International Starch Institute

POTATO GROWING IN A HOT CLIMATE TM14-3e

GENERAL

The potato prefers the temperate climatic zones of the world. However, heat tolerant varieties have been adapted to warmer climates and expand growing areas. F.e. more Danish varieties are successfully grown in The Mediterranean and at the Capricorn. The cultivation of potatoes under tropical conditions has also been demonstrated in India, now an important producer.

Potatoes may be grouped in classes characterised as:

i) Low dry matter - as low as possible - "ware potatoes" for cooking

ii) Medium dry matter - 20 - 24% - "processed potatoes" for industrial processing to chips, French fries, boats etc.

iii) High dry matter - as high as possible - "starch potatoes" for starch manufacturing.

Industrial opportunities on the agenda, when potato farmers met with Industrial Starch Institute in India.

A typical relation between starch content and dry matter is:

% Total dry matter = % Starch dry matter + 5.75

Varieties of acceptable starch content for starch manufacturing are available for hot climates. Means and potential for further improvement by breeding exists. The possibility of taking more than one crop allows more operating days, and cold stores in some areas facilitate operation all year round with practically no need for starch storage.

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Sugars are formed at low temperatures and act as a natural anti-freeze in the tuber. The formation of sugars during cold storage of some varieties may be considerable, but can be limited by elevating the storage temperature. The optimum temperature is in each case found by experimentation. As an example Bintje is stored in bulk in a 4 m high layer in a Danish warehouse at 5.8 ^{o}C without sprouting and sugar formation for as long as 9 month. While sugars have an adverse effect on processed potatoes, it does not necessarily affects operational cost in starch manufacturing because potatoes normally are paid by their starch content. It may however interfere with the routine analysis.

While early harvest and small potatoes are tasty and attractive as ware potatoes, mature potatoes are essential for starch. Up to and during withering away of the top, the potato collects as much of its total energy and store it as starch in the tuber as a reserve for next season sprouting.

HISTORY AND TRENDS OF PRODUCTION IN INDIA

India is amongst the five major potato producing countries of the world. The others are the USSR, China, Poland and the USA. In 1989-90 the potato production in India was 15.14 million tonnes i.e. over 5% of the world's production.

The Portuguese introduced potato in India in the early part of the 17th century. It was first cultivated in Surat on the West Coast. From there it spread to other areas, like Goa, which were under

Figure 1: TREND IN PRODUCTION FOR POTATOES

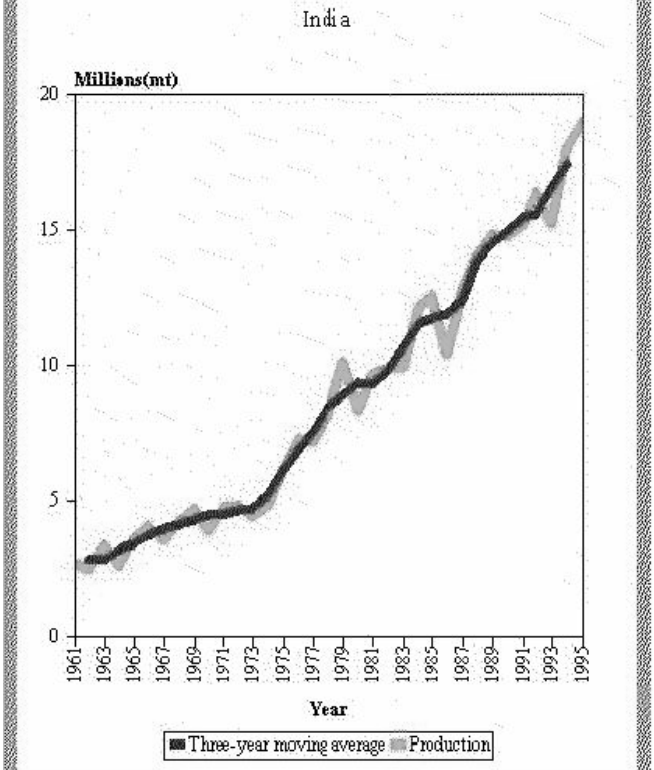
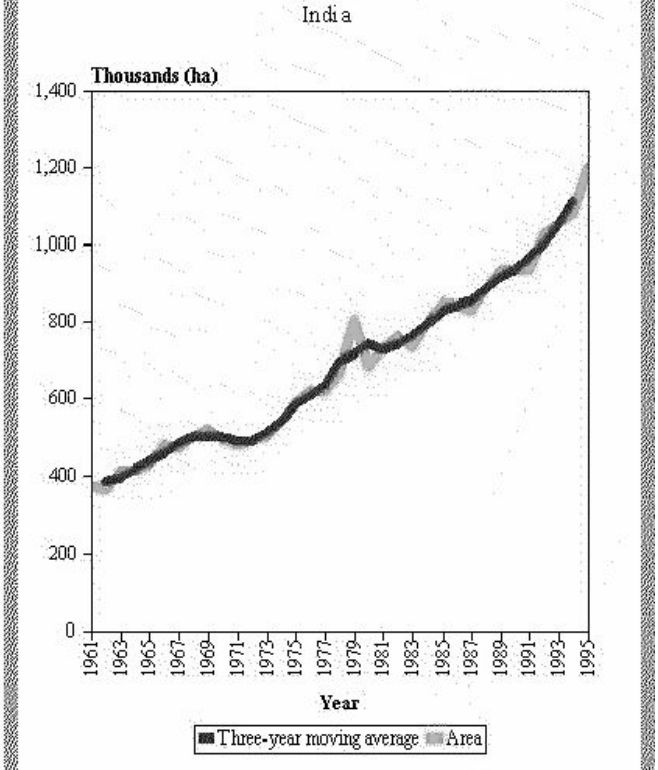


Figure 2: TREND IN AREA HARVESTED FOR POTATOES



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Portuguese influence. In Goa, potato was called "Batata Surrata", pointing towards the likely introduction of Potato from Surat. As early as 1675, Fryer mentions Potato as one of the common garden crops after his survey of Karnataka. The spread of Potato to the Southern parts of the country was apparently quite rapid.

Simultaneously potato was successfully introduced in the hilly parts of the erstwhile state of Punjab. In Uttar Pradesh, Major Young introduced it in the early part of 19th century. The area under potato cultivation has increased from 200,000 in 1950-51 to 533,000 in 1973-74. By 1977-78 while the area increased by 60%, the production increased three-fold i.e. from 2.59 million tonnes in 1963-64 to 8.15 million tonnes in 1977-78. Average yield has simultaneously increased from 69.5 quintals/ha to 86.8 quintals/ha. Despite such a sizeable increase in the area under production, still it constitutes only about 0.3% of the total arable area. But compared to other crops, growth rate of area under potatoes has been the fastest particularly since 1967-68.

