey et al. 2007). Potato is a perishable commodity and its harvest time (Feb/March) coincides with steep rise in temperature in the Indo-Ganges plains which account for 87% of the production in the country. From April onwards, temperatures in the plains start shooting up and the produce has either to be consumed within a short period or is required to be shifted to the cold stores. Due to inadequate, expensive and unevenly distributed refrigerated storage facilities, there are frequent gluts in the market causing substantial economic loss to the farmers and wastage of precious food. Such gluts have occurred every 3 to 5 years, whenever there had been an increase in potato production by 7–8% (Pandey et al. 2008b). The glut years are followed by a reduction in potato area in the following year and the boom and bust cycle continues. Therefore, it is essential that potato consumption is increased to sustain this increase in production and to ensure remunerative prices to the farmers. Under the existing circumstances, processing of the bulky perishable potato into various processed products is a viable option which can help to extend the shelf-life, save the wastage of precious food during gluts, solve the problem of storage, cater to consumer preferences belonging to different age groups and social strata and serve as a means to increase the supply in off seasons thus maximizing the potato utilization (Marwaha et al. 2006).

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. In spite of this recent spurt, both organized and unorganized Indian processing industries presently consume about 4% of the total potato produce in the country as compared to about 30–67% in developed European countries and North America (Rana and Pandey 2007).

Present status of processing

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 and presently constitute 85% of salty snack business worth Rs 25 billion (John 2005) and account over 60% of the total potato processing capacity of the industry. Frito Lay with 45% market share is the snack food leader followed by 27% share by Haldiram and 11% by Indian Tobacco Company (ITC) (Eijck 2007). The production of potato flakes/powder is witnessing an impressive growth with their share in total processing sector touching about 17.6% in 2005. Multinationals like M/s PepsiCo India Holdings Pvt. Ltd. and M/s McCains Food Ltd are steadily consolidating their market shares with diverse processed, frozen, canned and value-added potato products and simultaneously other foreign multinationals are directly or indirectly tying up with their Indian counterparts on different collaborative ventures to supplement and diversify this emerging sector.

The utilization of raw material by the organized potato processing industries in India during 2007 was about 4.40 lakh tons which was about 2% of the total potato production. During 2008, about 10 lakh tons of potatoes were processed both by the organized and unorganized sectors and out of which Frito-Lay, the food arm of PepsiCo India Holdings Pvt. Ltd. alone utilized around 1.5 lakh tons of potato for different products. About 28 industries manufacturing potato chips, flakes and French fries have been installed in the organized sector in India from just 4 or 5 companies in 2003 (Pandey et al. 2008b, Singh et al. 2008a). Till 2002, all the major potato processing industries were located in and around Delhi and in Punjab, but thereafter several new multinational and Indian processing industries came into existence in different parts of India, particularly at Kolkata (West Bengal), Guwahati (Assam), Indore (MP), Rajkot and Mehsana (Gujarat), Haridwar (Uttaranchal), Pune (Maharastra) and Coimbatore (Tamil Nadu). This has become possible mainly due to increased demand of processed potato products in the country and the suitability and availability of indigenously developed potato processing varieties, like 'Kufri Chipsona-1', 'Kufri Chipsona-2' and 'Kufri Chipsona-3'. Presently, these varieties are the choice of processing sector for the production of quality potato chips and French fries.

The development of Chipsona varieties is a land mark in efforts to diversify potato utilization and development of potato processing industry in the country. The availability of quality raw material of Chipsona varieties and standardization of storage techniques for processing potatoes at 10–12°C with sprout suppressant Isopropyl N-(3-chlorophenyl) carbamate (CIPC) has changed the entire scenario of potato utilization in India within a short span of 10 years from the time when the farmers were often forced to throw harvested potatoes on road to the present situation, where the processors are ready to pay good premium for processing potatoes. The release of Chipsona varieties have benefited all those associated with potato production, supply and utilization chain due to unprecedented growth in processing industry.

History of potato processing in India

With liberalization of economy in early nineties, several multinational companies (MNC) entered the field of potato processing. Since indigenous varieties were not suitable for producing international quality processed products, the MNCs insisted on bulk import of potato varieties from Europe and America. However, in view of quarantine problems related to bulk import, involving risk of entry of new pests and diseases in the country, the Indian government allowed import of limited quantity of seeds of a few processing varieties like 'Atlantic' and 'Frito-Lay' hybrids. These varieties when grown under Indian conditions produced low yields and were also susceptible to late blight the most devastating disease of potato.

The European and American potato varieties were developed for long day (about 14–16 h photoperiod) and long crop durations of 120–180 days. But in India, potatoes are grown mainly in sub-tropical plains in winter under short day conditions, very different from those prevalent during the potato crop season in temperate countries (Table 1). Also, unlike temperate countries, where the potato harvest is followed by severe winter, the harvest in the plains of India is followed by hot summers, making post-harvest operations difficult. Thus the variety and technological requirement of potato cultivation in India are totally different from those of temperate countries. Obviously, this important aspect was overlooked by the industry while importing exotic varieties. Among exotic processing varieties introduced by processing industry, only 'Atlantic' showed some promise. Despite its low yield and susceptibility to late blight, it was introduced in some selected regions. But the variety suffered high post-harvest losses due to 'hollow heart', a physiological disorder. These factors deterred wide scale adoption of 'Atlantic'. Due to non-availability of suitable raw material, the potato processing industries had no option but to use Indian table varieties for processing into chips.

Thus, availability of processing quality potatoes became a major bottleneck for growth of potato processing industry in India, which posed a challenge to the Central Potato Research Institute, Shimla. The institute accepted the challenge and initiated a breeding programme for development of indigenous processing varieties which culminated in the release of India's first 2 processing varieties, 'Kufri Chipsona-1' and 'Kufri Chipsona-2' in 1998 (Gaur et al. 1998, 1999b) and an improved processing variety 'Kufri Chipsona-3' in 2005 (Pandey et al. 2006b) for the Indian plains and first chipping variety 'Kufri Himsona' for the North-Western hills (Pandey et al. 2008c). These varieties have brought a revolution in the Indian processing scenario and long pending demand of the industry was met as these indigenous processing varieties produced >21% dry matter and contained low reducing sugars (<0.1% on fresh wt basis) when grown at different locations in India (Pandey et al. 2002, 2008d). These varieties can be grown in most parts of the country to produce high quality processing potatoes which can be used fresh as well as after storage at 10–12°C with CIPC (Ezekiel et al. 2007, Kumar et al. 2006, 2007b). Besides production of processed products, several companies in the country are trading potatoes of Chipsona varieties stored at 10–12°C as 'low sugar potatoes' for table or ware consumption and selling them at a premium price (Pandey et al. 2008b). Ever since the release of 'Chipsona' varieties, there has been an upsurge in production of potato chips, French fries and flakes and a large number of Indian and multinational potato processing companies have come up in organized sector in India (Table 2).

Desirable quality characteristics for processing

All the potato varieties available in the country are not suitable for processing. For making superior quality processed products, the potatoes must possess certain minimum morphological and biochemical quality characters. The tuber quality requirements for different products could be summarized as follows.

Shape, size and depth of eyes: For making chips of uniform size, the tubers should be round to oval in shape having a diameter of 45–80 mm (Table 3). For French fries, oblong to long tubers having >75 mm length are preferred, while for flakes, though round to oval shape is desirable, the requirement of shape is not very obligatory (Gaur et al. 1999a). For canning, small tubers of round to oval shape are suitable. Medium to large size tubers with shallow eyes are preferred for most of the processed products as these results in lower peeling losses (Kumar et al. 1999).

