Development of processing potato cultivars by conventional and biotechnological approaches for the Indian subtropics

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The bulk of potato produced in India is utilized for table consumption. However, with the liberalization of economy, demand for processed potato products started increasing since 1990. At present, nearly 4-5% of the total produce is being processed and the processing sector is witnessing continuous growth. This created a demand for processing variety that can be grown under short-day condition with a growing period of 90-100 days. Therefore, an ambitious project on developing processing varieties suitable for growing under short-day winter months in subtropical plains was initiated that revolutionized the potato processing sector in India. The institute has so far developed four varieties suitable for processing into chips and one variety for French fries. These varieties are suitable for growing during winter months and give higher processing grade yield than any exotic variety within 90-100 days of growing period. Cold storage is an integral requirement of post-harvest handling of potato in India. Unfortunately, potato accumulates high amount of reducing sugars during cold-storage that makes it unfit for processing. This poses a serious impediment to otherwise fast emerging potato processing industry. It is not possible to develop cold-chipping potato cultivars through conventional breeding due to lack of suitable germplasm. Two different biotechnological approaches through metabolic engineering have been adopted to block the step leading to conversion of sucrose to reducing sugars either by inhibiting the vacuolar invertase activity, the enzyme responsible for synthesis of reducing sugars, or silencing of gene encoding potato vacuolar invertase (*INV*) at post transcriptional level.

Keywords: Indian processing varieties, Tuber characters, Potato products, Cold sweetening.

Potato is mainly consumed as a vegetable and forms an indispensable ingredient of Indian diet. However, with the liberalization of economy demand for processed potato products started increasing since early nineties, and several multinational companies (MNC) entered the field of potato processing. Since indigenous varieties were not suitable for producing quality processed products, the MNCs imported bulk 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 seed 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 (Pandey *et al.,* 2008a).

The European and American potato varieties are developed for long-day (about 14-16 hr photoperiod) and long crop durations of 120-180 days. But in India, the potatoes are grown mainly in sub-tropical plains in winter under short-day condition, very different from that prevalent during the potato crop season in temperate countries. Also, unlike temperate countries, where the potato harvest is followed by severe winter, the harvest in the plains of India is followed by hot summer, making post-harvest operations difficult (Table 1). Thus the variety and technological requirement of potato cultivation in India are totally different from those of temperate world (Marwaha *et al.,* 2005). Obviously, these important aspects were 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 even for processing into chips. The varieties like Kufri Jyoti and Kufri Lauvkar, procured mainly from warmer climate of Malwa region in Madhya Pradesh, (Ujjain, Indore), formed the main stay of the industry. The bulky and perishable raw material from these regions used to be transported at high cost over long distances to the industries located in north-western plains, which resulted in increase in the cost of production of products (Pandey *et al.,* 2005). Besides, these varieties contained low dry matter (<20%) and high reducing sugars (>0.1% on fresh wt basis), and produced chips of inferior quality.

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

Parameter	Sub-tropical	Temperate
Day/night temperatures	25-30 °C / 2-15 °C	15-25 °C / 15 °C
Photoperiod	9-11 hr/day	14-16 hr/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

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 an ambitious project for development of indigenous processing varieties in 1990. The breeding strategy involved - (a) identification of parents with high tuber dry matter and good general combining ability for yield; (b) hybridization in the hills at Kufri during summers and raising of the segregating progenies in the plains, the same year to save time; (c) assessment of segregating populations for as many easily identifiable characters (viz. tuber colour, shape, eye depth, specific gravity, late blight resistance, etc.) as possible in the initial stages to eliminate undesirable genotypes; (d) extensive evaluation of selected genotypes in subsequent generations for tuber dry matter, reducing sugars, chip colour and yield; and (e) final evaluation of selected hybrids under industrial processing conditions.

With consistent efforts of eight years and after sifting through several hundred thousand genotypes, India's first potato processing varieties christened as Kufri Chipsona-I and Kufri Chipsona-2 were released in 1998 (Gaur *et al.,* 1998, 1999). Both the varieties have high tuber dry matter, produce light colour chips, possess resistance to late blight and give good tuber yield. Of the two Indian processing varieties, Kufri Chipsona-1 became very popular with the farmers and industry. This variety is capable of producing high quality processing potatoes in all parts of the country besides giving high yields similar to popular table varieties of the region.

Release of two indigenous high yielding disease resistant processing varieties provided the much needed relief to processing industry. After cultivation of these varieties for 3-4 years, it has been realized that Kufri Chipsona-1 produces low proportion of processing grade potatoes at some place in India and Kufri Chipsona-2 has poor storability. Keeping above problems in view, another processing variety, Kufri Chipsona-3, was developed in year 2005 (Pandey *et al.,* 2006). This variety produces about 11-15 per cent more total and processing grade tuber yield than the best control variety Kufri Chipsona-1 by virtue of its larger tuber size. This variety has good storability and can be stored for longer period for use in processing (Kumar *et al.,* 2007). These attributes 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.

