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Review

Perspectives in consumer-oriented breeding for potatoes in India

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Abstract
Potato has become an integral part of human diets world over and is consumed alone or with wide variety of other vegetables. Consumer preference of the regions varies and is dependent upon market specifications, variety; tuber appearance, size, shape, colour; absence of disease or tubers defects; texture and flavour of cooked potatoes. Breeding for consumer preference related traits is integral part of the varietal development efforts world over and thus helps to write the success story of a variety evolved.In recent years there has been a surge in the consumer awareness in India, with consumers becoming more conscious about the food, its nutritional valueand its use. The desired products fetch higher premium prices in the market. A potato is not merely a potato anymore in recent times, but a commodity having varied uses, with each user having a specific requirement. In view of the above, it becomes pertinent to delineate the various consumer-oriented breeding objectives for potato, based on its use. Indian consumer-based profiles of potato have been proposed, based on recent overview and prevailing Indian scenario for orientingspecific breeding programmes, guiding consumers and seed producers to breed, consume and multiply the variety of their choice and formulation of selection indices for genotype screening.

Keywords: consumer preference, marketability, organoleptic attributes, acceptability, flavor,cooking, shelf life, nutritional quality, potatoes

INTRODUCTION

Potato is the most consumed vegetable in the world, with rapidly increasing consumption in the developing and underdeveloped countries. It is second only to maize in terms of the number of countries growing the cropand fourth largest food crop in terms of fresh produce after rice, wheat and maizein global production. The projected world population by 2050 is 9.73 billion entailing a 49% increase in agricultural productivity (FAO, 2010) to ensure food security.Potato has been identified as a key crop to counter this challenging scenario producing 47.6 kg of food/ha/ day as compared to wheat, rice and maize which produce 18.1, 12.4 and 9.1 kg food/ha/day, respectively (Kumar and Pandey 2008). Its higher yields, affordability and storability have led to its identification as a potential crop for ensuring food and nutritional security to the world population (Devaux *et al.,* 2014). It produces highest calories per unit land in comparison to any other major crop(Nunn and Qian 2011).The developed countries have higher potato intake in their diet in contrast to the developing oneswithaverage potato intake of 130 and 41 kcal/day/ person respectively(Burlingame *et al.,* 2009).

In recent years, advances in science along with concomitant extensive media coverage and consumer education programs have increasingly delineated the link between diet and health leading to increased prioritization of healthy and nutritional foods by the masses. The potatoes not only grow in a wide range of climates and soil types, yielding tubers as quickly as 60 daysbut also have a rich nutritional profilewith generous amounts of phytonutrients, vitamin C and several other minerals.

Fresh potatoes can be baked, boiled, or fried and are used in a staggering range ofrecipes. They are included in the meal in various forms likesalads, soups and snacks to side dishes or even the main meal itself. In India, a country of “unity in diversity”, potato has made its place in the food recipes of all 29 states of India. Besides, these international potato recipes like mashed potatoes, potato pancakes, potato dumplings, twice-baked potatoes, potato soup, potato salad and potatoes au gratin, are servedas premium dishesin luxury hotels and restaurants. Specialtybaby potatoes and colored antioxidant rich potatoes have started finding fancy with Indian consumers being included in rich cuisines and fetching premium prices. Besidesthese, potato is consumed as processed food in the form of dehydrated, canned, fries, chips etc. Organic potatoes are the recent fad with consumers becoming more mindful of hazards of agro-chemicals on their health. Simultaneously, the crop offers multifarious industrial uses like feed, starch alcohol production etc. Each of the recipes and uses entails specific quality requirements for ensuring product quality and consumer contentment.

Potatopossesses a high level of moisture contentwhich makes itbulky and highly perishable in nature, especially under tropical and subtropical conditionscausing upto 40% to 50% losses due to the poor handling and storage. Processing of potatoes is therefore preferred to facilitate storage, transportation and increase in shelflife. It adds value to potatoes yielding higher returns, especially for the urban population seeking ready to eat foods. Potato processing is also desirable in view of the seasonal gluts, which are a dominant feature in India, leading to distress sale and loss of profitability to the farmers. Processed potato products, like potato flour, are highly versatile being used in manufacture of a wide variety of convenience foods andcan be used to improve the functional properties of several food products.

Based on these consumer expectationsa lot is happening around the globe to improve the consumer and user-based profile of potato. The major consumer-based uses of potato have been illustrated in **Fig. 1**. For plant breeders working on crop improvement this has offered both new opportunities and new challenges. There is an increasing need to develop cultivars for meetingthese diverse evolving consumer preferences and satisfying changing market demands (Martin and Li 2017; Kumar *et al.,* 2018). The boundary of breeding objectives has expanded way beyond historical priorities like yield and disease resistance to meet the emerging consumer preferences. In view of these, there is a dire need to developconsumer-oriented breeding objectivesin sync with the agroclimate situation prevalent in the country.

The availability of large genetic variability in potato genetic resources with 98000 accessions *ex situ* and 80% of them being maintained in 30 key locations (FAO, 2010) offers massive opportunity to breed consumer oriented varieties. Desirable characters related to potato quality, which includes biological (e.g., proteins, carbohydrates, and minerals) and sensorial traits (e.g., flavour and texture) and industrial traits (e.g. tuber shape, cold sweetening and starch quality) can be easily selected and introgressed, using conventional and modern breeding tools.