Tuber dry matter content: The dry matter content of tubers is the most important character determining the quality and yield of fried and dehydrated products. The higher

Table 1 Potato growing conditions in sub-tropical and temperate regions

	Sub-tropical	Temperate
Day/night temperatures	25–30°C/2–15°C	15–25°C/15°C
Photoperiod	9–11 h/day	14–16 h/day
Frosting	Common	Absent
Crop duration	90–100 days	140–180 days
Post-harvest conditions	Harvesting followed by hot summer and rains	Harvesting followed by severe winter
Result	Low yields, low dry matter, high reducing sugars, short dormancy and poor keeping quality	High yields, high dry matter, low sugars, long dormancy and good keeping quality

Table 2 The status of potato processing sector in India during 2007

Manufacturer	Location	Product	Raw material processing capacity, MT/year
Ace Foods	Mangalore	Chips	2400
A-One Wafers	Mumbai	Wafers	1000
Arumugam Industries	Coimbatore	Chips	4000
Balaji Wafers	Rajkot	Chips	30000
Bikano Namkeen	Delhi	Potato products	1000
Budhari Brothers	Pune	Chips	4000
Merino Industries Ltd.	Hapur	Flakes	30000
Golden Fries	Coimbatore	French fries	15000
Faber leather	Kolkata	Flakes	30000
GP Foods	Kolkata	Chips	30000
Frito Lay	Channo, Pune, Noida and Kolkata	Chips	90000
Haldiram	New Delhi, Kolkata, Nagpur and Bikaner	Chips	40000
ITC	Haridwar	Chips	30000
Janata Wafers	Mumbai	Wafers	1800
Kakaji Namkeen	Delhi	Potato products	1000
Kishlay Foods	Guwahati	Chips	2400
Little Bee Products	Ludhiana	chips	3000
McCains Foods	Gujarat	French fries & wedges	30000
Mota Chips	Mumbai	Wafers	2400
MTR Foods	Bangalore	Chips	1000
Potato King	Kolkata	Flakes	36000
Satnam Agri. Prod Ltd.	Jalandhar	French fries & flakes	25000
Shivdeep Foods	Bikaner	Chips	10000
Twinkle Chips	Faridabad	Chips	2400
Vista Foods	Mumbai	French fries	4000
Welcome Wafers	Mumbai	Wafers	1800
Welga Foods	Badayun	French fries	7500
Wimpy's	Delhi	French fries	7500

Table 3 Quality requirements of potatoes for different processed products

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

dry matter or solids content results in higher recovery of processed products, lower oil absorption, lesser energy consumption and imparts a crispy texture to the product (Marwaha et al. 2005b, 2008c). The lower oil content in the fried products results in longer shelf life of the product. Conversely, for canning the tubers with low dry matter are preferred as higher dry matter content results in sloughing of tubers. Specific gravity of potatoes is commonly used by the potato processing industry as a tool for quick estimation of dry matter content, as both are highly correlated (Grewal and Uppal 1989). Dry matter content of 18–20% is considered acceptable for canning but for chips, French fries and dehydrated products, the tubers must possess >20% dry matter or >1.080 specific gravity (Ezekiel et al. 1999).

Reducing sugar content: Reducing sugars play a critical role in determining the colour of fried products which develops during frying at high temperatures due to the 'Maillard reaction' between reducing sugars and free amino acids present in the tubers. Excessive amounts of reducing sugars in potato tubers result in unacceptably dark colour and bitter taste in fried products (Marwaha 1997, Marwaha et al. 2008b). 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. It has been reported that acrylamide has serious reproductive and carcinogenic effects on human health (LoPachin 2004). A number of studies have shown that there is a significant correlation between acrylamide and reducing sugars in raw potatoes with the storage temperature affecting its concentration (Matthaus et al. 2004). During frying, the greatest amount of acrylamide is formed from asparagine and reducing sugars, while the alternative routes of formation via acrolein and acrylic acid are less important (Weisshaar 2004). For making good quality fried (chips, French fries) or dehydrated (flakes, powder) products, potatoes should have low reducing sugars (< 0.1% on fresh wt basis).

Phenolic compounds: In addition to the discoloration of fried products, tubers show enzymatic discoloration and after-cooking discoloration. 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 polyphenoloxidase enzyme and tuber flesh turns brown (Schaller and Amberger 1974). This type of discoloration can be prevented if potatoes are not exposed to air and are immersed in water. After-cooking discoloration develops in the tubers upon cooking and exposure to air. The canners often face this problem. However, this is not a major problem in our country as almost all the cultivated varieties are free from this defect (Pandey et al. 2000).

Glycoalkaloids: Potato tubers contain small quantities of naturally occurring steroidal glycoalkaloids, a class of potentially toxic compounds, found throughout the Solanaceae family. Approximately 95% of the total glycoalkaloids present in potatoes are -solanine and -chaconine, both of which are structurally similar with solanidine as aglycone moiety but have different forms of glycosides. 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 (>15 mg/100 g fresh wt) these impart bitterness and levels above 20 mg/100 g fresh wt are considered unsuitable for human consumption resulting in symptoms typically associated with food poisoning (Pandey et al. 2008e). However, the glycoalkaloids are thought to confer a degree of protection to the plant against various insect pests. 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 present-day Indian potato varieties contain glycoalkaloids within the permissible limit and pose no threat to human food safety (Pandey and Sarkar 2005).

Besides, the requirement of above morphological and biochemical traits, the tubers of processing varieties should not show >3% greening and the total tuber defects such as growth cracks, hollow heart, internal brown spots and secondary growth should not exceed 15%.

Quality of Indian processing varieties and suitability for different processed products

All the indigenous processing varieties viz., 'Kufri Chipsona-1', 'Kufri Chipsona-2', 'Kufri Chipsona-3' and 'Kufri Himsona' contain 21–24% dry matter, <0.1% reducing sugars on fresh tuber weight basis, low phenols and glycoalkaloids and produce high yield of light coloured chips (Tables 4 and 5, Fig. 1). Large tubers of these varieties produce high yield of French fries having mealy texture and are highly acceptable (Table 5). Besides fried products, these processing varieties also produce higher yield of dehydrated products such as dehydrated chips, flour, flakes and starch in comparison to table varieties (Table 6).

Indigenous processing varieties yield 30–40 t/ha and are resistant to late blight, while 'Kufri Chipsona-2' and 'Kufri Himsona' also have tolerance to frost. Among processing varieties, 'Kufri Chipsona-3' produces 11–15% more total and processing grade tuber yields when compared to other processing and table varieties (Kumar et al. 2005b). This attribute will enhance the profit of the farmers and give them greater freedom in selling the produce to the processor or to the ware market, depending upon the prices.

Based on tuber morphological and biochemical characters and quality evaluation tests, varieties and advanced processing hybrids suitable for making different processed products were identified (Table 7).

Industrial testing of indigenous processing varieties for production of chips

The industrial tests conducted at the factory of M/s PepsiCo India Holding Pvt. Ltd., Channo, Sangrur (Punjab) confirmed the excellent chipping quality of Chipsona varieties grown in Punjab and Western UP. The extent of unacceptable traits in chips like internal defects (ID), external defects (ED), greening (G), undesirable colour (UC) and total potato defects (TPOD) in these varieties were well within the prescribed limits (Fig. 2). All the three Chipsona varieties showed <5% undesirable colour and <15% total

Table 4 Salient features of Indian processing potato varieties

	General features	Processing quality
'Kufri Chipsona-l'	Medium maturing; resistant to late blight; tubers white, medium to large, oval, smooth skin, fleet eyes, dull white flesh	Low reducing sugars (<100 mg/100g tuber fr wt); high tuber dry matter (21.1%); low levels of total phenols (30.1 mg/100 g tuber fr wt); low free amino acids (82.8 mg N/100 g tuber fr wt); suitable for chips, French fries and dehydrated products
'Kufri Chipsona-2'	Medium maturing; resistant to late blight; tolerant to frost; tubers white, medium, round oval, smooth skin, fleet eyes, cream to pale yellow flesh.	Low reducing sugars (<100 mg/100g tuber fr wt); high tuber dry matter (22.4%); low levels of total phenols (27.1 mg/100 g tuber fr wt) low free amino acids (66.9 mg N/100 g tubers fr wt); suitable for chips and dehydrated products
'Kufri Chipsona-3'	Medium maturing; resistant to late blight; tubers defect free and white, medium to large, round-oval, smooth skin, fleet eyes, flesh cream to pale yellow	Low reducing sugars (<50 mg/100g tuber fr wt); high tuber dry matter (>21%); low levels of total phenols (<30 mg/100 g tuber fr wt); low free amino acids (<60 mg N/ 100 g tuber fr wt); suitable for chips and dehydrated products
'Kufri Himsona'	Medium maturing; resistant to late blight; tolerant to frost; tubers white, medium, round, smooth skin, fleet eyes, flesh cream to pale yellow	Low reducing sugars (<50 mg/100 g tuber fr wt); high tuber dry matter (>23%); low levels of total phenols (<50 mg/100 g tuber fr wt) low free amino acids (<25 mg N/ 100 g tuber fr wt); suitable for chips and dehydrated products

Table 5 Processing qualities of some potato varieties and some advanced processing hybrids