Initially potato was limited to certain pockets of a few states, but with significant improvements in irrigation facilities and the seed varieties, potatoes are being cultivated in almost all parts of the country. Its cultivation is more concentrated in the Gangetic plain comprising Uttar Pradesh, Bihar and West Bengal. Production and area for the period 1961-95 are shown in Figure 1 and 2.

In India, potato is grown in different seasons in one part or the other, in the Indo-Gangetic plains which accounts for over 80% of the total production, potatoes are grown as an irrigated crop during the short days of the cooler months of September - October to March - April. In the northern hills, they are raised mainly as a rainfed crop during the long days of March - April to September - October. In the plateau region, an irrigation crop is taken during November to March - April, and a rainfed crop is grown during the rainy season from June - July to September-October. And, in the Nilgiri hills of southern India, three crops of potato are taken; a summer crop from April - May to September, an autumn crop from August - September to December and an irrigated spring crop during January to May.

Before the advent of cold-storage facilities, potatoes were stored at room temperature. This resulted in storage of potatoes at as high a temperature as 35 degree C in summer. Lack of proper storage facilities meant that foreign varieties, which were intolerant of such high temperatures, could not be cultivated.

The first cold storage for potatoes was started in Meerut in 1938. Now there are over 1400 cold stores in India accounting for the storage of about one-third of the total produce. The storage capacity for potatoes has to be increased considerably to prevent huge amount of losses, which occur due to storage at room temperatures

Bulks of the potatoes produced in the plains, is harvested at the beginning of hot and dry summer followed by hot and humid rainy season. Such ambient conditions are not favourable for storage of potatoes for an extended period, and often a greater proportion of stored potatoes is lost (Singh and Verma 1981). Refrigerated storage, thus is a necessity to reduce such losses. At the end of 1989, the installed cold storage capacity in India was 6.198 million tonnes (Bhatnagar 1990). Approximately 93% of which were exclusively for potato. In the cold stores, potatoes are stored between 2-4 ^{o}C and 90-95% rh with a marginal loss in weight during 6-8 months of storage.

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Singh and Verma (1981) have estimated that about 8% of the total produce are kept for domestic use and immediate sale. An additional 10% has to be disposed off immediately, as it is cut and damaged during harvesting. Thus the surplus, which includes about 10% to be stored for use as seed, is approximately 82%. The installed cold storage capacity is, therefore, inadequate for the storage of potatoes produced in India.

Efforts have been made to develop alternate storage facilities. The Central Potato Research Institute (CPRI) has designed a double walled storage structure using locally available materials (CPRI 1957). More recently, any evaporatively cooled potato store has been designed and evaluated (Kaul and Sukumaran 1984). Potatoes can be stored in such a structure till the end of May with marginal losses in weight[1]. If sprout suppressants like MH or CIPC are used, another could extend the period few weeks. However, at present only MH is cleared for use as a sprout suppressant, but the farmers are reluctant to use it, as the decision to spray MH has to be taken while the crop is still in the field[2].

For storage of potatoes for the processing industry, the current storage practices followed in India are not suitable, as potatoes stored below 5 ^{o}C are rendered unfit for processing due to an increase in reducing sugars. Relatively higher temperatures are recommended in European countries (Hesen 1986) and in the USA (Schippers 1975). At these temperatures, sprout suppressants such as CIPC or IPC are used to prolong the period of storage (Talburt and Smith 1987; Hesen 1986b), but they are likely to be discontinued by the end of this decade, in the countries of the European Economic Community.

It has been reported that only about one half of the annual potato production in the world is used for human consumption, the rest of it is used for animal feed, industrial purposes and of course, as seed for the next crop.

In many developed countries a large proportion of potatoes used for human food are processed into different products. In the UK about 34% of potatoes for human consumption were processed (Pmb 1990), and in USA, 63% of the annual consumption was in the form of processed potatoes (Brock 1989). But in most of the developing countries, potatoes are generally used unprocessed, though in the countries in the Andes region, they are processed into 'chuno' and papa seca. And, in the Indian subcontinent, many traditional potato based fast foods are available. Mention may be made of 'massage dosa', 'tikkis' and 'samosas'. Dehydrated and fried potato based snacks are also available. But, the processing for such products, mainly sun-dried, is done by individuals or small scale entrepreneurs. However, there is a growing demand for some processed products such as French fries and chips in urban areas in developing countries (Zaag 1990).

Potatoes are processed into many types of products,

i) Fried products such as chips and French fries etc.;
ii) Dehydrated products such as dice and granules etc.;
iii) Canned (Talburt and Smith 1987).

[1] *Weight loss is due to evaporation of water. This does not affect starch content and it is use for starch manufacturing.*
[2] *In Denmark sprout inhibitors are applied at the store.*

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For such diverse forms of products, the raw material requirements are likely to be different. While Bureau of Indian Standards has laid down standards for products like edible potato starch, the processing industry has not formulated any standards on its own and uses the ones developed by their collaborators or their principals, as in the case of Pepsi Foods Private Ltd. (private communication). Notwithstanding the above, based on the published information (Hunnius 1981, Johansens 1985, Hesen 1986).

The raw material requirement for some of the processed potato products is compiled in table 1.

Table 1: Quality requirements of potatoes for processing

Characteristics Products	Dehydrated	French fries	Chips	Canned
Tuber size mm	30	50	40-60	35
Eyes	Shallow	Shallow	Shallow	Shallow
Specific gravity	1.080	1.080	1.085	1.080
Dry matter (%)	22-25	20-24	22-25	18-20
Starch (%)	15-19	14-16	15-18	12-24
RS (%) after 8 ^{o}C storage	2.5	2.5	1.25	2.5
TS (%) after 6 ^{o}C storage	5.0	5.0	5.0	5.0
ACD	Slight	Slight	--	Nil
ED	Slight	--	--	--
Texture	Fairly firm to mealy	Fairly firm to mealy	Fairly firm	Firm(waxy)

On dry weight basis, RS = Reducing Sugars; TS = Total Sugars;
ACD = After Cooking Discoloration; ED = Enzymatic Discoloration.

THE PRESENT STATUS

Perhaps the first attempt at processing of potatoes in India on a commercial scale was made by Rennick (Rennick 1911), who established a factory at Narkanda in Himachal Pradesh, to produce potato 'meal'.

Dehydration of potato on commercial scale was also taken up during the Second World War to meet the demands of the defence forces. Solar dehydration of potatoes in the form of slices, shreds and 'papads' is carried out in many households for their own use. Many small units prepare such items using dehydrated and fried slices or shreds. Such products are available almost everywhere and it has been estimated that these account for about 50% of the sales of potato products in Delhi (Hpu undated). Recently, however, there has been a lot of interest in India in processing potatoes. Before the announcement of the liberal policy by the government of India for processing of fruits and vegetables, including potatoes, it was reported that the installed capacity for the processing of potatoes in the organised sector was 25000 tonnes per annum (Kankan 1986). It may have increased by now to about 45000 - 50000 tonnes per annum. Naik Kurade (1986) reported that 6 plants for production or potato chips and two for the production of French fries has been set up. In addition about 2000 tonnes per annum were canned and dehydrated for the use of armed forces. The installed

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capacity for the production of potato chips in the organised sector is at present 6000 tonnes (Goenka 1990) and five brands including one multinational are in the market.