Based on our studies on potato breeding and observations related to the Indian consumers an elaborate compilation of the various potato characteristics relevant tovaried potato consumer sector has been compiled and specific breeding objectives have been formulated for each. This can be an important resource for not only initiating specific breeding programmes but alsoprovide a basic road map for potato breeders, consumers and seed producers to breed, consume and multiply the variety of their choice, offering higher renumeration as well as consumption contentment. Selection indices can be formulated based on this compilation for evaluation of genetic stocks belonging to different consumer preference type.

Potatoes in India

On the basis of area and production, India stands fourth and second respectively in the world(FAO, 2010). Increasing population and urbanization in India have changed the consumer market preferences which also affect potato consumption in the country in tune with other developing nations(Pandey and Sarkar 2005).In India potato is cultivated in almost all parts of the country but mainlyin the states of Uttar Pradesh, West Bengal, Punjab, Bihar, Haryana, Madhya Pradesh, Gujarat and Maharashtra, with other states contributing to small areas under potato cultivation. The unique Indian agroclimate witnesses potato cultivation all around the year, in one part of the country or other. Of the total potato production in the country 90% comes from the plains, where potato is planted under the short-day winter conditions, while the hillsand plateau regions each contribute5% of the total production.

ICAR-Central Potato Research Institute which is the major potato research Institute in India has released 66 different varieties of potato till date, which mostly cater to the different agro-ecological regions of the country besides addressing the various stresses afflicting the productivity of the crop. Besides, these some exotic varieties and varieties of private companies and growers are also cultivated in India. Potato variety software developed by ICAR-Central Potato Research Institute provides basic knowledge on the different potato varieties developed indigenously for diverse Indian conditions

Fig. 1. Consumer oriented uses of Potato

(Rawat *et al.,* 2020). This database can be easily accessed and queried to retrieve this information. Detailed account of Indian potato varieties, their adaptability, resistance/ tolerance to biotic/abiotic stresses and quality attributes has also been compiled by Luthra *et al.* (2020). The major attributes of nutritional and consumer importance of Indian potato varieties have been compiled in **Table 1.**

Irrespective of the fact that the Indian vegetable basket is incomplete without the potato, it is merely a potato for the masses, who are mostly unaware of the existence of large number of prevalent varieties in India and their differential characters. Varietal differences crudely regulate the market value, in India where processing varieties were observed to fetch higher remunerations as compared to table use varieties. Lack of knowledge among the consumers and the seed producers about potato varieties, has negative implications in correct targeting of the varieties for both cultivation and its consumption.

A major lacuna is observed in a lack of adoption of varieties based on the traits value. Three indigenous varieties namely Kufri Pukhraj, Kufri Jyoti and Kufri Bahar are reportedly the most popular among the farmers occupying 33%, 21% and 17 % areas respectively in the 6 major potato growing areas of the country. These again occupy 2nd, 5th and 6th place in southeast Asian potato growing countries (Bhardwaj *et al.,* 2010). This is a clear indicative of the absence of consumer driven demand. Only the varieties having higher productivity and adaptability as suited to the growers are being cultivated which are being merely bought by consumers, irrespective of choice, based on availability. Lack of consumer feedback and institute-industry collaboration has been reported as a major factor severely hampering the adaptability of released varieties and development of consumer driven varieties (Bhardwaj *et al.,* 2010). Reducing the gap between consumer and use-based preference of potato and breeding such varieties with due consideration to productivity and its various constraints (biotic and abiotic stresses) will lead to development of more successful varieties in India.

Consumer preference

Like everywhere else, there is a risingcognizance in the country about the quality of food we eatandthe novel productsthat can be derived from food crops in the form

Table 1. Major characters related to nutritional and consumer interest in Indian potato varieties