	Chips		French fries			
	Yield, %	Colour[1]	Yield, %	Colour	Texture	Overall acceptability
'Kufri Chipsona-1'	29.3	3.0	45.3	LC	Mealy	HA
'Kufri Chipsona-2'	28.7	2.5	45.0	MB	Mealy	A
'Kufri Chipsona-3'	28.9	3.0	46.1	LC	Mealy	HA
'Kufri Himsona'	29.2	2.0	46.5	LC	Mealy	HA
'Kufri Surya'	27.4	4.5	45.8	LY	Mealy	HA
'MP/97-625'	30.1	4.0	44.7	MB	Mealy	A
'MP/97-637'	27.9	5.0	45.7	LC	Mealy	HA
'MP/97-921'	30.8	2.25	45.6	LC	Crispy	HA
CD (5%)	1.1	0.12	1.8	-	-	-

[1]On a 1-10 scale of increasing dark colour, chip colour score >3 was unacceptable, (n=4) LC: Light cream, MB: Medium brown, LY: Light yellow, HA: Highly acceptable, A: Acceptable

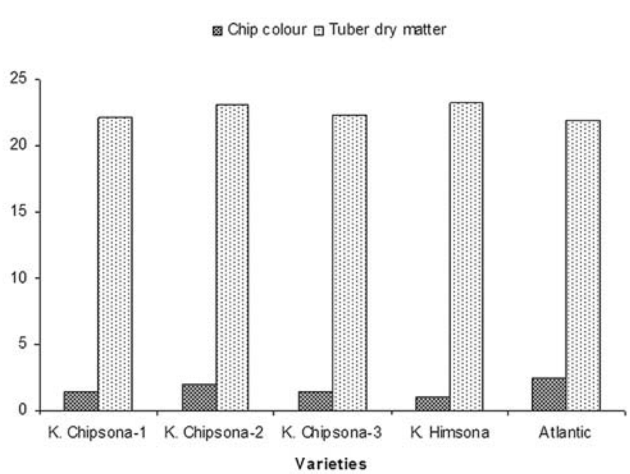

Fig. 1 Chip colour and tuber dry matter content (%) of Indian and exotic processing varieties (On a 1–10 scale of increasing dark colour, chip colour score up to 3 was acceptable)

defects, which are the maximum acceptance limits for chips (Pandey et al. 2005c).

Industrial constraints

Availability of desired quality and quantity of raw material is the first and foremost requirement for setting up any processing unit. The major factor responsible for slow growth of potato processing sector in the past has been the non-availability of suitable processing varieties having high dry matter and low reducing sugars (Pandey et al. 2008a). For producing good quality fried or dehydrated products, potatoes should have low reducing sugars (<0.1% on fresh wt basis) and high dry matter content (>20%).

Potato varieties developed in India till 1998 were meant for table purpose only. These contained low dry matter and high reducing sugars which are undesirable traits for processing. Due to non-availability of suitable raw material, the potato processing industries had no other alternative and were compelled to utilize these table varieties even for

Table 5 Processing qualities of some potato varieties and some advanced processing hybrids

	Chips		French fries			
	Yield, %	Colour[1]	Yield, %	Colour	Texture	Overall acceptability
'Kufri Chipsona-1'	29.3	3.0	45.3	LC	Mealy	HA
'Kufri Chipsona-2'	28.7	2.5	45.0	MB	Mealy	A
'Kufri Chipsona-3'	28.9	3.0	46.1	LC	Mealy	HA
'Kufri Himsona'	29.2	2.0	46.5	LC	Mealy	HA
'Kufri Surya'	27.4	4.5	45.8	LY	Mealy	HA
'MP/97-625'	30.1	4.0	44.7	MB	Mealy	A
'MP/97-637'	27.9	5.0	45.7	LC	Mealy	HA
'MP/97-921'	30.8	2.25	45.6	LC	Crispy	HA
CD (5%)	1.1	0.12	1.8	-	-	-

[1]On a 1–10 scale of increasing dark colour, chip colour score >3 was unacceptable, (n=4) LC: Light cream, MB: Medium brown, LY: Light yellow, HA: Highly acceptable, A: Acceptable

Table 6 Yield and colour quality of dehydrated products prepared from Indian processing and table varieties

	Dehydrated chips				
	Yield %	Colour	Flour yield, %	Flakes yield, %	Starch yield, %
'Kufri Chipsona-1'	17.6	HA	18.8	17.1	10.9
'Kufri Chipsona-2'	17.3	HA	19.2	19.8	10.4
'Kufri Chipsona-3'	17.2	HA	19.9	18.2	10.1
'Kufri Himsona'	17.6	HA	19.5	18.7	10.3
'Kufri Badshah'	13.7	UA	15.3	15.2	6.7
'Kufri Chandramukhi'	16.7	A	17.7	16.8	8.5
'Kufri Jawahar'	15.7	A	17.3	16.4	6.5
'Kufri Jyoti'	14.1	UA	15.8	16.2	7.6
'Kufri Lauvkar'	15.9	A	16.7	15.8	7.7
'Kufri Pukhraj'	12.5	UA	14.1	13.7	7.1
CD (5%)	0.82	-	0.61	0.73	0.45

A: Acceptable, HA: Highly acceptable, UA: Unacceptable, (n=4)

Table 7 Identification of Indian potato varieties/hybrids suitable for different processed products

Processed product	Varieties/hybrids
Chips	'K*. Chipsona-1', 'K. Chipsona-2', 'K. Chipsona-3', 'K. Himsona', 'MP/97-921'
French fries	'K. Chipsona-1', 'MP/98-71'
Laccha	'K. Chipsona-1', 'K. Chipsona-2', 'K. Chipsona-3', 'K. Himsona'
Dehydrated chips	'K. Chipsona-1', 'K. Chipsona-2', 'K. Chipsona-3', 'K. Chandramukhi'
Flour and starch	'K. Chipsona-1', 'K. Chipsona-2', 'K. Chipsona-3', 'MP/97-921'
Flakes	'K. Chipsona-1', 'K. Chipsona-3', 'K. Himsona'
Canning	'K. Bahar', 'K. Ashoka'

K*=Kufri

processing into chips. The industry worked under-capacity utilizing Indian varieties like 'Kufri Jyoti' and 'Kufri Lauvkar', procured from certain selected pockets of India and to some extent, an exotic variety 'Atlantic'. The problem of availability of good quality raw material, however, still persisted. 'Atlantic' proved to be a poor yielder and was severely attacked by late blight disease. Post harvest losses in 'Atlantic' were also high and all these factors deterred wide scale adoption of this variety. The varieties 'Kufri Jyoti' and 'Kufri Lauvkar' grown in relatively warmer climate of Malwa region in Madhya Pradesh served the purpose to some extent, but it involved a lot of expenses on the transport of bulky and perishable raw material to the industries located in far-off places in the North-Western plains. Moreover, Malwa region alone could not sustain all the processing units. Thus, availability of processing quality potatoes was a major bottleneck for the growth of potato processing industry in India. The Institute released India's first 2 processing varieties, 'Kufri Chipsona-1' and 'Kufri Chipsona-2' in 1998 and an improved processing variety 'Kufri Chipsona-3' in 2005. The introduction of Chipsona varieties, although, provided suitable raw material, but fresh