In order to provide suitable raw material to the processing industries located in the north-western plains during the crisis months of shortage from August to November, the Institute has released Kufri Himsona, the first potato chipping variety for the hills (Pandey *et al.,* 2008b), which can be grown in Kangra and Mandi districts in Himachal Pradesh and supplied to the industry.

To meet the demand of the French fry industries, an advanced hybrid MP/98-71 has been developed by the Institute, which has shown high French fry grade tuber yield, high dry matter and superior fry colour at different locations in India and has been just released as Kufri Frysona (Singh *et al.,* 2008).

Salient features of processing varieties

Kufri Chipsona-1: Kufri Chipsona-I is a selection from the progeny of the cross CP 2416 x MS/78-79 made in 1990. The plant has medium compact canopy with white flowers and the tubers are white cream, ovoid with shallow eyes and white flesh. The variety is well adapted to north-Indian plains and has a maturity period of 90-

110 days. It has resistance to late blight and gives an average yield of 30-35 t/ha and possess very good storability at ambient temperature.

Kufri Chipsona-2: Kufri Chipsona-2 is a selection from the progeny of the cross CP 2346 (F-6 from Peru) x QB/B 92-4 made in 1991. The plant has medium compact canopy with white flowers and the tubers are white cream, round with shallow eyes and creamy flesh. The variety is well adapted to north-Indian plains and has a maturity period of 90-110 days. It is resistant to late blight and gives an average yield of 30-32.5 t/ha.

Kufri Chipsona-3: Kufri Chipsona-3 is a selection from the progeny of the cross Kufri Chipsona-2 x MP/91-86 made in 1996. The plant has medium compact canopy with white flowers and the tubers are white cream, ovoid with medium-deep eyes and creamy flesh (Fig. 1). The variety is well adapted to north-Indian plains and has a maturity period of 90-110 days. It is resistant to late blight and gives an average yield of 35-40 t/ha and has good storability.

Kufri Himsona: Kufri Himsona is a selection from the progeny of the cross MP/92-35 x Kufri Chipsona-2. The plant has medium canopy with purple flowers and the tubers are white to creamy, round-oval with shallow eyes and cream pale yellow flesh. The variety is adapted to hilly regions of the country and has a maturity period of 120-140 days. It has field resistance to late blight and gives an average yield of 25 t/ha.

Kufri Frysona: Kufri Frysona is a selection from the progeny of the cross MP/92-30 x MP/90-94 made in 1998. The plant has medium compact canopy with light-red flowers with white tips and the tubers are white, oblong to long in shape with shallow eyes and white flesh (Fig. 2). The variety is well adapted to north-Indian plains and has a maturity period of 100-110 days. It is resistant to late blight and gives an average yield of 38-40 t/ha and has good storability.

Figure 1. Tubers of Kufri Chipsona-3

Figure 2. Tubers of Kufri Frysona

All the indigenous processing varieties viz., Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3 and Kufri Himsona contained 21-24% dry matter, <0.1% reducing sugars on fresh tuber weight basis, low phenols and produced high yield of light coloured chips (Marwaha *et al.,* 2008). Kufri Frysona had 23% dry matter and produced high yield of French fries having mealy texture which were of international quality (Table 2). Besides fried products, these processing varieties also produced higher yield of dehydrated products such as dehydrated chips, flour, flakes and starch (Table 3).

Table 2. Processing qualities of potato varieties and some advanced processing hybrids

Varieties/hybrids	Chips		French fries			
	Yield (%) on fresh tuber wt	Colour[1]	Yield (%) on fresh tuber wt	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 Frysona	30.1	4.0	46.7	LC	Crispy	HA
Kufri Surya	27.4	4.5	45.8	LY	Mealy	HA
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 (P • 0.05)	1.1	0.12	1.8	-	-	-

[1]On a 1-10 scale of increasing dark colour, chip colour score >3 was unacceptable
LC, Light cream; MB, Medium brown; LY, Light yellow; HA, Highly acceptable; A, Aacceptable

Table 3. Yield (on fresh tuber wt) and quality of dehydrated products prepared from Indian processing and table varieties

Varieties	Yield of dehydrated chips (%)	Colour of dehydrated chips	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 (P • 0.05)	0.82	-	0.61	0.73	0.45

A: Acceptable, HA: Highly acceptable, UA: Unacceptable

The development of processing 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 these varieties and standardization of storage techniques for processing potatoes at 10-12 °C with sprout suppressant CIPC [Isopropyl N-(3-chlorophenyl) carbamate] 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 (Pandey et al., 2008a). The release of these varieties has benefited all those associated with potato production, supply and utilization chain due to unprecedented growth in processing industry.