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute		Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
1	Kufri Alankar	White-cream	Ovoid	Cream	Medium deep eyes	North Indian Plains	Medium	Easy To cook, Texture Floury, Flavour Mild	Early Bulker	Average	L ≤ 30	M 16-25	-	-	-	>45	18.6
2	Kufri Anand	White Cream	oblong	White	Shallow Eyes	North Indian Plains	Medium	Easy To cook, Texture Floury, Flavour Mild	Tolerant to hopper burn and frost, good for growing in spring season	Average	M 31-20	M 16-25	L ≤ 25	M 50-100	L ≤100	>45	17.3
3	Kufri Arun	Red	Ovoid	Cream	Medium Deep Eyes	North Indian Plains	Medium	Easy To cook, Texture Mealy, Flavour Mild		Good	M 31-50	L ≤ 15	-	-	-	>45	20.4
4	Kufri Ashoka	White	Ovoid	Cream	Medium deep eyes	North Indian Plains	Early	Easy To cook, Texture Waxy, Flavour Mild		Good	L ≤ 30	M 16-25	M 26-35	M 50-100	L ≤100	>45	18.2
5	Kufri Badshah	White	Ovoid	Cream	Shallow Eyes	North Indian Plains and plateau	Medium	Easy To cook, Texture Floury, Flavour Mild. Coloration on exposure to light		Average	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	>60	18.1
6	Kufri Bahar	White	Ovoid	Cream	Shallow Eyes	North Indian Plains and plateau	Medium	Easy To cook, Texture Floury, Flavour Mild, Coloration on exposure to light		Average	L ≤ 31	M 16-26	L ≤ 26	M 50-101	L ≤101	>61	19.0
7	Kufri Chamatkar	Yellow	Round	Yellow	Medium deep eyes	North Indian Plains	Late	Easy to cook, texture waxy, Flavour Mild	Mainly Medium size Tubers	Poor	M 31-50	L ≤ 15	M 26-35	H > 100	L ≤100	>60	19.9
8	Kufri Chandramukhi	White Cream	Ovoid	White	Shallow Eyes	North Indian Plains and plateau	Early	Easy to cook, texture floury, Flavour Mild	Attractive Tubers with excellent flavour, Suitable for processing also	Good	L ≤ 30	M 16-25	M 26-35	H > 100	L ≤100	>45	19.5
9	Kufri Chipsona -1	White Cream	Ovoid	White-Cream	Shallow Eyes	North Indian Plains	Medium	Easy to cook, texture waxy, Flavour Mild		Good	L ≤ 30	M 16-25	H ≥ 36	M 50-100	L ≤100	>45	21.2
10	Kufri Chipsona -2	White Cream	Round	Cream	Shallow Eyes	North Indian plains	Medium	Easy to cook, texture waxy, Flavour Mild	Good for growing in spring season, frost tolerant, Suitable for processing also	Average	L ≤ 30	M 16-25	H ≥ 36	M 50-100	L ≤100	>45	22.3

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Table 1. Continued..

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute	Storability	Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
11	Kufri Chipsona-3	White Cream	Ovoid	White	Shallow Eyes	North Indian plains	Medium	Easy to cook, texture waxy, Flavour Mild		Good	L ≤ 30	L ≤ 15	M 26-35	M 50-100	M 101-350	>45	21.7
12	Kufri Chipsona-4	White Cream	Round	White	Shallow Eyes	Karnataka, West-Bengal and Madhya Pradesh	Medium	Easy to cook, texture waxy, Flavour Good	Suitable for processing also	Good	L ≤ 30	M 1 6-25	L ≤ 25	M 50-100	L ≤100	>45	22
13	Kufri Dewa	White Cream	Ovoid	Cream	Deep Eyes	North Indian Plains	Late	Easy to cook, texture waxy, Flavour Mild	Frost tolerant and good keeper	Very Good	L ≤ 30	L ≤ 15	M 26-35	M 50-100	M 101-350	>45	21.5
14	Kufri FryoM	White-cream	Oblong,	White	Shallow	North-western plains, Central plains	Medium to Late	Mealy texture, pleasant flavour	Good for French fries	Average	-	-	-	-	-	>45	20.1
15	Kufri Frysona	White Cream	Long-oblong	white	Shallow Eyes	North Indian Plains	Medium	Easy to cook, texture floury, Flavour Mild		Good	L ≤ 30	L ≤ 15	M 26-35	M 50-100	L ≤100	>45	23.6
16	Kufri Ganga	White Cream	Ovoid	Cream	Shallow Eyes	North Indian Plains	Medium	Easy to cook, texture Mealy, Flavour Good	Tolerate to moderate drought conditions	Good	-	-	-	-	-	>60	17
17	Kufri Garima	Light Yellow	Ovoid	Light Yellow	Shallow Eyes	Indo-Gangetic Plains and Plateau	Medium	Easy to cook, texture Mealy, Flavour Good		Good	L ≤ 30	M 16-25	-	-	-	>45	18
18	Kufri Gaurav	White Cream	Ovoid	White-Cream	Medium deep eyes	North Indian Plains	Medium	Easy to cook, texture Mealy, Flavour Good	Nutrient use efficient even at sub-optimal doses	Good	L ≤ 30	M 16-25	H > 100	H > 100	L ≤100	>45	15
19	Kufri Girdhari	White Cream	Ovoid	White	Shallow Eyes	Indian Hills	Medium	Easy to cook, Texture waxy, Flavour Mild	Long dormancy of tubers	Average	M 31-50	M 16-25	L ≤ 25	M 50-100	L ≤100	>60	18.3
20	Kufri Giriraj	White Cream	Ovoid	White	Shallow Eyes	North Indian Hills	Medium	Easy to cook, texture waxy, Flavour Mild		Average	L ≤ 30	M 16-25	M 26-35	H > 100	L ≤100	>45	17.4
21	Kufri Himalini	White Cream	Ovoid	Cream	Medium deep eyes	North Indian Hills	Medium	Easy to cook, texture waxy, Flavour Mild	Yields good in hills and plains, possess day-neutrality feature	Average	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	>60	19.4
22	Kufri Himsona	White Cream	Round	creamy	Shallow Eyes	Indian Hills	Late	Easy to cook, texture waxy, Flavour Mild		Good	L ≤ 30	L ≤ 15	H ≥ 36	M 50-100	M 101-350	>45	23.7

Table 1. Continued..