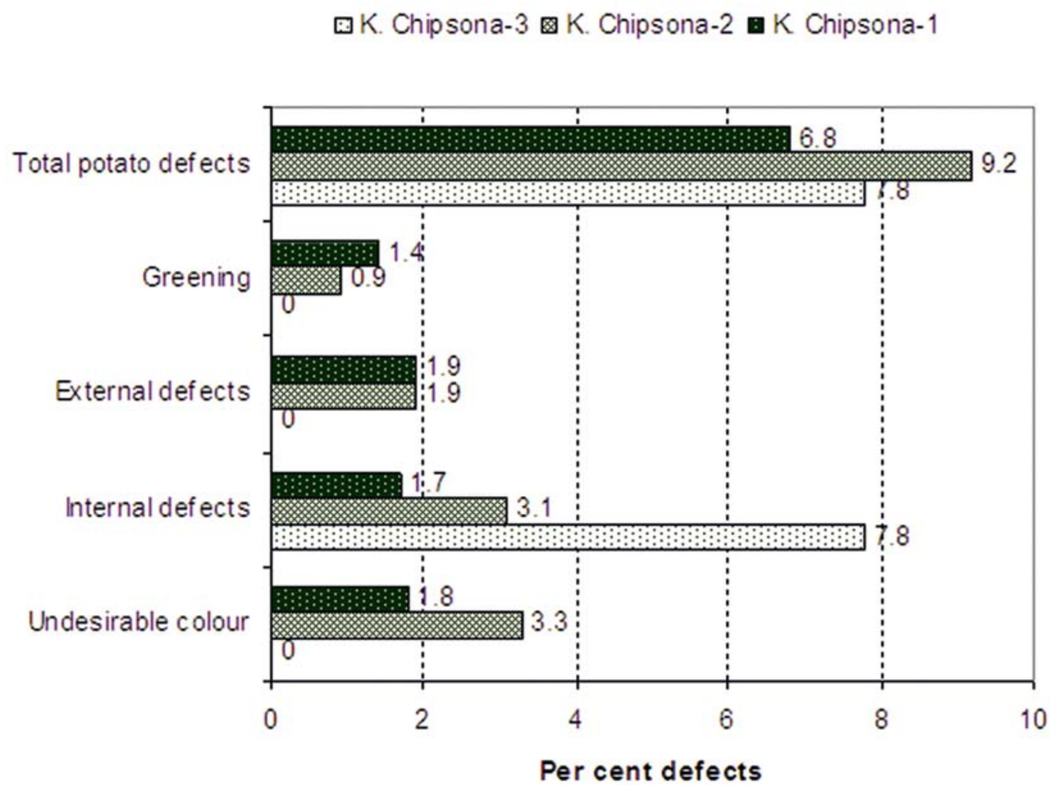

Fig. 2 Per cent defects observed in potato chips prepared from Chipsona varieties during industrial testing

potatoes of these varieties remain available for a short span of 3–4 months (January to April) and this is not enough to sustain the industry. Therefore, to ensure round the year availability of potatoes to the industry, medium to long-term storage (4–10 months) is required. Storage of potatoes at 2–4°C, although, is very effective and prevalent, but it results in excessive accumulation of reducing sugars due to a phenomenon known as "low temperature sweetening" (Duplessis et al. 1996, Edwards et al. 2002). Tubers with high sugars are of no use to the industry as these produce undesirable dark colour in fried products. High temperature storage, although suitable for processing, but has its own limitations as it causes shrinkage, rottage, and sprouting resulting in high weight losses and tubers can be stored only up to 3 months (Mehta and Singh 2002). Therefore, processing potatoes are stored at 10–12°C with CIPC, but best processing varieties also produce satisfactory chips only up to 5–6 months (Kumar and Ezekiel 2005). Thus, the unavailability of processing potatoes in desired quantities throughout the year remained the major bottleneck for the growth of industry even after the development of indigenous processing varieties.

Challenges ahead

Arranging round the year supply of processing varieties to the industries: Presently, 'Kufri Chipsona-1' and an exotic variety 'Atlantic' are the major sources of raw material for processing industries located in Northern India. The industries get fresh supply of these varieties from January to March from North-Western and West-Central plains (Pandey et al. 2004). From April onwards, the industries utilize potatoes of these varieties stored at intermediate temperatures (10–12°C) with CIPC. However, after July, these varieties also start accumulating higher amounts of reducing sugars and the potatoes become unsuitable for processing. This is a very crucial period for the industry, since fresh potatoes are not available anywhere. During this period, processing industries located in the North have to procure potatoes from Hassan in Karnataka spending huge expenditure on transportation thus leading to increased cost of production (Kumar et al. 2007a). So, there is an acute shortage of processing potatoes from July to December in the vicinity of industries. The industries are in search of alternatives which can provide potatoes throughout the year at reasonable price.

Developing suitable varieties for French fries: Frozen French fries is the most popular processed product of potato throughout the world. It is estimated that nearly 60–70% of total world output is shared among U.S, Canada and the Netherlands. However, of late there is an increasing demand of frozen potato products in the developing Asian and Latin American countries. China and India have the potential for growth of frozen potato products where economic boom is likely to generate strong demand for convenience foods. In

India, there are only 4 or 5 French fry industries, but even these are either working under capacity or not producing fries of international standards. The industry is mainly dependent upon variety 'Kufri Chipsona-1', which although has good fry quality, but the proportion of fry grade tubers in the total yield is low (Kumar et al. 2004a). Another newly released heat tolerant variety 'Kufri Surya' has oblong tubers, but has lower total solids (Patel et al. 2005). India needs an exclusive French fry variety which can provide suitable material to the industry. Potatoes designed for French fries must have certain quality attributes viz. oblong to long-oval tubers, preferably >75 mm length, shallow eyes, >20% dry matter and low reducing sugars (<0.1% on fresh wt basis) so as to yield fries of international quality (Marwaha et al. 2003). Non-availability of desired raw material is the major bottleneck impeding the growth of French fry industry in the country. The available varieties either do not have desired tuber size or have poor processing quality. Therefore, development of a French fry variety is essential for the expansion of French fry industry in the country.

Developing early maturing processing varieties: Development of Chipsona varieties, although, provided a boon to the potato processing industry in India, however due to changing climatic conditions and requirements of the industry, early maturing potato varieties are in demand. The potato growing season is shrinking because of global warming, recurrent frosting in North-Western and North-central plains and late blight infection. Growers also demand potato varieties which can fit well in different cropping systems. Further, relatively warmer regions of the country like, Hassan and Chickmagalur districts in Karnataka and parts of Maharasthra and Jharkhand, where potato crop is grown during the *Kharif* season, face recurring infection with late blight at an early stage and therefore need varieties having shorter maturity period of 75–80 days.

Developing temperature insensitive processing varieties: Potato crop is grown throughout India in almost all the states having varied soil type and environmental conditions which greatly affect the yield and processing qualities of potatoes (Uppal and Khurana 2001). Variety and the temperatures prevailing during the growth and harvest are most important for obtaining potatoes suitable for processing (Marwaha 2001, Kumar et al. 2003). Regions of the country having mild climate with night temperatures not touching below 10°C generally produce tuber with high dry matter and low reducing sugars, which are prerequisite for processing (Ezekiel et al. 1999). Earlier, it was presumed that potatoes grown in the extreme cold conditions of North India were not suitable for processing due to low accumulation of dry matter and high reducing sugars. However, cultivation of Chipsona varieties exploded this myth, and it was proved that 'Kufri Chipsona-1', 'Kufri Chipsona-2' and 'Kufri Chipsona-3' were temperature insensitive varieties and can be grown in the entire cooler Northern plains for producing processing potatoes (Marwaha et al. 2005a). Experiments conducted with Chipsona varieties harvested on different dates after planting in main crop season in the North Western plains at Jalandhar revealed that these varieties were insensitive to low temperature and produced higher tuber yield, >20% dry matter and acceptable chip colour at all the stages (Table 8). The exotic varieties, 'Atlantic' and 'Frito Lay 1533', also produced acceptable quality potatoes, but their yields were low. The exotic varieties were highly susceptible to late blight disease necessitating additional expenditure on crop protection. The commonly cultivated Indian varieties 'Kufri Jyoti' and 'Kufri Lauvkar' were not suitable for making chips. Likewise, all 3 Chipsona varieties grown in West-Central plains also produced excellent quality tubers at all stages of harvest with very low reducing sugars and higher dry matter (Table 9). Although, Chipsona varieties produced good processing quality potatoes in cooler North-Western plains including Punjab, there is an urgent need to develop more temperature insensitive varieties, which should have shorter maturity period of 75–80 days as against 90–100 days for Chipsona varieties (Sandhu et al. 2008).

Breeding varieties resistant to cold sweetening: Potatoes being semi-perishable in nature are normally stored in the cold store (2–4°C) to prevent post-harvest losses. However, during cold-storage, reducing sugars accumulate in high amounts in potato due to a phenomenon known as 'cold-induced sweetening'. Sweetened potatoes are unsuitable for processing because of development of unwanted brown colouration in processed products. This is a very serious problem for the potato industry. All the currently used Indian processing varieties are susceptible to cold sweetening and need to be stored at intermediate temperature (10–12°C) with a sprout suppressant, CIPC (Singh et al. 2004, Kumar and Ezekiel 2005). The use of CIPC adds to the cost of storage and with the increasing food safety and environmental concerns, there is likely to be limited scope for the use of sprout suppressants in the future (Marwaha et al. 2008c). High temperature storage, although, suitable for processing potatoes, but is only good for 2–3 months (Ezekiel and Dahiya 2004). Under these conditions, it is imperative to identify new varieties which are resistant to cold sweetening and could be used round the year. Development of cold-chipping processing varieties will have a substantial effect on the processing industries and potato growers.