The installed capacity in the organised sector for processing of potatoes in India is only about 0.3% of the annual production. Thus, there is a considerable scope for an increase in the processing of potatoes in the country.

NEED AND SCOPE OF POTATO PROCESSING

The pattern of potato production in India, outlined earlier, necessitated the movement of potatoes over long distances to meet the demands. There are some distinct disadvantages in transporting this perishable commodity, which contains 75 - 80% water. For each tonne of dry matter, 3-4 tonnes of water has to be transported at a great cost and effort. Often there is a considerable spoilage during transport, especially in the summers, as refrigerated vans/wagons are not available for this purpose. Further, the installed cold storage space is adequate for only 35-40% of the production. Lack of proper modes of transport and inadequate storage capacity results in temporary gluts immediately after harvest in the plains. Frequent gluts also occur in areas of large production such as Uttar Pradesh and West Bengal (which together account for over 73% of the total production) where there is an exportable annual surplus of over 2 million tonnes (Srivastava and Rathi 1990, Ghosh 1990). Such gluts result in a crash of prices, which increase sharply as the year advances. If a part of the produce could be diverted for the production of processed food products and industrial products, both the growers and consumers would be benefited.

The situation appears to be ideal for the development of potato processing industry, but there has been hardly any progress in that direction. This is because processing plants cannot be operated economically on periodic or seasonal gluts or on unmarketable potatoes. A regular supply of raw material of the desired specific quality has to be available for a greater part of the year. Moreover, processed products will have to be priced so as to compete with fresh foods[3].

Presently potatoes in India, as a raw material, are not cheap, except for a few weeks soon after harvest. And, the cost of the frying medium, processing and packaging etc. adds to the cost of production making the finished product beyond the reach of a common Indian. For example, potato chips in 50 g packs are priced at Rs. 140.00/kg (approx. US$ 7.00/kg), packing accounting for a substantial part of it. In the USA, the price of one kg potato chips is only US$ 6.00 (Anon 1991).

The prospects for using potato as an industrial raw material appears to be limited at present to unmarketable potatoes, as cheaper alternative raw materials for the production of starch such as maize and tapioca are available. Similarly, molasses from sugar factories is abundantly available for production of industrial and potable alcohol.

Notwithstanding the above, there are some special situations where potato processing is extremely desirable, for example, in the Nilgiri hills where cyst forming nematodes occur. The movement of potatoes from this area is a potential hazard. Processing in situ will reduce the risk. Similarly, Darjeeling district in West Bengal, where wart disease is prevalent, will benefit from potato processing.

[3] *In USA and Europe processed potatoes does not compete with fresh potatoes on price but on convenience.*

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Processing is certainly an attractive proposition in areas of high production/productivity as in certain districts of Uttar Pradesh, West Bengal and Gujarat. Some form of processing may also help the farmers in the hilly and other regions where lack of transportation is still a major constraint.

Considering that the potato products using sophisticated processing technology are at present very costly, there appears to be a limited scope in the immediate future. The cost of the products such as chips is pushed up because of the scarcity of frying medium, which is not even sufficient for meeting the requirements of housewives.

In order to make processed potato products available to a common Indian at a reasonable price; it would be desirable to develop appropriate technology and products. In these context products like dehydrated dice (piece), flour or granules may be desirable. Dehydrated dice or pieces can be used in the households for preparation of curries, and also by the fast food outlets for stuffing in the massage doss or samaras, while potato flour or granules can be used, as is the practice In USSR (Verma 1984), to prepare 'tikkis' and extruded products like 'papads' etc.

For processing potatoes into these products it would be desirable to identify/select/breed long dormancy varieties with round or oval tubers with fleet eyes. The dry matter content of the tubers should be high for greater yield of dehydrated products. The sugar content should be low and the tubers should be free from after cooking darkening. For production of dehydrated dice or pieces, firm to mealy texture would be desirable but for the granules, waxy texture may be preferred.

SEED SOURCES AND VARIETIES

The state of Himachal Pradesh was the most important source of seed till the development of the seed plot technique. With the development of the seed plot technique, the centre of seed production has shifted to the state of Punjab and the neighbouring states.

The Himalayan hills above 2,500 m are particularly suited for raising healthy seed potatoes. But the relative paucity of such suitable areas and the increased cost of cultivation made the research for alternative seed developing techniques almost an absolute imperative.

The Central Potato Research Institute (CPRI), Simla, supplies about 1500 tons of breeders' seed to the National Seed Corporation and the State Departments of Agriculture. These agencies in turn multiply the breeders seed thrice in their fields or in those of contract/ certified growers fields, and then it's distributed to the farmers.

As the programme develops, large quantities of breeders' seed will become available to feed the seed production programme in the states to bring about the complete meeting of seed requirements with the certified seed.

CPRI has developed more than 20 varieties for different agro-climatic conditions in the country (Bhardwaj, 1985). Some of the important varieties are:

1.Kufri Chandramutchi: white skin, early bulking habit with oval tubers with fleet eyes, resists PLRV and PVY, best suited to the plains.

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2.Kufri Alankar: white skin, maturing early, oval shaped tubers, field immune to late blight suited to the plains

3.Kufri Jyoti: this variety was developed at Shimla with the material of Dr. Black. White skin variety, maturity medium. Field resistant to late blight both on foliage and tubers, Wart immune. Best suited for hills and spring crops in plains, where late blight is a limiting factor.

4.Kufri Sheetman: white skin, oval shape tuber, medium maturity, resistant to frost, suited for western plains where frost is a problem.

5.Kufri Shinduri: red skin variety, tubers round, maturity medium late, moderately resistant to late blight, suited for cultivation in the plains.

MORPHOLOGICAL CHARACTERS

During the past 40 years or so, the CPRI has released 27 different varieties for cultivation. But at present only seven are in the seed production programme of the country as they are the ones, which are widely used. These varieties are listed in table 2. It will be observed that many of the varieties have morphological characters, which meet the requirements listed in table 1.

Table 2: Tuber Characters of Some Indian Potato Varieties.

Variety	Shape	Size	Eyes	Flesh Colour	Texture
Kufri Bahar	Round-Oval	Large	Medium Deep	White	Mealy
Kufri Chandra-Mukhi	Oval-Flattened	Large	Fleet	Dull-White	Mealy
Kufri Jyoti	Oval	Large	Fleet	White	Waxy
Kufri Lalima	Round	Medium	Medium	White	Mealy
Kufri Lauvkar	Round	Large	Fleet	White	Mealy
Kufri Sindhuri	Round	Medium	Medium Deep	Dull	Waxy

SPECIFIC GRAVITY AND DRY MATTER CONTENT

In addition to the morphological characters, some other factors determining the suitability of potatoes for processing are the specific gravity or the dry matter content of potatoes and their sugar content.