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute	Storability	Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
23	Kufri Jawahar	White Cream	Round	Cream	Medium deep eyes	North Indian Plains and Plateau	Early	Easy to cook, texture waxy, Flavour Mild	Slow rate of degeneration and suitable for inter-cropping	Average	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	>45	18.6
24	Kufri Jeevan	White Cream	Ovoid	Cream	Shallow Eyes	North Indian Plains	Late	Easy to cook, texture floury, flavour mild		Average	L ≤ 30	M 16-25	M 26-35	M 50-100	M 101-350	>45	20.4
25	Kufri Jyoti	White-cream	Ovoid	Cream	Shallow Eyes	Hills, Plains and Plateau	Medium	Easy to cook, texture waxy, Flavour Mild good for processing	Wide adaptability, early bulker and show rate of degeneration	Good	L ≤ 30	L ≤ 15	L ≤ 25	M 50-100	L ≤100	>75	18.6
26	Kufri Kanchan	Red	Ovoid	Cream	Medium deep eyes	North-Bengal Hills and Sikkim	Medium	Easy to cook, texture floury, flavour mild	Slow rate of degeneration	Good	L ≤ 30	L ≤ 15	M 26-35	M 50-100	M 101-350	>60	19.1
27	Kufri Karan	White cream	Ovoid	Cream	Shallow	Hills and Plateau	Medium	Easy to cook, texture mealy, flavour mild	Multiple disease resistant varietyfor late blight, viruses andPCN disease	Good	-	-	-	-	-	>80	18.8
28	Kufri Khasigaro	Yellow	Round	Cream	Medium deep eyes	North-eastern Hills	Late	Easy to cook, texture floury, flavour mild		Average	M 31-50	M 16-25	-	-	-	>45	22
29	Kufri Khyati	White	Ovoid	Cream	Medium deep eyes	North Indian Plains	Early	Easy To cook, Texture Waxy, Flavour Mild	Early bulker, suitable for high cropping intensity	Good	M 31-50	M 16-25	L ≤ 25	L < 50	L ≤100	> 60	16.1
30	Kufri Kuber	White	Ovoid	White	Medium deep eyes	North Indian Plains and Plateau	Early	Cooks on prolonged boiling, texture floury, flavour mild		Poor	L ≤ 30	M 16-25	-	-	-	>45	22.7
31	Kufri Kumar	Yellow	Ovoid	White	Shallow Eyes	North Indian Hills	Late	Easy to cook, texture floury, flavour mild		Good	L ≤ 30	M 16-25	M 26-35	H > 100	M 101-350	>45	19.5
32	Kufri Kundan	White	Ovoid	White	Medium deep eyes	North Indian Hills	Medium	Cooks on prolonged boiling, texture floury, flavour mild		Poor	L ≤ 30		M 26-35	M 50-100	M 101-350	>45	24.2
33	Kufri Lalima	Red	Round	White	Medium deep eyes	North Indian Plains	Medium	Cooks on prolonged boiling, texture floury, flavour mild		Average	L ≤ 30	M 16-25	M 26-35	M 50-100	M 101-350	>75	19.9

Table 1. Continued..

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute	Storability	Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
34	Kufri Lalit	Light red	Round	Light Yellow	Medium deep eyes	Eastern Hills	Medium	Easy to cook, texture mealy, flavour good		Good	L ≤ 30	L ≤ 15	-	-	-	>45	18
35	Kufri Lauvkar	White	Round	cream	Medium deep eyes	Plateau	Medium	Easy to cook, texture floury, flavour mild, good for processing	Heat tolerant	Average	L ≤ 30	M 16-25	M 26-35	M 50-100	M 101-350	>45	19.2
36	Kufri Lima	White-cream	Ovoid	cream	Shallow Eyes	North Indian Plains	Medium to late	Easy to cook, texture floury, flavour good	Tolerant to early heat, leaf hopper & mite and suitable for early and main season planting	Good	-	-	-	-	-	> 60	19
37	Kufri Megha	White	Ovoid	Cream	Medium deep eyes	North -eastern Hills	Medium	Easy to cook, texture floury, flavour mild		Good	L ≤ 30	M 16-25	M 26-35	H > 100	L ≤100	> 60	18.6
38	Kufri Mohan	White-cream	Ovoid	White	Shallow Eyes	Northern and Eastern Plains	Medium	Easy to cook, texture mealy, flavour good		Good	-	-	-	-	-		17
39	Kufri Muthu	White	Ovoid	Cream	Shallow Eyes	South Indian Hills	Medium	Easy to cook, texture floury, flavour mild	Tolerant to hopper burn	Poor	L ≤ 30	M 16-25	M 26-35	M 50-100	M 101-350	> 60	18.7
40	Kufri Naveen	White	Round	Yellow	Medium deep eyes	North -Eastern Hills	Late	Easy to cook, texture waxy, flavour mild		Poor	L ≤ 30	M 16-25	M 26-35	H > 100	M 101-350	>45	19.6
41	Kufri Neela	White	ovoid	Cream	Shallow Eyes	South Indian Hills	Late	Easy to cook, texture floury, flavour mild		Average	L ≤ 30	M 16-25	L ≤ 25	H > 100	L ≤100	>45	19.7
42	Kufri Neelima	White	ovoid	White	Shallow Eyes	Nilgiri Hills	Medium	Easy to cook, texture floury, flavour good	Possess combined resistance to late blight and PCN	Good	-	-	-	-	-	> 60	17
43	Kufri Neelkanth	Dark purple black	ovoid	Cream	Medium deep eyes	North Indian Plains	Medium	Easy to cook, texture mealy, flavour excellent	Speciality potatoes, rich in anti-oxidants with excellent flavour	Good	-	-	M 26-35	H > 100	M 101-350	> 60	18.5
44	Kufri Pukhraj	Yellow	Ovoid	Yellow	Medium deep eyes	North Indian palins and Plateau	Early to medium	Easy to cook, texture waxy, flavour mild, Coloration on exposure to light	Early bulker, suitable for low-input ecosystem	medium	L ≤ 30	M 16-25	L ≤ 25	M 50-100	M 101-350	>45	16.1

Table 1. Continued..