Zone specific breeding for processing varieties: Potato in India is grown under diverse agro-climatic conditions where planting and harvesting periods are entirely different. In hills, it is grown during March-April to August-September, while in the Indo-Gangetic plains, it is grown during October-November to January-February. In certain states, like Karnataka, Maharasthra and Jharkhand, it is grown during *Kharif* or rainy season from June-July to September-October. The crop raised during *Kharif* at high temperatures and humidity is seriously affected with late blight, insects/

Table 8 Processing traits of varieties harvested at different time intervals in the main autumn season in cooler North-Western plains

	Days after planting (DAP)		
Cultivar (C)	70	80	90
Chip colour[1]			
'Kufri Chipsona-1'	2.6	2.3	3.0
'Kufri Chipsona-2'	2.5	2.4	2.0
'Kufri Chipsona-3'	3.0	2.5	2.0
'Kufri Jyoti'	7.0	6.5	6.0
'Atlantic'	4.0	1.6	2.0
'Frito Lay 1533'	4.0	3.5	3.0
CD (5%)	DAP = 0.15	C = 0.23	DAP × C = 0.37
Tuber dry matter, %			
'Kufri Chipsona-1'	20.5	20.6	21.0
'Kufri Chipsona-2'	21.6	22.0	22.1
'Kufri Chipsona-3'	20.8	20.9	21.6
'Kufri Jyoti'	17.0	17.4	17.0
'Atlantic'	21.2	21.1	21.7
'Frito Lay 1533'	19.7	20.3	21.1
CD (5%)	DAP = 0.17	C = 0.23	DAP × C = 0.4
Reducing sugars, mg/100 g tuber fr wt			
'Kufri Chipsona-1'	36	42	48
'Kufri Chipsona-2'	128	34	19
'Kufri Chipsona-3'	98	52	42
'Kufri Jyoti'	226	170	168
'Atlantic'	155	52	21
'Frito Lay 1533'	133	56	20
CD (5%)	DAP = 3.0	C = 3.8	DAP × C = 6.5
Sucrose, mg/100 g tuber fr wt			
'Kufri Chipsona-1'	345	466	246
'Kufri Chipsona-2'	622	500	228
'Kufri Chipsona-3'	443	405	261
'Kufri Jyoti'	351	342	263
'Atlantic'	402	365	234
'Frito Lay 1533'	307	301	212
CD (5%)	DAP = 9.0	C = 12.0	DAP × C = 23.0

[1]On a 1–10 scale of increasing dark colour, chip colour score up to 3 was acceptable, (n=4)

pests and viral diseases and requires number of chemical sprays which adds greatly to the cost of cultivation. To overcome the zone related problems, it is desired that the selection should be started from the first generation in the target environment or in the particular zone so as to make rigorous selection by exposing the plants to the serious diseases and insects, pests prevalent in that area. This will help in developing specific variety suited for a particular zone. There is an urgent need to breed heat tolerant early-maturing potato varieties for the South peninsular region.

Developing yield and quality enhancing technologies in processing varieties: Since processing varieties generally yield less than table/ware varieties, it is imperative to develop and diffuse suitable yield-enhancing technologies. Agronomic practices have been traditionally standardized for growing seed and table potatoes, but different package of practices is required for the production of processing grade and high specific gravity/dry matter potatoes meant for processing (Kumar et al. 2004b). 'Kufri Chipsona-1', a much sought after variety for chipping in different states, produces low proportion of processing grade tubers at some places. Realizing this limitation, there is a need to refine nutrient management, crop geometry and population density for getting higher tuber yield, productivity and quality.

Table 9 Processing traits of varieties harvested at different time intervals in the main autumn season in cooler West-central plains

	Days after planting (DAP)		
Cultivar (c)	90	100	110
Chip colour[1]			
'Kufri Chipsona-1'	1.2	1.2	1.0
'Kufri Chipsona-2'	2.7	1.9	1.4
'Kufri Chipsona-3'	2.1	1.3	1.0
'Atlantic'	1.0	1.2	2.1
CD (5%)	DAP = 0.22	C = 0.25	DAP × C = 0.43
Tuber dry matter, %			
'Kufri Chipsona-1'	20.7	21.4	21.7
'Kufri Chipsona-2'	21.6	21.9	23.1
'Kufri Chipsona-3'	20.5	21.6	22.4
'Atlantic'	20.4	21.1	21.4
CD (5%)	DAP = 0.2	C = 0.23	DAP × C = 0.4
Reducing sugars, mg/100 g fresh tuber wt			
'Kufri Chipsona-1'	34.7	24.2	18.0
'Kufri Chipsona-2'	60.8	27.8	25.8
'Kufri Chipsona-3'	57.2	20.5	22.6
'Atlantic'	16.3	35.9	63.0
CD (5%)	DAP = 5.5	C = 6.3	DAP × C = 10.9
Sucrose, mg/100 g fresh tuber wt			
'Kufri Chipsona-1'	189	172	167
'Kufri Chipsona-2'	246	198	161
'Kufri Chipsona-3'	196	157	142
'Atlantic'	174	184	174
CD (5%)	DAP = 8.3	C = 9.6	DAP × C = 16.7
Free amino acids, mg/100 g fresh tuber wt			
'Kufri Chipsona-1'	949	908	923
'Kufri Chipsona-2'	1000	895	978
'Kufri Chipsona-3'	854	777	848
'Atlantic'	839	889	829
Total phenols, mg/100 g fresh tuber wt			
'Kufri Chipsona-1'	16.3	15.6	13.7
'Kufri Chipsona-2'	14.4	15.7	15.0
'Kufri Chipsona-3'	18.4	17.9	16.2
'Atlantic'	14.8	15.2	16.8
CD (5%)	DAP = 1.0	C = 1.1	DAP × C = 1.9

[1]On a 1–10 scale of increasing dark colour, chip colour score up to 3 was acceptable, (n=4)

The progress in yield-enhancing technologies must be compatible with suitable quality-enhancing technologies.

Finding low-cost alternative storage technology for processing potatoes: Post-harvest management of bulky and perishable potatoes had been a challenging task for the scientists and policy makers entrusted to popularize this crop among the growers as well as consumers. Potatoes need refrigerated storage under sub-tropical summer conditions. It would be unrealistic to say that the development and spread of cold-storage facilities have been commensurate with overall potato growth and development in India, but it is equally true that government-supported synergy between public and private investments has played a significant role in establishing a cold-chain in the country, although its distribution still continues to be uneven (Pandey et al. 2006a). Nation-wide cold-storage facilities have been responsible for stabilizing potato prices, which used to crash every year at harvest. But processing potatoes require stores maintained at 10–12°C with CIPC which are still in shortage in central and Northern India. In the areas where there is shortage of 10–12°C stores, processing varieties like, 'Kufri Chipsona-1', 'Kufri Chipsona-3' and 'Kufri Himsona', can be conveniently stored for 90 days in the traditional on-farm storage without involving much expenditure. There is an immediate need to develop efficient cost-effective non-refrigerated storage structures for processing potatoes utilizing passive evaporative cool stores and traditional *kutcha* storage facilities. Besides, improved traditional on-farm storage methods like heaps and pits, which are economical, should be developed for small and marginal farmers unable to afford expensive cold-storage facilities.

Improving infra-structure facilities for frozen fried potato products: Many of the developing countries have now improved transportation facilities, which have partly been possible due to rapid infrastructural development such as construction of roads/broadways linking the production and marketing centres as well as rural and semi-urban/urban areas under various developmental projects funded by UNDP, World Bank and IMF. For example, in India, rapidly expanding potato-based processing sector owes much of its success to improved transportation facilities linking the production areas of processing potatoes to the processing units distantly located in industrial urban/semi-urban areas. Good quality processing potatoes produced in North-Western Indo-Gangetic plains are transported to the processing units located in and around Delhi. There are ample facilities for transport of packaged chips and dehydrated potato products, but there is an acute shortage of refrigerated vans for transport of frozen French fries from production centres to big cities. High cost of establishing the refrigerated stores in the French fries plants and lack of refrigerated vans are the main factors responsible for less popularity of frozen fries in India, although these hold a better edge over chips due to their filling properties and low oil content. The Government is giving subsidy on the installation of food processing plants, but much needs to be done to promote the French fry industries in India. The long-term governmental policies towards development of infrastructures and subsidies will prove to be vital for sustaining potato processing industry in the developing countries, particularly India.