Potatoes, high in specific gravity[4] (or dry matter) are preferred for preparation of chips, French fries or dehydrated products, whereas those of lower specific gravity are used for canning or for such other products where a firm piece is desired. Yield of chips and flour etc. is higher from high specific gravity potatoes (Grewal and Uppal 1989, Rai 1990). Besides high yields of the product, the uptake of fat or oil during frying is lower (Grewal and Uppal 1989). Moreover,

[4] *For processing at certain dry matter content is required to produce a crisp and attractive consistency. If the content is too low the products gets flabby and if the dry matter is too high the product cook out.*

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relatively much less moisture has to be removed per unit of products when high specific gravity potatoes are used (Hesen 1986a). However, potatoes of very high specific gravity may not be suitable for the production of French fries etc. French fries produced from furore potato with a specific gravity of 1.106 were too hard and biscuit like (Aspinwall 1966). Hesen (1986a) is also of the opinion that very high specific gravity potatoes may yield 'hard chips'. Lugt (1960) states that in the USA specific gravity graders was developed to select 'Boilers' (low specific gravity) and 'brakers' (high specific gravity potatoes).

Dry matter content of fruits and vegetables, including potatoes is determined by oven drying, but a non-destructive method is also available for potatoes and sweet potatoes. Von Schee et al. (1937) demonstrated that the specific gravity and dry matter content of potatoes are directly related to each other. Since then relationships have been established in other countries including India (Verma et al. 1971), and for different regions (Verma et al. 1972). This is desirable as the dry matter content of potatoes of identical specific gravity's differs from place to place (Verma et al. 1972). Specific gravity's of potatoes can be determined by a number of methods e.g. use of

i) Brine solution of known specific gravity's (Burton 1989),
ii) Potato hydrometer,
iii) Archimedes principle (Nissen 1967),
iv) Variable load hydrometer (Sukumaran and Ram Dass 1980), and
v) Ordinary scales (Misra 1983).

A number of factors affect the specific gravity or dry matter content of potatoes (see Verma 1990). The specific gravity and the dry matter content of many varieties and hybrids grown at different locations in the country (Verma et al. 1975 a, b) are given in tables 3 and 4 respectively. These include some varieties, which are listed in table 2. It will be observed that both the specific gravity and the dry matter content of 4 varieties grown at 4 different locations in great Britain and Scotland; the dry matter content of variety record (the preferred variety for processing) ranged between 20.2-25.2%. The dry matter content of variety Bintje (the preferred processing variety in The Netherlands) ranged between 19.6-21.3% (Buekama and Zaag 1979).

Table 3: Specific Gravity of Potato Varieties Grown at Different Locations

	Potato density			Potato starch content		
Variety	JLN	RGN	Patna	JLN	RGN	Patna
Kufri Alankar	1,0620	1,0866	1,0847	10,2%	15,5%	15,1%
Kufri Chandramukhi	1,0849	1,0921	1,0925	15,2%	16,7%	16,8%
Kufri Chamatkar	1,0806	1,0936	1,0928	14,2%	17,1%	16,9%
Kufri Dewa	1,0837	1,0915	1,0958	14,9%	16,6%	17,5%
Kufri Lauvkar	1,0683	1,0856	1,0878	11,6%	15,3%	15,8%
Kufri Sindhuri	1,0910	1,1006	1,0854	16,5%	18,6%	15,3%

Jln = Jalandhar Rgr = Rajgurunagar
Potato Density Is According To CPRI.
Potato Starch Content Calculated On Basis of Potato Density According To ISI TM5-2e Page 15.

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Many of the varieties and hybrids listed in tables 3 and 4 fall within the range of specific gravity and dry matter content required for preparation of various dehydrated and fried potato product (table 1). Some of the varieties are also suitable for canning.

Table 4: Dry matter content of potato varieties grown at different locations

Cultivar	Dry Matter Content (%)		
	Jln	Rgr	Patna
Kufri Alankar	18.6	21.0	20.1
Kufri Chandramukhi	20.2	22.0	22.2
Kufri Chamatkar	19.5	22.9	21.8
Kufri Dewa	19.9	21.6	23.0
Kufri Lauvkar	18.2	20.9	20.9
Kufri Sindhuri	20.6	23.0	21.6

Jln = Jalandhar Rgr = Rajgurunagar

SUGAR CONTENT

Sugar content of potatoes plays a very important role in determining the acceptability of fried products. Chips and French fries prepared from potatoes containing large amounts of sugars, especially reducing sugars, i.e. glucose and fructose, turn brown and black and become unacceptable to the consumers (Talburt and Smith 1987). This discoloration is ascribed to a reaction, between the reducing sugars and amino acids, which takes place when the moisture content is low and the temperature is high. Generally, freshly harvested mature potatoes contain acceptable levels of reducing sugars (Rai and Verma 1989) but when stored at low temperatures, the sugar content increases and potatoes become unfit for processing (Verma et al. 1974a, Marwaha et Al. 1990). One of the methods of overcoming this problem is to store the potatoes at high temperatures (Verma et al. 1974a). It has been shown that when potatoes were stored at ambient temperatures, there was very little increase in the reducing sugar content of potatoes (table 5), irrespective of the variety[5].

This observation has been confirmed (Uppal and Verma 1987). But under such conditions sprouting and weight loss was excessive (Verma et al. 1974b). However, when potatoes were stored in an evaporatively cooled store, similar changes in the sugar content were observed (Khurana et al. 1985) but with a lower weight loss of the potatoes (Kaul and Sukumaran 1984), yet the problem of sprouting remained. To overcome this problem, potatoes were treated with CIPC and stored in an evaporatively cooled store (Khurana et al. 1985), and also at lower temperatures recommended for storage of potatoes meant for processing.