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute	Storability	Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
44	Kufri Pukhraj	Yellow	Ovoid	Yellow	Medium deep eyes	North Indian palins and Plateau	Early to medium	Easy to cook, texture waxy, flavour mild, Coloration on exposure to light	Early bulker, suitable for low-input ecosystem	medium	L ≤ 30	M 16-25	L ≤ 25	M 50-100	M 101-350	>45	16.1
45	Kufri Pushkar	Yellow	Ovoid	cream	Medium deep eyes	North Indian Plains	Medium	Easy to cook, texture waxy, flavour mild		Good	L ≤ 30	M 16-25	L ≤ 25	H > 100	L ≤100	>75	17.5
46	Kufri Red	Red	Round	Cream	Medium deep eyes	North-Eastern Plains	Medium	Cooks on prolonged boiling, texture waxy, flavour strong		Good	M 31-50	M 16-25	-	-	-	>75	19.9
47	Kufri Sadabahar	White	Ovoid	White	Shallow Eyes	Uttar Pradesh and adjoining areas	Medium	Easy to cook, texture mealy, flavour mild	Early Bulker	Good	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	>45	17.9
48	Kufri Sahyadri	Light yellow	Oval	Yellow	Shallow eyes	Nilgiri Hills of Tamil Nadu.	Medium	Mealy texture, good taste, flavour and appearance.	PCN and late blight resistance, suitable for table and processing	Good	-	-	-	-	-	>75	18.5
19	Kufri Safed	white-cream	Round	cream	Medium deep eyes	North Indian Plains	Late	Cooks on prolonged boiling, texture waxy, flavour mild		Good	L ≤ 30	L ≤ 15	M 26-35	H > 100	M 101-350	90	21.0
50	Kufri Sangam	White cream	Ovoid	Cream	Shallow eyes	Northern plains and Central plains	Medium	Easy to cook texture mealy	Suitable for processing as well as table purpose	Good	-	-	-	-	-	> 70	22.0
51	Kufri Shailja	white cream	Ovoid	white	Shallow Eyes	North Indian Hills	Medium	Easy to cook, texture waxy, flavour mild		Average	L ≤ 30	M 16-25	H ≥ 36	M 50-100	L ≤100	> 60	18.2
52	Kufri Sheetman	White-cream	Round	cream	Medium deep eyes	North-Western Plains	Medium	Easy to cook, texture waxy, flavour mild	Frost tolerant	Good	L ≤ 30	L ≤ 15	M 26-35	M 50-100	M 101-350	>45	21.9
53	Kufri Sherpa	Yellow	Round	cream	Medium deep eyes	North Bengal Hills and Sikkim	Medium	Easy to cook, texture floury, flavour mild		Poor	L ≤ 30	M 16-25	M 26-35	M 50-100	L ≤100	>45	21.4

Table 1. Continued..

S. No	Variety Name	tuber colour	tuber shape	tuber flesh colour	Tuber eyes	Adaptability area	Maturity	Consumer and processing quality	Special attribute	Storability	Iron (PPM)	Zinc (PPM)	Ascorbic acid (mg/100g FW)	Anthocyanin (µg/100g FW)	Carotenoids	Dormancy	Dry Matter (%)
54	Kufri Sindhuri	Red	Round	cream	Deep Eyes	North-Indian Plains	Late	Easy to cook, texture waxy, flavour mild	Suitable for low input eco-system	Good	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	>75	20.3
55	Kufri Surya	white	Oblong	cream	Shallow Eyes	North Indian Plains and Plateau	Early	Easy to cook, texture waxy, flavour mild, Good for making French fries	Heat tolerant, suitable for early planting in plains, tolerant to hopper burn	Good	M 31-50	M 16-25	H ≥ 36	M 50-100	M 101-350	>45	17.8
56	Kufri Sutlej	White Cream	Ovoid	White	Shallow Eyes	North Indian Plains	Medium	Easy to cook, texture waxy, flavour mild		Average	L ≤ 30	M 16-25	L ≤ 25	M 50-100	L ≤100	> 60	19.2
57	Kufri Swarna	White Cream	Ovoid	White	Shallow Eyes	South Indian Hills	Medium	Easy to cook, texture floury	Possess combined resistance to late blight and PCN	Poor	L ≤ 30	L ≤ 15	L ≤ 25	M 50-100	M 101-350	>45	20.1
58	Kufri Thar 1	Light yellow	Ovoid	Yellow	Medium deep eyes	Middle Gangetic plains, East coast hills and plains	Early	Texture Mealy	Water use efficient variety	Medium to good	-	-	-	-	-	>50	>19
59	Kufri Thar 2	Light yellow	Ovoid	Light yellow	Shallow eyes	Drought prone areas	Medium	Pleasant flavour, Texture mealy	Water use efficient with Drought tolerance, high resistance to late blight	Good	-	-	-	-	-	>45	20-21
60	Kufri Thar 1	White	Round-oval	Cream	Medium deep	Transgangetic plains, Upper Gangetic plains, Eastern plateau and hills region.	Early medium and Medium	Easy to cook, texture waxy	Water use efficient variety	Good	-	-	-	-	-	>45	17.9