Developing inexpensive technologies for the production of diverse potato products: In contrast to many developed countries, consumption of potato in India is very low as it is consumed mainly as a vegetable. The high price of processed potato products viz., chips and French fries in comparison to cereal-based processed products is an important factor limiting their consumption by a majority of Indian population with low income levels (Pandey et al. 2005d). To make processed products available to a large section of the population at an affordable price, there is a need to develop indigenous technologies for the production of inexpensive potato products such as dehydrated potato chips and cubes, which are easy to prepare, and can be produced at a cottage industry level. There is an enormous scope for this sector to be sustained at the village level by forming rural cooperatives in India. There is also need for developing more novel potato products, which are nationally/internationally acceptable, economically viable, healthy and environment friendly. This will connect the poor small and marginal farmers to the markets. Enhanced direct market accessibility may prove to be beneficial to these millions of poor farmers struggling to survive in complex socio-economic background.

Providing low calories, antioxidant rich fried products to the consumers at affordable price: As stated above, there is an acute scarcity of good quality raw material for the industries during the months of August to December and several processing units located in North-Western plains (M/s Pepsi Foods Pvt. Ltd., Sangrur, Punjab); M/s Haldiram Snack Pvt. Ltd., Noida; M/s Jainco Foods Ltd., Faridabad; M/s Kakaji Namkeen and Sweets, Delhi; M/s Wimpi International Ltd., New Delhi; M/s Nirulas, Delhi) have to transport very large quantities of potatoes from far away places in MP and Karnataka involving very high transportation cost. This involves huge transportation cost reflecting in near unaffordable prices of potato chips for the common man. Secondly, the only variety 'Kufri Jyoti' (having <18% dry matter) available from MP and Karnataka during this period produces lower yield of chips which absorb high oil (38–40%) on frying and provide high calories on consumption. There is a need to provide high dry matter varieties to the industries during this period which will be economical to the industries and the consumers will get low fat fried products.

Of late, the consumers have become very conscious about the nutritional status of processed products and there is an awareness and interest in the presence of antioxidants in the diet. Potatoes contain significant levels of phenolic compounds and vitamin C as potent antioxidants, which inactivate reactive oxygen species, reduce oxidative damage, lead to improved immune functions and reduce risk of several chronic and metabolic disorders, such as cardiovascular diseases, cancer, cataract, diabetes and aging (Brown 2005, Singh et al. 2005a). Since potatoes are consumed as a main vegetable in the developing countries, they form an important source of antioxidants. Secondly, keeping in view the changing taste and calorie consciousness of the people, it is very important to market superior quality, low fat chips at a reasonable price. This is only possible, if high dry matter and low sugar potato varieties are available to the industries. There is also an immediate need to identify Indian varieties which contain high antioxidants.

Future projections of processing activity in India

Potato processing is increasing at fast pace in India after liberalization of economy and availability of suitable raw material. Currently 2% of the total produce is processed in organized sector and almost similar quantity is processed in unorganized sector (Rana and Pandey 2007). The utilization of raw material by the organized potato processing industry in India has increased from 1.25 lakh tons in 2003 to 4.40 lakh tons in 2007 and the total consumption of potatoes in the organized and unorganized sector is expected to be about 17.40 lakh tons in 2010 which will be > 6% of the total potato production (Rana and Pandey 2007).

Growth rate of potato processing in organized sector is approximately 25% which is likely to continue for the next 5 years, placing lot of demand on quality processing raw material. Amongst various processed products, French fries are in great demand. The internal demand of French fries in the country is around 8700 MT per annum, which is expected to increase to 24000 MT by 2010–2011 (Singh et al. 2008b). There is a need to meet this demand through indigenous production of fries which will not only cut down on the cost of fries in the retail chain, but also save millions of rupees on foreign exchange through reduced imports. The demand of potato flakes is growing continuously in India due to increased usage of fried snacks (*Alu Bhujiya*), extruded products, soup powders, pasta, fabricated chips and French fries. India presently imports about 3500 MT of potato flakes every year, although, there are 4 big flakes manufacturing industries in the country (Marwaha et al. 2008f). According to projections, India which presently produces about 25 million tonnes of potato would be producing about 50 million tonnes by year 2020 (CPRI 1997). Potato processing, therefore, will be essential to sustain the present rate of growth of production which is likely to increase further. A conservative estimate shows that nearly 10% of this projected potato production (5 million tonnes) will account for processing.

Future vision and remedies to meet challenges

The Institute has a clear vision and has formulated several plans to meet the arising challenges. It has already started working on some of the problems and has geared up to solve the remaining ones in the shortest possible time. Some of the strategies to solve the problems of the industry and to achieve the targets are as follows.

For arranging regular supply of processing potatoes to the industry round the year, we have identified different locations in the country which produce high dry matter and low reducing sugars.

During 2004–2008, potato samples of processing and table varieties grown in 106 districts in 11 states were assessed for chip colour, dry matter and reducing sugars and the data were compiled and developed in the form of national potato maps (Marwaha et al. 2008a). This information will help the industries located in different parts of the country to procure potatoes from nearby places and to plan assured supply of required raw material throughout the year. The study demonstrated that Malwa region of Madhya Pradesh viz., Indore, Ujjain and Dewas districts and Kota district in Rajasthan produced excellent quality processing potatoes with very high dry matter and lowest reducing sugars and would be the favoured places for the procurement of potatoes by the processing industries. The processing potatoes from these places can be stored at 10–12°C with CIPC to produce good quality chips for a longer period. Likewise, Nagrota block in Kangra district of Himachal Pradesh can supply processing potatoes in June and July to the industries, although the dry matter content of the commonly cultivated variety ‘Kufri Jyoti’ is not high. In Karnataka, Hassan, Chickmagalur, Belgaum and Dharwad districts, which grow *Kharif* crop of potato are most important places for supplying suitable raw material to the industries in the months of August-November, when fresh processing potatoes are not available anywhere.

Normally, processing industries located in different parts of the country prefer to procure potatoes from the nearby areas to reduce the cost of transportation. The findings suggested that processing potatoes grown even in the cooler North-Western plains of Punjab and UP can be used by the processing industries after following proper package of practices and post-harvest measures. The study further indicated that good quality processing potatoes can be grown in the states of Bihar, West Bengal and Assam, which can supply suitable raw material to the industries located in the Eastern states (Marwaha et al. 2007a, 2007c).

Based on exhaustive survey, we have formulated a comprehensive scheme for supplying processing potatoes to the industries round the year (Fig. 3). As per the scheme, the processing units located in and around Delhi and in North-Western plains can get processing potatoes from Punjab and Agra and Meerut commissioneries in Western Uttar Pradesh right in the vicinity for about 6 months. This would not only ensure a steady supply of raw material to the processing units from November to April, but will provide the much needed raw material at a cheaper transportation cost. From April to July, the industries can utilize the potatoes stored in 10–12°C stores with CIPC in their vicinity. During the crisis months of shortage of raw material from August to December, they can purchase processing potatoes from July/August to October from Kangra and Mandi districts in Himachal Pradesh, a nearby state instead of purchasing from Karnataka. This would curtail a lot of expenditure on long transportation of potatoes. The Institute has released ‘Kufri Himsona’, the first potato chipping variety for the hills, which can be procured by the industry. For lean period in November-December, the chipping industries can procure ‘Kufri Surya’, a heat tolerant variety, which gives high yield in 75 days and produces good quality chips during early autumn planting in September in Hoshiarpur and Jalnadhar districts of Punjab (Pandey et al. 2005c). This scheme is viable, economical and can provide processing potatoes to the industries round the year.