[5] *An obstacle at high temperature storage is the increased risk of fungal attack and the resulting deterioration of the tuber.*

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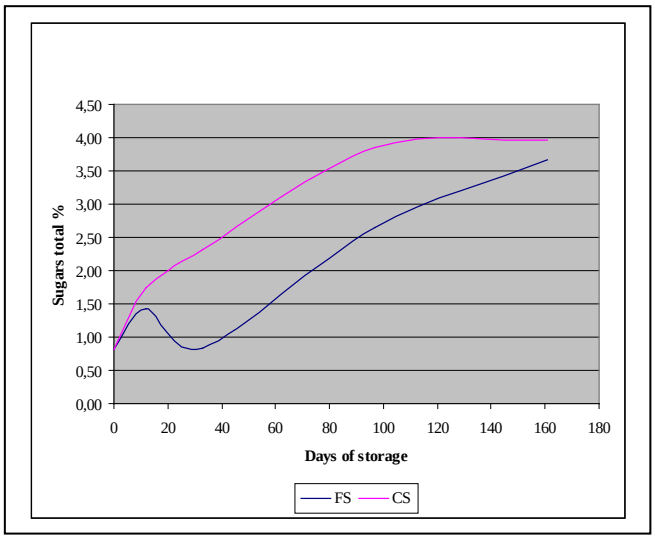
Table 5: Sugar content (g/100g fresh weight) of potato tubers (Cv. Kufri Sindhuri) during storage

		Period of Storage (Days)				
		0	12	33	97	161
Total sugars						
	FS	0,82	1,42	0,84	2,64	3,66
	CS	0,82	1,74	2,32	3,86	3,96
Reducing sugars						
	Fs	0.30	0.34	0.31	0.59	0.58
	Cs	0.30	0.54	1.13	1.31	2.62
Sucrose						
	Fs	0.49	1.03	0.50	1.95	2.92
	Cs	0.49	1.17	1.14	2.42	1.28

FS = FARM STORE (24.7 - 36.2 ^{O}C, CS = COLD STORE 2.8 ^{O}C)



Even under such conditions of storage, potatoes became unfit for processing within a very short period (Marwaha and Verma 1990). Recourse had to be taken to reconditioning another method used to overcome the problem of excess sugar in cold stored potatoes. During reconditioning, cold stored potatoes are stored at 15-20 ^{o}C for 2-3 weeks. Under such conditions a reduction in the contents of sugars take place. However, in many cases this was also not very effective (Verma et al. 1971) and dark coloured chips were produced (Rai and Verma 1989). In an attempt to produce acceptable colour, the chips were fried at lower temperatures.

While the colour of chips was acceptable the oil content of the chips so produced was about 30% higher that the oil content of chips produced by frying under the normal conditions (Srivastava s.n.s. and Verma s.c. unpublished).

The discoloration of chips and French fries due to high sugar content of cold stored potatoes is a problem faced by the industry all over the world and attempts have been made to identify varieties which do not accumulate large amount of sugars during the low temperature storage. Johansen (1985) identified nd 860-2 as one such selection. In UK, a variety Brodick has been released (Cotterell et al. 1990) and in India, Kufri Sherpa has been found to accumulate much lower quantities of sugars (table 6) than many other potato varieties examined (Uppal and Verma 1990).

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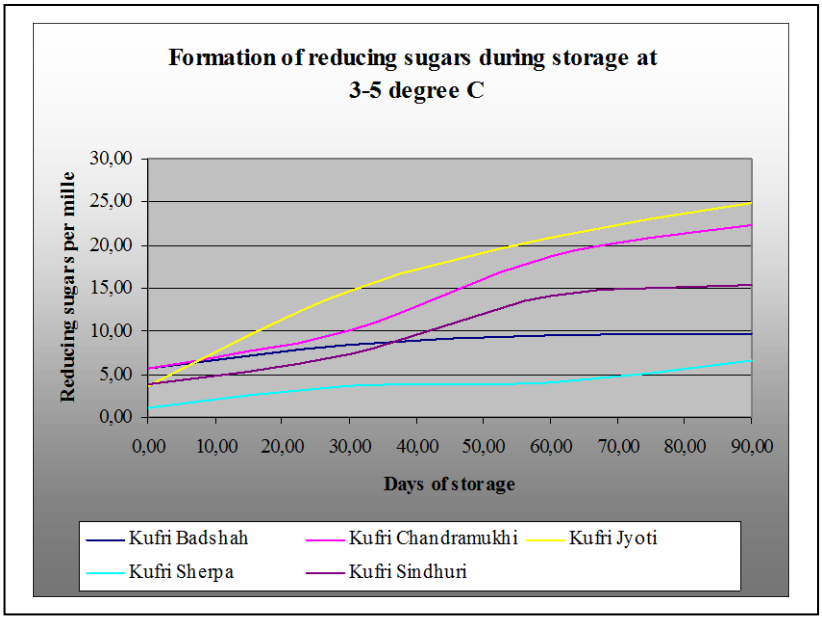
Table 6: Reducing Sugar Content (mg/g Fresh Weight) of Potatoes Stored at 3-5 °C.

Cultivar	Sugar Period, Days				
	0	30	60	90	Mean
Kufri Badshah	5.7	8.5	9.5	9.7	8.4
Kufri Chandramukhi	5.6	10.0	18.6	22.3	14.1
Kufri Jyoti	3.7	14.7	20.8	24.8	16.0
Kufri Sherpa	1.1	3.7	4.1	6.5	3.9
Kufri Sindhuri	3.8	7.4	14.0	15.3	10.1
Mean	3.98	8.86	13.40	15.72	



DISCOLORATION

Potato and potato products are prone to three types of discoloration:

i) Enzymatic discoloration,

ii) After cooking discoloration and

iii) Discoloration of fried products such as chips and French fries.

ENZYMATIC DISCOLORATION

Enzymatic discoloration develops in peeled or cut potatoes when they are exposed to air. The problem is encountered in sun drying of potatoes and is due to the action of polyphenoloxidase enzyme on the phenolic compounds. Similar reaction takes place in the development of black spot in potatoes during harvesting, handling and transport, especially at low temperatures.

Enzymatic discoloration and black spot in potatoes can be prevented by the application of potassium fertilisers (Verma et al. 1981, Vertregt 1968), especially muriate of potash. But the application of muriate of potash resulted in a decrease of the dry matter content of potatoes (Verma et al. 1981). Therefore, the industry uses other methods to overcome the problem of enzymatic discoloration, i.e., The application of chemicals to peeled potatoes. Sulfiting, as the common procedure is known as, helps to reduce or eliminate enzymatic browning but is a potential health hazard, specially to people prone to asthmatic conditions. As such efforts have been made to select varieties which do not show any enzymatic discoloration. Mapson et al. (1963) had observed varietal differences in enzymatic discoloration and Verma and Joshi (1974) reported that variety d 2286 and c 2703 did not show much enzymatic discoloration.

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AFTER COOKING DISCOLORATION (ACD)

As the term suggests, it develops in cooked potatoes and potato products after exposure to air, especially in boiled and steamed Potatoes, but can also develop in French fries and canned potatoes. ACD often develops as grey or black areas at the stem end of the tubers and is therefore, also known as stem end discoloration. The discoloration develops due to the oxidation of a complex (formed during cooking) of Iron and polyphenols, especially chlorogenic acid. Almost all the Indian potato varieties are free from ACD, though it has been observed occasionally in Kufri Jyoti. But ACD develops in gamma irradiated potatoes stored at or below 15 ^{o}C for 2.5 to 3 months (Thomas 1981, Thomas and Joshi 1977). The problem could be overcome by storing potatoes at higher temperature or by reconditioning such potatoes at 30-35 ^{o}C for 2 weeks.