L: Low; M: medium; H: high; PCN: Potato cyst nematode of processed food products, feedand industrial uses. In recent years, potato has also evolved such multifarious uses, each having a specific quality requirement. This can be related to its visual appeal, organoleptic preference of the consumer, and also its ability to accommodate to the specific end use and meet market specifications. The tuber colour, shape, size, eye depth, appearance, disease or defects, flavour and texture, keeping etc. all determine the quality of the produce for varied uses. The use and the ethno-diversity of the population in a region affect the consumer preference of potato.It is evident that an understanding of the potato's culinary aptitude based on its organoleptic, intrinsic and extrinsic quality parameters is most vital for not only its better utilization but also consumer wise introduction, dissemination and acceptance. Limited study on this aspect has been carried out in India till date. Kharumnuid *et al.*(2020)studied that the ranking of attributes on consumer preferences of table potatoes in Punjab region of India. He reported that consumers preferred medium sized tubers, red smooth skin, round shape, with long shelf life, white flesh colour, medium eye depth, mealy texture, medium cooking time and medium aroma. With yield being a major priority in all breeding programmes (new varieties are introduced based on their higher yield and agronomical performance), the future potato industry will most likely depend on the consumer oriented marketing of higher value product in the specific sector. This will also generate greater prospects to the growers for getting premium prices for their produce and increasing their profitability.

Potato development as a food

In India, potato was introduced in early seventeenth century by the Portuguese in the western coast and by the British in Bengal (Pandey *et al.,* 2003). It was cultivated in the highlands of South-India and North-eastern India. The varietal requirements for food use of potato have been described as highly varied, consisting of the sum of favourable characteristics of the tuber. It has been described as a subjective and dynamic concept influenced by tradition, lifestyles and food habits of consumers (Richards *et al.,* 1997). The flavour of food derives from the various chemical transformations that occur during cooking/ heating and are closely associated with the cooking method used like boiling, baking, deep-frying etc. These finally result in a characteristic 'potato flavour' which is relatively unique neutral and bland and accounts for not only its world-wide acceptance and consumption but also its the ability to blend itself to a wide variety of foods. Potato is an inclusion in mostly all national cuisines and also as staple food.

Consumer preferences for potato as food in India

An internet search on the list of potato recipes eaten in India gives a figure of more than 140 different recipes having potato as the main ingredient. The Indian preparations of potato utilize different methods of cooking potato including boiling, steaming, pressure cooking, baking and frying. Based on its use as food popularly potatoes are defined as table potatoes and processed potatoes. Processed potato products likechips, frozen fries, dehydrated potato flakes and granules, alcohol based beverages are available in the market. Highest SI (satiety index) has been reported for boiled potatoes as compared to the 38 other foods items grouped in six food classes viz. fruit, bakery products, snack foods, carbohydrate-rich foods, protein-rich foods, and breakfast cereals (Holt *et al.,*1995).

Dry matter is most crucial factor for consumer acceptance and use, while low glycoalkaloids content (<15mg/100gram fresh tuber weight) and ability to withstand cold induced sweetening are added advantages. Characters like tuber defects, glycoalkaloids, greening and nutritional values are highly important for both processors and table potato consumers. Characters like enzymatic browning, sugar content and dry matter are more preferred by processors as compared to table potato consumers. Flavor had higher importance for consumers as compared to processors. Relationship between dry matter, texture and its preferable typical use have been described by (Mosley and Chase 1993, Singh *et al.,* 2016, Luthra *et al.,* 2004, 2019). Low dry matter potatoes with dry matter lesser than 18 % having very soggy to soggy textures are preffered for pan frying, salads and canning. Higher dry matter potatoes with dry matter above 20.3% are mealy or dry and suitable for processing and baking. Medium dry matter potatoes (18-20.3 %) with dry matter within these ranges can be used for boiling, mashing and canning.

Tuber colour, size and shape: The wide genetic diversity of potato has allowed the perpetuation of its varied types/ varieties in the different regions of the world as well as the country *per se*. Varieties with white, yellow or red skin colour and having shallow or medium eyes are mostly preferred by consumers in India. However, there is an increased interest in yellow and coloured fleshed varieties. The morphological and organoleptic preferences among different regions also vary.The consumers of Gujarat state prefer sweet tasting and small red coloured potato tubers, while the eastern states prefer red skinned varieties.

Colour is animportant food quality parameterwhich affects both consumer acceptance and sentiments, besides indicating its higher antioxidant levels and increased health benefits(Ou *et al.,* 2004, Jansen and Flamme 2006). Dark yellow-coloured tubers reportedly indicate higher levels of vitamin A and rich flavour compared to traditional fleshed potato varieties in India, while also exhibiting less after-cooking discolouration than some red skinned varieties (Luthra *et al.,* 2004). Preference for yellow fleshed varieties with white and purple skins as compared to yellow flesh, red skin varieties has been reported from USA(Jemison *et al.,* 2008). They also reported preference to be associated with tuber skin quality.