To meet the demand of French fry industries, we have identified an advanced hybrid MP/98-71, which produced high French fry grade tuber yield, high dry matter and

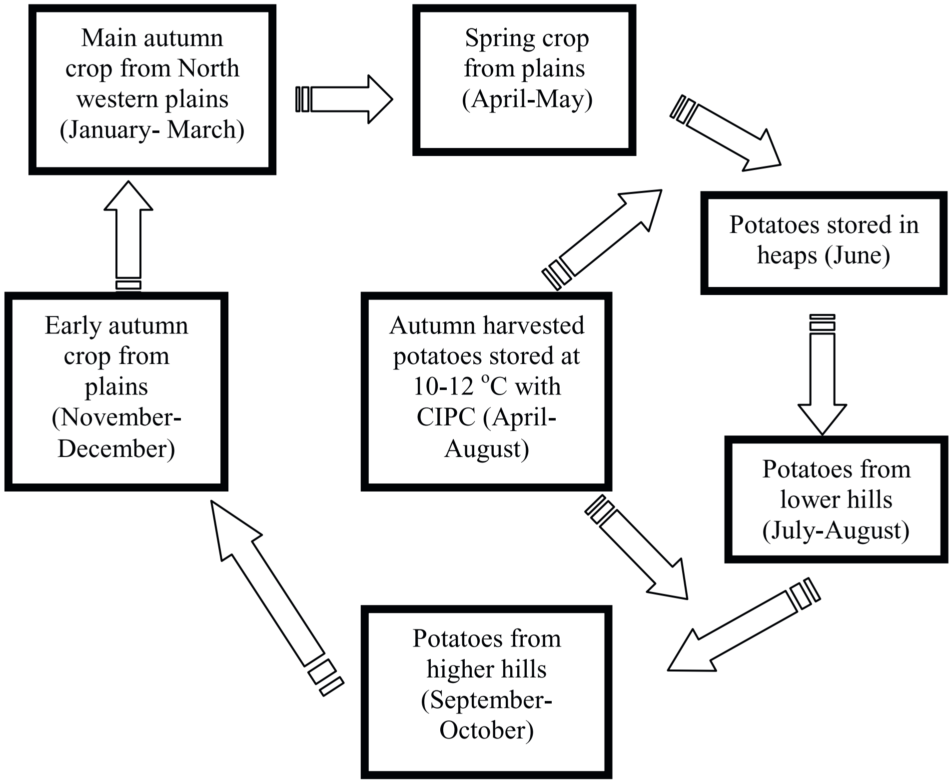

Fig. 3 Proposed comprehensive scheme for supplying processing potatoes to the industries round the year

Table 10 Tuber yield and French fry quality of advanced processing hybrid 'MP/98-71' and varieties grown in North-Western plains

Variety	Total yield, t/ha	French fry grade tubers, %	Fry colour[1]	Dry matter, %
'MP/98-71'	45.5	67.5	2.5	23.5
'Kufri Chipsona-1'	43.9	47.3	1.8	21.6
'Kufri Chipsona-3'	40.0	48.3	2.8	22.1
'Kufri Surya'	40.8	70.0	5.5	19.5
CD (5%)	2.04	2.7	0.3	0.7

[1]On a 1–10 scale of increasing dark colour, fry colour >3 was unacceptable, (n=4)

Table 11 Tuber yield and French fry quality of advanced processing hybrid 'MP/98-71' and varieties grown in West-central plains

Variety	Total yield, t/ha	French fry grade tubers, %	Reducing sugars, mg/100 g	Fry colour[1]	Dry matter, %
'MP/98-71'	35.2	59.9	94.7	1.5	22.8
'Kufri Chipsona-1'	29.1	33.1	22.8	1.0	21.4
'Kufri Surya'	34.5	57.2	53.4	1.0	20.1
'Kufri Anand'	34.2	45.2	196.8	3.2	18.5
'Kufri Sutlej'	30.7	52.1	105.4	3.4	18.9
CD (5%)	3.1	3.4	52.9	0.6	0.8

[1]On a 1–10 scale of increasing dark colour, fry colour >3 was unacceptable, (n=4), Fresh weight basis

superior fry colour at different locations in India (Table 10, 11) and is likely to be released shortly (Marwaha et al. 2008h, Singh et al. 2008b). The development of this hybrid as a variety will not only meet the internal requirements of the country, but would also earn foreign exchange.

The Institute has developed a promising advanced hybrid 'MP/01-916' for warmer regions of peninsular India for the *Kharif* season and has been evaluated at different locations in Hassan and Chickmagalur in Karnataka, parts of Maharasthra and Jharkhand (Marwaha et al. 2008g). At Hassan, this hybrid produced maximum total yield (146.1 q/ha) and processing grade tuber yield (68.1 q/ha), very good chip colour (2.0), maximum tuber specific gravity (1.083) and dry matter (24.3%), high chip yield (25.3%) and contained low level of reducing sugars (28 mg/100 g fresh wt), minimum content of total phenols (38.6 mg/100 g fresh wt) and was moderately resistant to late blight (Fig. 4, Table 12, 13). Conversely, 'Kufri Jyoti', a popular variety in Karnataka produced lower total yield (114.3 q/ha) and processing grade tuber yield (58.6 q/ha), showed minimum tuber specific gravity (1.055) and dry matter (16.9%) and produced unacceptable chip colour (Marwaha et al. 2008g).

Although, 'Kufri Chipsona-1', 'Kufri Chipsona-2' and 'Kufri Chipsona-3' are temperature insensitive varieties and can be grown in the entire cooler Northern plains for producing processing potatoes, emphasis is on to develop more temperature insensitive short duration early maturing varieties. The Institute has developed 5 short duration chipping hybrids viz., MP/2000-516, MP/01-916, MP/01-1006, MP/01-1142 and MP/02-105, which are under advanced stages of evaluation and are giving high yields in 75 days.

The Institute is working on the development of cold chipping varieties and after evaluation of 911 germplasm

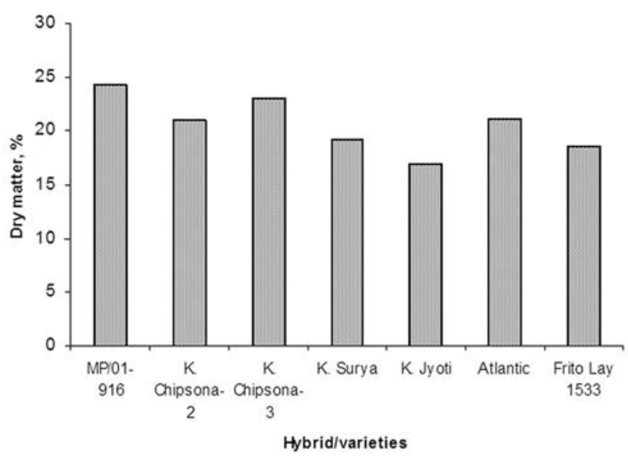

Fig. 4 Dry matter content of tubers of 'MP/01-916' and other varieties

accessions and 216 andigena germplasm accessions have identified one tuberosum germplasm accession namely 'CP 3103' (Pandey et al. 2005b) and two andigena cultures viz., 'JEX/A 663' and 'JEX/A 785' (Marwaha et al. 2008e), which are cold chippers and produce very good chip colour after 6 months of cold storage (2–4°C) followed by 4 weeks of reconditioning at 20°C. These accessions are being exploited as parents in the breeding program to develop cold sweetening resistant lines. Different biotechnological approaches are also being employed to target genes encoding two different rate limiting enzymes of the cold-sweetening pathway, vacuolar acid invertase (INV) and UDP-glucose pyrophosphorylase (UGPase). Reduction of INV level has been attempted either by inhibition of enzyme activity at the post-translational level by over-expression of a tobacco gene encoding inhibitor protein called vacuolar invertase inhibitor (*Nt-Inhh*); or by silencing of *INV* gene expression at the post-transcriptional level through RNA interference (RNAi), artificial microRNA (amiRNA) or ribonuclease P (RNase P)-mediated silencing (Chamail et al. 2008). Reduction of UGPase enzyme level is being attempted by silencing of the gene either at the transcriptional level (Transcriptional Gene Silencing) by introduction of intron containing inverted repeat gene construct against UGPase promoter or at the post-transcriptional level (PTGS) by introduction of amiRNAs against *UGPase* gene. Tobacco invertase inhibitor (*Nt-Inhh*) and INV RNAi transgenic lines are at glasshouse stage of evaluation, while rest of the transgenic lines are at laboratory stage of development. Emphasis is being laid on zone specific breeding for varieties. In the first instance, keeping in view the serious problems such as late blight, viruses and insects/pests of the warmer peninsular regions of the country, the Institute has finalized to breed varieties specific for such problematic regions.