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. 3). All the three Chipsona varieties showed <5% undesirable colour and <15% total defects, which were the maximum acceptance limits for chips. Likewise, Kufri Frysona tested at the factory of Satnam Agri Food Products, Jalandhar, produced superior quality of French fries both at the time of harvest and after four months of storage at 10-12 °C with CIPC.

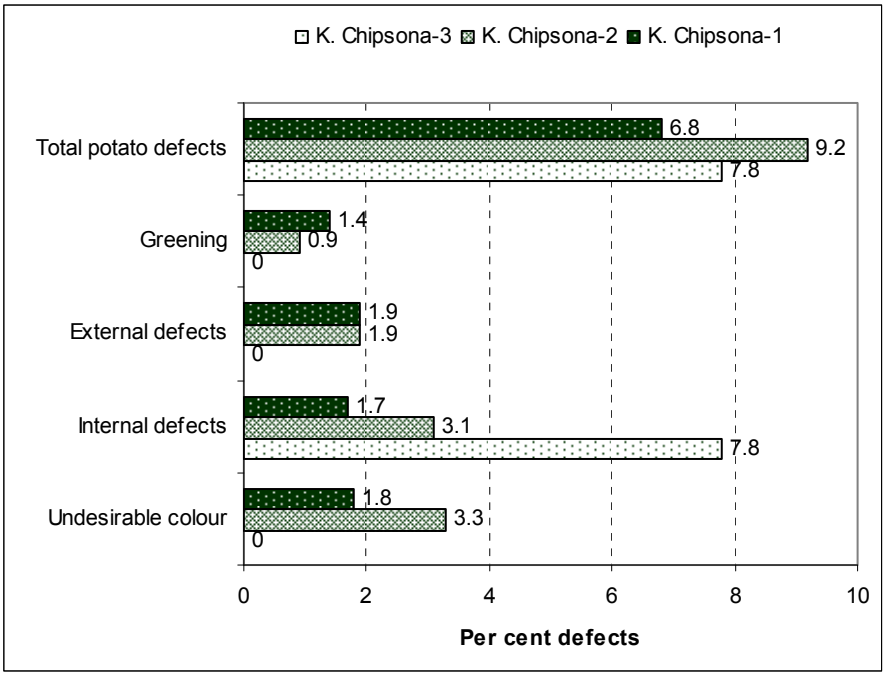

Figure 3. Per cent defects observed in potato chips prepared from Chipsona varieties during industrial testing at Channo, Sangrur (Punjab)

Industries use fresh potatoes of processing varieties from January to March. After this, they have to depend upon potatoes stored at 10-12 °C with CIPC. Due to rising food safety concerns, CIPC may have limited use in the future. Conversely, cold stored potatoes are unsuitable for processing due to high accumulation of reducing sugars yielding unacceptable dark colour and/or off-flavour in fried products. This is a very serious problem for potato processors and all the currently used Indian processing varieties are susceptible to cold sweetening. Cold-induced sweetening is a complex physiological process involving interplay of different factors. Therefore, different biotechnological approaches are being employed either to inhibit activity of two different enzymes of the cold-sweetening pathway, vacuolar acid invertase (vaINV) and UDP-glucose pyrophosphorylase (UGPase), or to silence expression of genes encoding these two enzymes. The transgenic lines are at different stages of development and expected to complement breeding efforts of the institute to circumvent the problem.

With the introduction of Chipsona varieties, consumption of potatoes by the organized potato processing industry in India has increased from 125,000 tons in year 2003 to 440,000 tons in 2007 and is growing annually at the rate of 25%, the present total processing of potatoes in the organized and unorganized sector being about 967,000 tons (Rana and Pandey, 2007). The organized and unorganized potato processing sectors presently consume about 4% of the total potato production, which was merely <1% in the year 2003. It is expected that the total utilization of potatoes in the processing sector in the year 2010 will rise to 17,40,000 metric tons or about 6% of the total production of the country. A large number of new industries manufacturing potato crisps, flakes and French fries have been installed in the organized sector in India. From just 4 or 5 companies in year 2003, the number has gone up to 30 in year 2009. This has become possible due to suitability of Indian processing varieties.

The potato processing scenario in the country has undergone a sea change in last decade. The release of indigenous processing varieties and their excellent performance in different agro-climatic zones of the country, in different crop seasons, in staggered planting in the main autumn season and during storage at 10-12 °C with CIPC has enhanced the availability of desired raw material for smooth and round the year operation of the processing industries. The national and multinationals potato processing companies in India now prefer indigenous processing varieties over exotic ones. With all these developments, India is set to have a 'crunchy revolution'.

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