DISCOLORATION OF FRIED PRODUCTS

A reference has already been made to the discoloration of fried products, such as French fries and chips due to high levels of reducing Sugars and to some of the methods of overcoming this problem. Besides the methods mentioned earlier, two other methods have been suggested for overcoming the problem. In one of the methods, excess quantity of sugars is fermented to lactic acid by lactobacillus plantarun (Manan et al. 1987). The authors claim that "satisfactory product, with respect of colour, flavour/aroma, texture and general acceptability could be produced by this method". In another method, the reactants were removed by repeated washing of the raw slices in water. It was claimed (Misra and Chand 1988) that about 50% of the reducing sugars and about 40% of the free amino acid were removed by washing the raw slices in water. It may be pointed out that these two reactants are involved in the development of the discoloration of fried products.

PERFORMANCE OF INDIAN POTATO VARIETIES

Many Indian potato varieties have been evaluated for Processing into different product by the Central Food Technological Research Institute, Mysore; the directorate of fruit utilisation, Uttar Pradesh, Lucknow; and the CPRI. On the basis of these evaluations, a list of varieties suitable for different products has been compiled (Verma and Sukumaran 1986). More recently, a number of investigations have been conducted to evaluate present-day potato varieties.

Ten potato varieties grown at Kufri, in the hilly regions of Himachal Pradesh and seven grown at Jalandhar in the plains of Punjab were evaluated for chipping after cold storage for short (2 months) and long (6 months) periods (Beerh et al. 1988). The authors did not evaluate the varieties before cold storage.

Peeling losses were 7.5 to 13.6% and the yield of chips Ranged from 25% (Kufri Jyoti) to a little over 31% (Kufri Dewa and Kufri Sherpa) of the peeled potatoes. The oil content of the chips ranged from 29% (Kufri Dewa) to 45% (Kufri Bahar). As expected, chips produced from all the varieties even after short cold storage were too dark to be acceptable. However, acceptable coloured chips could be produced from Kufri Sherpa, reconditioned after a short period of cold storage. After the long period of cold storage, none of the varieties yielded chips of acceptable colour even after reconditioning.

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In an extensive investigation conducted at CPRI with potatoes grown at Patna, Bihar over a number of years (Rai and Verma 1989), it was found that variety Kufri Chandramukhi was the most suitable variety for chip making. It had an acceptable level of dry matter (22.0%) and sugars (314 mg). The chip colour on the pcii scale was 1.6 (table 7).

Table 7: Dry Matter and Reducing Sugar Contents and Chip Colour of Indian Potato Varieties

Cultivars	Dry Matter (%)	Reducing Sugars (mg%)	Chip Colour
Kufri Alankar (4)	20.9	327	2.6
Kufri Badshah (3)	20.0	368	3.3
Kufri Chamatkar (3)	23.4	374	2.4
Kufri Chandramukhi (4)	22.0	314	1.6
Kufri Jyoti (3)	21.0	375	2.2
Kufri Lauvkar (4)	21.5	238	2.0
Kufri Sindhuri (4)	22.3	243	2.4

A value in brackets denotes the number of years the variety was evaluated. Chip colour based on the colour chart of the Potato Chip Institute, International Ithaca, New York. The lighter the chip colour, the lower the score.

Varieties Kufri Sindhuri and Kufri Chamatkar were also suitable for chipping soon after the harvest. While the chips produced from all the varieties after cold storage for seven months were unacceptably dark, chips of acceptable colour could be produced from Kufri Chandramukhi and Kufri Sindhuri after reconditioning at 22.0 ^{o}C. They identified a number of hybrids, which did not accumulate large amounts of sugars during cold storage and thus were suitable for producing light coloured acceptable chips (e-4451, jh-544, ps/e-431, ps/e 3570 & Bs/e-775) or which could be reconditioned satisfactorily (bs/e-775, E-4451, f-3349, jc-1203, ji-1857 and ji 5871). They also listed a number of hybrids which accumulated large quantities of reducing sugars Resulting in dark coloured chips, and/or could not be reconditioned Satisfactorily. They concluded that some of the present day Indian varieties were suitable for chipping, before and after cold storage, and that it was possible to select cultivars which can be processed after cold storage and reconditioning, to provide the raw material to the chipping industry for a greater part of the year.

Grewal and Uppal (1989) reported that the yield of chips and their oil uptake was related to specific gravity of potatoes. The yield of chips increased and their oil content decreased with an increase in the specific gravity of the potatoes. The colour of the chips was also better if the specific gravity of the potatoes was high (table 8).

Table 8: Yield and Oil Content of Chips In Relation To Potato Specific Gravity

Specific Gravity	Yield (%)	Oil Content (%)
1.0599	30.1	54.4
1.0599 - 1.0633	31.7	50.4
1.0633 - 1.0707	32.3	47.0
1.0707 - 1.0782	34.6	42.2
1.0782	35.7	38.2

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Chipping trials were conducted recently with five varieties of potatoes grown at Jalandhar and stored at three different temperatures (Marwaha et al. 1990). Chips of acceptable colour could be produced from freshly harvested potatoes and those stored for 9 weeks at 18-20 ^{o}C. But chips of dark colour were obtained when potatoes were stored for even 3 weeks at either 3-4 ^{o}C or 8-10 ^{o}C. However, when tubers stored at 8-10 ^{o}C, were reconditioned[6], the colour of the chips was acceptable. But after longer storage at this temperature, satisfactory reconditioning was not possible (Schippers 1975).

POTATO DEHYDRATION

As already indicated, there is a very limited demand for processed potato products in India. Therefore, extensive research work has not been conducted. But the evaluation of different potato varieties for dehydrated products has been carried out from time to time. Successful attempts have also been made to develop some processes for vacuum puffing of potato products (Eapen and Ramanathan 1966 a,b).

A home drier for fruits and vegetables (including potatoes) was fabricated by lal Singh and Girdhari lal (1941). Best product was obtained when the potatoes were peeled, sliced, and blanched for 3-5 min at 81-100 deg; the slices could be dried in 9-11 hr. The dehydrated slices could be rehydrated to normal shape, appearance and flavour if yhey were soaked for 24 hr in water. Peeling and trimming losses were lower in 'new' potatoes but the yield of the dried product (22-29%) was higher in old potatoes.

CONVENTIONALLY DEHYDRATED POTATO DICE

Kuppuswamy (undated) standardised the procedure for the preparation of dehydrated dice from potatoes and evaluated some potato varieties. Varieties Great Scot, President, Craig's Defiance, Kufri Kuber, s-1759 and s-1766 were the most suitable ones for preparation of dehydrated dice.