Yield and quality enhancing technologies such as nutrient management, crop geometry and population density have been standardized for processing varieties, particularly for 'Kufri Chipsona-1', which is being used both for chips and French fries. It is recommended that nitrogen should be applied at the rate of 270 kg/ha to achieve maximum proportion of processing-grade tubers (84%) and total yield,

Table 12 Yield and late blight score of processing hybrid 'MP/01-916'and varieties grown in Hassan (Karnataka)

Hybrid/varieties	Tuber Yield, q/ha	Processing grade tuber yield, >45 mm, q/ha	Non- processing grade tuber yield, <45 mm, q/ha	Late blight score[1]
'MP/01-916'	146.1	68.1	78.0	6
'Kufri Chipsona-2'	138.1	47.4	90.7	4
'Kufri Chipsona-3'	111.9	29.6	82.3	5
'Kufri Surya'	104.7	52.9	51.8	2
'Kufri Jyoti'	114.3	58.6	55.7	3
'Atlantic'	100.5	51.4	49.1	1
'Frito Lay 1533'	89.6	53.1	36.5	2
CD (5%)	17.5	15.9	13.2	-

[1]Where 1 is susceptible and 9 is resistant, (n=4)

high dry matter/specific gravity, permissible level of low reducing sugars and superior chip colour both at the time of harvest and after storage at 10–12°C with CIPC (Kumar et al. 2007b). Phosphorus and potassium should be applied at the rate of 80 kg P_2O_5/ha and 150 kg K_2O/ha to obtain maximum yield and high yield of processing grade tubers (Kumar et al. 2004c, 2005c). Application of potassium as potassium sulphate is more beneficial than potassium chloride as it increases the tuber dry matter content and recovery of chips, besides reducing oil absorption in chips on frying (Kumar et al. 2007a). Planting should be done at a inter and intra-row spacing of 67.5 × 26.5 cm for French fry-grade tuber production and 67.5 × 20 cm for production of chipping grade tubers for all the Chipsona varieties (Kumar et al. 2004a).

Improved low-cost non-refrigerated storage technology for processing potatoes in the heaps with CIPC treatment has been developed, where potatoes can be stored up to 90 days with total tuber losses <7–8% (Mehta and Ezekiel 2008). This is particularly useful for small farmers who cannot afford storing potatoes in 10–12°C stores. Following this method, the farmers can hold the produce for 3 months and sell at a time when the prices are high. Heap storage without CIPC treatment is quite popular in several parts of the country because this technology is cheap and heaps can be prepared easily with locally available materials (Ezekiel and Dahiya 2004, Kumar et al. 2005a). Heaps maintain lower temperature and higher relative humidity as compared to ambient conditions and help in maintaining low reducing sugar levels in potatoes (Marwaha 2002, Kumar and Ezekiel 2006). The experiments on traditional storage demonstrated that potatoes meant for ware market or cottage level processing (like *Alu Bhujia, Tikkis, Samosas*) can be stored on-farm in heaps at a low cost and supplied to the local markets and un-organised processing industries at premium price as these contain low sugars (Kumar and Ezekiel 2005). Varieties like 'Kufri Chipsona-1', 'Kufri Chipsona-3' and 'Kufri Himsona' were found to be most suitable for heap storage.

The Institute has developed simple technologies for the production of dehydrated chips, cubes, *warris, papads*, flour and starch from potatoes at the cottage industry level (Marwaha and Sandhu 2003a, b, Marwaha and Pandey 2006). Twenty six value added fried and non-fried potato products have been developed and out of which two products, especially potato custard powder and dehydrated chips, have potential for commercialization (Marwaha et al. 2006). These products are easy to prepare, and can be scaled up for commercial ventures by unemployed rural youths and village women. Inexpensive dehydrated processed products can sustain the indigenous markets essentially comprising the low-income population and their production at the rural

Table 13 Processing attributes of processing hybrid 'MP/01-916' and varieties grown in Hassan (Karnataka)

Hybrid/varieties	Chip Colour score[1]	Reducing sugars[2]	Sucrose[2]	Free amino acids[2]	Total phenols[2]
'MP/01-916'	2.0	28	188	489.8	38.6
'Kufri Chipsona-2'	1.5	23	155	742.0	52.3
'Kufri Chipsona-3'	2.0	15	158	620.2	58.0
'Kufri Surya'	4.0	21	186	784.8	90.0
'Kufri Jyoti'	4.75	70	151	739.0	89.2
'Atlantic'	2.0	52	218	633.9	53.4
'Frito Lay 1533'	1.0	18	112	659.2	53.2
CD (5%)	0.2	17.5	15.9	13.2	3.2

[1]On a 1–10 scale of increasing dark colour, chip colour score up to 3 was acceptable, (n=4)
[2] mg/100 g fresh tuber wt

Table 14 Antioxidant compounds and processing parameters of Indian and exotic varieties grown in North-Western plains

Varieties	Total phenols, mg/100 g	Vitamin C, mg/100 g	Total carotenes, µ g/100 g	Dry matter, %	Chip colour[1]	Chip yield, %	Oil in chips, %
'Kufri Chipsona-1'	34.9	12.3	41.1	22.1	2.5	29.3	33.9
'Kufri Chipsona-2'	41.2	14.4	52.8	23.1	2.5	29.7	32.3
'Kufri Chipsona-3'	45.5	11.3	51.3	21.9	3.0	28.9	33.6
'Kufri Surya'	58.0	14.9	147.4	19.5	4.0	26.8	35.9
'Kufri Jyoti'	57.7	16.3	35.7	17.2	5.5	25.9	38.1
'Atlantic'	40.9	10.6	39.5	22.6	2.8	29.9	34.3
'Frito Lay 1533'	21.1	11.6	41.4	22.1	2.5	30.1	34.2
CD (5%)	2.2	0.81	3.7	1.2	0.2	1.1	1.8

[1]On a 1–10 scale of increasing dark colour, chip colour score up to 3 was acceptable, (n=4), All on fresh weight basis

level will avoid distress sale of potatoes at harvest by the small farmers and will bring remunerative returns. In addition, varieties suitable for chips, French fries, fried *Lachha*, flakes, flour and starch have been identified (Kumar Raj et al. 2004, Marwaha et al. 2005c, 2006, 2007b, Singh et al. 2005b).

In order to reduce the cost of production of industries and to provide processed products to the consumers at affordable price, it is essential that the desired raw material is available to the industries at cheap price throughout the year. For this, the industries during the crisis months of August to December, should procure raw material from the identified places. This is one way of reducing the cost of production by the industries. Secondly, the use of high dry matter and low sugar varieties such as Chipsona varieties and 'Kufri Himsona', would give high chip recovery and consume less oil resulting in significant saving for the industries. Our results show that varieties having high dry matter (>21%) produce higher yield of chips with 32.3–34.3% oil uptake, while 'Kufri Jyoti' with (<18%) dry matter produces chips which absorb 38.1% oil on frying (Table 14). Generally, with every 1% increase in tuber dry matter, there is about 0.75% increase in chip yield and about 1% reduction in oil content of chips (Gould 1999). The use of high dry matter varieties produce higher chip yield (3–4%) and absorb about 4–6% less oil which lowers the cost of production. The profit earned by the industries by using high dry matter varieties should be passed on to the consumers so as to boost the consumption of processed products and create more demand for future. Besides, use of high dry matter varieties will also provide low fat and low calorie product to the consumers which will be preferred by the health conscious people. As regards antioxidants, the study revealed that processing varieties, 'Kufri Chipsona-1', 'Kufri Chipsona-2', 'Kufri Chipsona-3', 'Atlantic' and 'Frito Lay 1533' contained lower amounts of antioxidants namely, total phenols, vitamin C and total carotenes, while 'Kufri Surya' and 'Kufri Jyoti', although, unsuitable for processing, contained high levels of two/three antioxidants and were most suited for table consumption (Table 14).

Recently, antioxidant rich purple coloured potatoes are being marketed for table consumption in Japan, Canada and the US and chips made from these potatoes are also being sold by several companies in the US (Eijck 2008a). In order to provide antioxidant rich processed products to the Indian consumers, six anthocyanin rich purple pigmented andigena cultures were identified by the Institute during 2007-08 and evaluated for chips (Marwaha et al. 2008d). All the six cultures produced chips in different colour and shades. Tubers of 'JEX/A 911' showed maximum dry matter content (24.8%) and produced most attractive chips having deep yellow colour with purple shade. It is likely that such coloured chips will also be popular in India in the near future.

Conclusion

Potato processing is very important in making India self-reliant in sustaining the food production and nutrition. Value added processed products are opening up new market avenues in the national and international markets, and as a result, the farmers are finding it highly remunerative to grow processing potatoes even in areas traditionally unknown to potato cultivation. Growing urbanization, changing food habits and preference for ready-cooked snacks have made potatoes to travel from kitchen and dining tables to pouches and packets liked by everyone. The national and multinationals potato processing companies in India now prefer indigenous processing varieties over exotic ones. There is a big market for inexpensive dehydrated potato chips, cubes and other products which can be easily prepared at the cottage industry level and can provide employment to the rural youth and village women. A comprehensive, viable and economical scheme for supplying processing potatoes to the industries round the year has been proposed which will help the industries in planning the supply from nearest locations. The new arising challenges have been highlighted and concrete remedial measures have been suggested. With all these developments, India is set to have a 'crunchy revolution'.

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