Fernqvist *et al.* (2015)in their study carried out in Sweden, reportedconvenience as the most important factor affecting changing food behaviorof potato as compared to the other factors like health, information and packaging, sensory appeal, purchase price, familiarity and habit, sustainability and ethics. In a similar study by MacPherson *et al.*(2012), choice tactics at store (size, color, shape and size uniformity), post-purchase evaluation at home and the value orientations (taste and lifestyle)drove consumption in Canada. Dukeshire *et al.* (2016) recorded positive attitudes towards potato nutrition, taste, preparation and enjoyment among high- and low-frequency potato users in eastern Canada. While age of participants and its perceived importance in everyday meal wererecorded as strong predictors of its consumption. Potato packaging, itsfirmness, and local production werethe most important point-of-purchase characteristics.Durham *et al.* (2015)based on consumer test of six unreleased varieties (four coloured) along with variety Yukon Gold reported that providing antioxidant informationof potato tubers increased purchase intent for coloured potato varieties, indicating consumers interest in improving personal health. Therefore, availability of nutritional information can play a pivotal role in increasing the demand of a variety and also to fetch premium prices for the same.

Organoleptic characters: Organoleptic charactersare the most important criterion for the acceptability and popularity of any food product. It constitutes not only the taste and flavor but also the aroma, colorand texture of the food, and are powerful driversfor repeated food purchase. Flavor can potentially increase consumer interest for fresh market and consumption and will help counter malnutrition especially in growing children (Jansky 2010a, Poelman *et al.,* 2013). Flavor comprises of precursors of sugars, amino acids, RNA, and lipids, which react during cooking to produce Malliard reaction products and degradation products of these precursors to impart potato flavour (Duckham *et al.,* 2002). The factors affecting potato flavor have been reviewed by Jansky 2010a and 2010b. Although potato has a wide genetic diversity, there is a requirement of validating the screening methods for identification of superior clones based on sensory and biochemical parameters.

Taste: Human taste receptors can monitor a wide range of taste and their gradations like bitter, sour, sweet, salty, and umami flavors (Luthra *et al.,* 2020).Bonierbale *et al.* (2009) and Dobson *et al.* (2004), adjudged the Phureja group to be the “better tasting” correlating its taste attributes to the relatively elevated abundance of certain branched amino acids in raw tubers and of branched short-chain aldehydes in cooked tubers as compared to the Tuberosum volatile profile. The higher scoring of tubers for acceptable flavour having higher levels of the certain compounds is an important advancement in our understanding of potato flavour. These flavouring compounds have been referred to as the *umami* compounds.

Bitterness:Bitterness as a rule is a deterrent and sweetness a strong stimulant for increasing consumption of vegetables (Friedman, 2006). Glyoalkoloids (oc-solanine and oc-chaconine) which are the inherent mechanism for protection of potato tubers against pests and diseases (Valkonen *et al.,* 1996) also impart strong bitter flavour to the tubers, making them unsuitable for consumption. Distribution of these glycoalkaloids in the tubersis not uniform. Higher concentrations occur in periderm and cortex as compared to the pith, showing both genotypic and environmental variation (Ross 1978, Omayio *et al.,* 2016).Domestication of potato over time has led to the selection of cultivars with low levels of glycoalkaloids(Johns and Alonso 1990).Their levelsfor the release of any new cultivar/ variety have been delineated at 20mg/100g fresh weight.Although higher levels of glycoalkaloids beyond 14mg/100g can be easily detected in the form of bitterness in tubers, they have been reported to positively contribute towards the unique potato flavor at low levels (below l0 mg/l00g) (Sinden,1976, Jansky 2010a).The Indian potato varieties contain glycoalkaloids within the permissible limit ensuring their safe consumption (Pandey and Sarkar 2005).

Aroma: Aroma isa complex character for sensory evaluation and identification of the better flavoured variant. Variation in consumer preference is much dependent on the region and personal attributes. A complex array of aromatic compounds are found in cooked potatoes. Coleman *et al.*(1981)identified 228 volatile compounds belonging to the lipids family, which contribute to the baked potato flavour. Although, potato lacks inherent aroma as observed in fruits and flowers, which promotes pollination and seed dispersal, its unique potato aroma is reported to inmate from cutting and cooking of potato in different ways.

Texture:Textureor mouth feel isanother important sensory attribute for potato preference which is related to the dry matter, specific gravity,starch content and quality, cell size and surface area and pectincontents in a particular potato variety(Thygesen *et al.,* 2001, Mayano *et al.,* 2007). Besides these cultivation and storage conditions also affect the texture of potato (Cottrell *et al.,* 1993).In general, dry and granular texture is reported as mealy, while a moist and gummy texture as waxy. A mealy texture is reportedly associated with high dry matter (Jansky 2008; Leung *et al.* 1983; Van Dijk *et al.,* 2002). The established chemical, biochemical and molecular levels markers of potato organoleptic parameters can be used to predict properties in the cooked/processed material.Presently, utility of a potato variety is generally determined by its dry matter content and texture, with a mealy texture indicating higher solids and a waxy texture low solids. Potatoes with more than 20% dry matter and a mealy texture are preferred for fried and dehydrated products, whereas small sized tubers with dry matter between 18- 20 % and waxy texture are preferred for salad making and canning. Important quality traits in respect to their importance to

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processors and consumers have been compiled by Dale and Mackay (1994).