At the Central Food Technological Research Institute, Mysore extensive investigations were carried out for evaluating different Potato varieties for preparation of dehydrated dice (CFTRI 1973-1976). When all the factors viz., blanching time, cooking time, sulphite Content and browning of dice during storage were taken into consideration, the varieties Kufri Chandramukhi, Kufri Kuber, c-990 and Vb-8 were found to be the most suitable for processing into conventionally dehydrated dice. This product could also be prepared from varieties Kufri Sindhuri and Kufri Naveen.

DEHYDRATED POTATO CUBES

No differences in consumer acceptability of potato cubes, prepared from 3 varieties by tray drying, were reported (Katara and Nath 1985) when the cubes were deep fried or used in curries. Blanching

[6] *The transformation of starch into sugars is catalysed by enzymes and this enzymatic process is to some extent reversible.*

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of cubes prior to dehydration helped in retention of ascorbic acid, improved the colour and rehydration ratio.

VACUUM-PUFFED PRODUCTS

A procedure for vacuum-puffed potato was developed by Eapen and Ramanathan (1966a). Boiling could rehydrate the vacuum-puffed pieces for 3 min in water but they often disintegrated. A Case-hardening treatment could effectively prevent the disintegration. Such pieces closely resembled fresh potatoes. While the conventionally dehydrated dice appeared shrivelled, the vacuum-puffed dehydrated potatoes were comparable (or even superior) to fresh potatoes in respect Of texture, flavour and colour. Further investigations at CFTRI (1975) showed that the cooking time for vacuum-puffed dried product was only 7-23 min and was much less than for the conventionally dehydrated dice (60 min). The bulk density of the vacuum-puffed dried potatoes was lower than the conventionally dehydrated dice (CFTRI 1974). The vacuum-puffed Dried potato developed browning faster that the dehydrated dice (CFTRI 1976). Kufri Chandramukhi, Kufri Sindhuri, Kufri Kuber, Kufri Jeevan and hybrid c-990 were found to be most suitable for the preparation of vacuum-puffed dried potatoes.

INSTANT POTATO FLAKES

Kuppuswamy (undated) standardised the conditions for the preparations of instant mashed potato in the form of flakes. Amongst older varieties, potato flakes of excellent quality could be prepared from up-to-date and of fairly good quality from Craig's defiance.

Eapen Ramanathan (1966b) prepared instant mashed potato by vacuum puffing. Cooked potato pieces were sulphited, cooled and mashed and were passed through a granulator. The mash was moulded and extruded to produce beads of 0.6 x 0.6 cm. The beads were steamed at atmospheric pressure to condition them for vacuum puffing and were then transferred to the puffing unit where a vacuum of 63.5 cm hg was applied for 5-10 sec. The porous beads were then dried in a truck drier. Drying was completed in 30 min. The product was crisp and could be fried. By soaking it in about 2.5 times (by weight) hot water for 30 min, it could be reconstituted into mash. The beads could be stored for 1 year at room temperature (22.2-33.3 ^{o}C) in alkathene bags without any change in the texture of flavour.

Sharma (1978) prepared flakes from freshly harvested tubers as well as those stored at 4 ^{o}C for 2 weeks. He observed that the cooking time yield, bulk density, and sulphite content and browning varied amongst the varieties.

Flakes prepared from cold stored potatoes showed generally greater browning than the flakes made from fresh potatoes. On the basis of the yield and properties of the potato flakes, Sharma (1978) concluded that Kufri Chandramukhi and Kufri Jyoti varieties were most suitable for the preparation of potato flakes.

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SOLAR DEHYDRATION

Solar energy has been used since ancient times to dehydrate potatoes in the Andes Mountains to prepare chuno. In India also, sun-drying of potatoes in the form of slices, shreds and papads, etc. Is practised by housewives. But quite often the products are varying shades of grey and therefore, unappealing. Investigations were; therefore, conducted at the central potato research institute and its regional stations to develop a procedure to prepare dehydrated potato slices of acceptable colour (CPRI 1974). Based on these investigations, Srivastava et al. (1973) described a method for preparing highly acceptable sun-dried potato slices. Discoloration of peeled potatoes and the slices is minimised by immersing them in cold water. Blanching of slices inactivates the enzyme(s) responsible for browning. Use of potassium metabisulphate ensures that such slices have a long shelf life, if stored in airtight containers or in sealed polythene bags. A yield of about 20% dehydrated slices containing 8-10% moisture was obtained. Such slices could be ground to prepare potato flour for use in the preparation of biscuits etc (see section on potato flour).

Nankar and Nankar (1981) prepared chips, shreds and cubes from Kufri Chandramukhi by sun drying. The yield of sun-dried chips was only 12.9% but that of shreds and cubes was much higher, respectively, 15.0 and 14.5%. About 35 grams of starch was obtained as by-product/kg potatoes.

Since 1973 a number of investigations have been conducted to study factors which have a bearing in solar dehydration of potatoes, e.g. Thickness of the slice, use of various surfaces for sun-drying, and evaluation of the efficiency of different types of solar dehydrators etc. Thus, it was observed that black polythene was a better surface for dehydration than clear polythene (Maini et al. 1985, Ezekiel et al. 1990). Similarly, nylon mesh was better for dehydration than clear polythene (Ezekiel et al. 1990). The thickness of slices affected the rate of dehydration, thinner slices dried in the sun at a faster rate than thicker ones (Maini et al. 1981, Ezekiel et al. 1990) variety of potatoes did not appear to have any effect on the rate of dehydration though at least in one case slices prepared from cold stored tubers, dried at a faster rate (Ezekiel et al. 1990). But Khurana and Randhawa (1985) reported lower yields of dehydrated slices from cold stored and reconditioned potatoes as compared to those stored in an Esc (8-13 ^{o}C) for 75 days.

Dry matter content of potatoes is reported to affect the yield of dehydrated products such as sun-dried chips and potato flour. Grewal and Uppal (1989) reported higher yields of sun-dried chips and potato flour from high dry matter containing potatoes (table 9). Rai (1990) also obtained higher yields of sun-dried chips and potato flour from potato varieties containing higher dry matter. Highest yield was obtained from potato variety Kufri Sindhuri (Grewal and Uppal 1989, Rai 1990) which contained 24.0% dry matter. But Khurana and Randhawa (1985) reported identical yields of 15% from both Kufri Chandramukhi and Kufri Sindhuri though the dry matter content of the latter was 4.7% higher. Khurana and Randhawa (1985) ascribed lower yield from Kufri Sindhuri tubers to deep eyes.

Table 9: Dry matter (DM) content of potato and yield of potato flour

Variety	DM (%)	Yield Of Potato Flour (g/kg)
Kufri Alankar	20.0	204
Kufri Chamatkar	23.2	234
Kufri Chandramukhi	21.6	217

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Kufri Jyoti	23.7	232
Kufri Sindhuri	24.0	247

Ramakrishna and Prakash (1986) described a procedure for preparing flat dehydrated potato slices. Partially dried potato slices are held between 5 x 5 mm wire mesh screen with clamps for further drying. This resulted in reduced bulk density and breakage during transportation.

A problem related to quality of sun dried products are the reported occurrence of dust, and at times dead insects, when dehydration is carried out in open (Kalra and Bhardwaj 1981). As such a number of solar dehydrators have been fabricated and evaluated (CFTRI 1984, CPRI 1974, Kalra and Bhardwaj 1981, Khurdiya and Roy 1986, Maini et al. 1985). These not only ensure better hygienic standards but also generally Result in faster drying, though at least in two cases the time taken for Dehydration in such solar dryers was about the same as in direct sun (Kalra and Bharadwaj 1981, Khurdiya and Roy 1986).

Singh and Verma (1975, 1981) described a cabinet solar drier. Larger cabinets with a solar concentrator were designed at CPRI (1980, 1981) and a domestic solar dehydrator was also developed (CPRI 1984). In a solar cabinet described by Singh (1985), the air temperature inside, was 13 ^{o}C to 21 ^{o}C higher than that of an ambient air. When the corrugated asbestos trays were painted black, the temperature was 26 and 39 ^{o}C higher than ambient, in April and November, respectively. A charge of 50 kg potato slices or cubes could be dehydrated in 4 to the power 1/4 to 3 to the power of 1/2 hours in this cabinet, and the product could be reconstituted with 4-5 times its weight of water.

Kalra and Bhardwaj (1981) evaluated two models of solar dryers model I with 3.6 sq. m. Loading area and model II and 2.4 sq. m. Temperature inside model I was 10-20 deg higher and in model ii 20-25 ^{o}C higher than ambient. Drying time for potato chips, French fries and papads was 3,8 and 4 hour in model II as compared to, respectively, 4, 10 and 5 hour in open air or model I.

INVESTIGATIONS WITH TPS FAMILIES

Plant breeders to produce new potato varieties use botanical seeds of potatoes. Of late, however, such seeds are being evaluated for raising a commercial crop, either directly or after raising a crop of tuberlets for use as seed potatoes. It is expected that in a few years, a number of farmers will be using these seeds, also known as true potato seeds (tps), or tuberlets, to raise commercial crops. With increasing quantities available, such produce may also be used for processing. Mehra and Upadhya (1990) have therefore, evaluated the produce of tps lines for production of sun-dried slices and strips. On the basis of the dry matter content, paring time, recovery rate of sun dried slices and strips, and cost of labour, they concluded that the produce of tps lines was by and large suitable for such products. The cost of producing strips was lower than that for sun-dried slices.

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SOLAR DEHYDRATION OF PARTIALLY COOKED POTATOES

In some parts of our country, particularly in Gujarat and Maharashtra considerable quantities of partially cooked potatoes are dried and are consumed after deep fat frying. Joshi et al. (1976) have shown that such slices take up much less cooking medium during frying and are, therefore, more economical. The procedure for preparing such slices consists of cooking the potatoes in boiling water for 8 min before peeling and slicing. Slices are then allowed to dry in the sun. Dehydration of such slices takes longer time and is usually accomplished in about 8-10 hours.

POTATO FLOUR

Potato flour is a very important product and is used in the baking industry, mainly to reduce the protein content of the mix, but also to impart softness to bread and for better retention of moisture. Potato flour can also be used to partially replace wheat maida in the preparation of biscuits (Srivastava et al. 1973). It is used as a base for the preparation of many soup mixes.

It can be prepared by any of the under mentioned procedures. Srivastava et al. (1973) prepared it by grinding sun-dried potato slices. Swaminathan (1960) used a kiln to dry potato shreds before grinding them. Roy Coudhari et al. (1963) used a through flow drier to dehydrate potato slices, before grinding in a hammer mill to prepare potato flour. Grewal and Uppal (1989) and Rai (1990) dried boiled mashed potatoes to prepare potato flour.

Swaminathan (1960) had suggested that potato flour could be used to partially replace wheat flour in the preparation of 'chapati' etc. Srivastava et al. (1973) found that potato flour could partially replace wheat 'maida' in the preparation of biscuits. This was confirmed by Chandra Shekhara and Shurpalekar (1984 a) who reported that up to 30% potato flour could be incorporated in the preparation of soft dough biscuits of acceptable quality. They also found that an addition of potato flour to contribute 15% solids could be made in the preparation of bread of acceptable quality (Chandra Shekhara and Shurpalekar 1984 B).

CANNING

Canning of potatoes is not a preferred form of processing, because

i) The cost of cans adds very substantially to the cost of raw material and the final product becomes prohibitively costly, and

ii) The weight and the bulk of the canned potatoes are many times that of the raw potatoes, making it costly to transport.

However, small quantities of potatoes, about 2000 tonnes, are canned annually, primarily, to meet the requirements of the armed forces. Therefore, potato varieties grown in the country have been evaluated from time to time for their suitability for canning.

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Amongst the older varieties and hybrids, on-208 (Tandon et Al. 1953) and up to date (Verma et al. 1966) were found most suitable for canning. Phulwa and Mysore rickets were also suitable (Tandon et al. 1953) nut kerrs' pink (Tandon et al. 1953), k-122 and military special (Verma et al. 1966) could be canned only after calcium chloride treatment. Darjeeling red round was, however, unfit for canning due to deep eyes and yellow flesh (Tandon et al. 1953).

Kapoor et al. (1975) found that processing losses were low (ca 14%) in varieties Kufri Alankar, Kufri Jyoti, Kufri Chandramukhi and E-6370 but high in Kufri Dewa (20%). Kufri Alankar showed the most superior characteristics for canning. Tubers with a specific gravity lower than 1.075 did not require calcium chloride treatment for canning but those of higher specific gravity could be canned, only after calcium chloride treatment, (Kapoor et al. 1975) which minimised the extent of cracking or bursting of tubers (Verma et al., 1966) and resulted in firm pieces (CPRI 1978, Rai and Verma 1990). Canning adversely affected the vitamin c content of potatoes and addition of calcium chloride caused higher losses; only 5-10% of vitamin c was found in potatoes canned with calcium chloride and stored for seven months at ambient temperatures (CPRI 1978, Rai and Verma 1990). Freshly harvested potatoes of varieties Kufri Sindhuri, Kufri Dewa and Kufri Alankar were reported to show good canning characteristics, but Kufri Jyoti, Kufri Sheetman and c-697 showed a greater percentage of cracking (CFTRI 1979). The taste of tubers was impaired when they were canned after six months of cold storage (CFTRI 1979). Such tubers also showed browning (CFTRI 1979) whereas freshly harvested tubers were reported to be free from after cooking discoloration (CPRI 1978). Tandon et al. 1953 and Jaffar et al. 1968 earlier reported adverse effects of cold storage on canning characteristics.[i]

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