Enzymatic Discolouration: The enzymatic and after cooking discolouration are genotype linked characters of much consumer relevance. Enzymatic discolouration occurs on cutting and peeling of potatoes due to a chemical reaction between tuber constituents like tyrosine and ortho-dihydric phenols with oxygen in the presence of the enzyme polyphenoloxidase resulting in tuber flesh browning (Schaller and Amberger 1974b).

After cooking darkening:The After cooking darkening (ACD) is a common phenomenon where a dark coloured ranging from grey to blue or purple to black patchy coating appears on cooked potatoes.It is reported to be caused by the oxidation of ferri-chlorogenic acid, showing direct correlation with itshigher concentrations in the potato tubers as compared to citric acid (Smith 1987, Pruskiand Nowak 2004; Heisler *et al.,* 1963). The degree of darkening shows variation inside the tuberand has been reviewed by Pruski and Novak 2004. Several methods like the exposure of potatoes to air and their immersion in water and chemical treatments have been reported to prevent ACD.Chemical chelating agents likeEthylenediaminetetraaceticacid (EDTA), sodium acid pyrophosphate (SAPP), gluconic acid, citric acid, sodium giuconate, sodium citrate, ammonium giuconate and sodium bisulfite have been reported to prevent ACD(Greig and Smith 1955, Ng and Weaver 1979;Mazza and Qi 1991). After-cooking discoloration is a major problem faced by potato consumers mainly canners.It reportedly shows both genotypic and environmental variation (Wang-Pruski*et al.,* 2003). Presently all the cultivated varieties in India are free from ACD(Pandey *et al.,* 2000).

Cold induced sweetening: The harvested semi perishable potato produce is stored under cold store conditions at 2–4°C to prevent post-harvest losses. Under these conditions thetubers accumulate high amounts of reducing sugars which alters the tuber flavour making it sweet and referred to as the'cold-induced sweetening' phenomenon. Besides losing theirdesirable flavour for table use the tubers also becomes unsuitable for processing into chips and french fries as the higher sugar content imparts a dark colouration on tubers during frying. Breeding varieties resistant to cold sweetening therefore becomes imperative for consumer preference of both table potato as well as processed potato consumers. Several studies on identification of varieties and germplasm resistant to cold induced sweetening, have been undertaken in India (Luthra *et al.,* 2009; Kumar 2011). Resistance to cold induced sweetening has been reported in some accessions of the species *S. albicans, S. demissum,*S. *jamesi*,*S. berthaultii, S. sparsi* and *S. tuberosum* ssp. *andigena* maintained low glucose level (glucose content <50 mg/ 100 g fresh tuber weight) (Meena *et al.,* 2009).However, at present none of the cultivated varieties in India are resistant to cold induced sweetening.

Keeping quality: The unique agro-climatic conditions of India allow potato to be cultivated inin almost every part of the county in different seasons of the year. However,90 % of this production comes from thesub-tropicalplains where high temperatures are prevalent immediately after potato harvestand lead to major post-harvest losses ofupto30% and therebyentailing the development of good keeping potato cultivarsto increase potato production.Post-harvest losses occur in the form of both physiological and quality losses.While, physiological losses are due to weight loss, sprouting and respiration in potato tubers, the quality losses occur in the form of rottage and reduction in firmness of tubers. The sprouting of tubers due to loss of dormany negatively affects the nutritional and processing qualities of potatoes, causing severe economic losses to producers. Currently sprouting is controlled chemically using synthetic sprout inhibitors which is a major cause of concern worldwide. Identification of key physiological processes that can be regulated naturally andgood keepinggermplasm lines to counter tuber dormancy and increase shelf life have been prioritized in recent years. In a study by Pandey *et al.* 2007(Pandey *et al.,* 2007) on keeping behaviour of 37 potato varieties it was observed that the dormancy period was the longest in Kufri Sindhuri and shortest in Kufri Lauvkarvarieties. The per cent weight loss after 60 days of sprouting was lower in varieties Kufri Safedand Kufri Chandramukhi (4.6 and 5.2% respectively).Similar study by Das *et al.* (2004)revealed K. Ashoka as a poor keeper under storage conditions in Bihar and emphasised the development of high yielding better keeping varieties for export and domestic consumption.Gupta *et al.* (2015) in their investigations onstorage behaviour of forty-four indigenous potato varieties at room temperature reported a highly significant and positive correlation between weight loss with sprout weight/Kg tubers andphysiological weight loss. Varieties namely, Kufri Chamatkar, Kufri Chipsona-1, Kufri Chandramukhi, Kufri Dewa, Kufri Jyoti, Kufri Kuber, Kufri Kundan, Kufri Lalima, Kufri Lauvkar, Kufri Pushkar, Kufri Red, Kufri Safed, Kufri Sheetman, Kufri Sindhuri were reported to possess excellent keeping attributes based on medium to long tuber dormancy (45 -75 days), low storage losses (upto 9.9 %), medium to high tuber dry matter (18.6-24.2) and good flavour. Development of good keeping quality with high productivity will be an unfailing solution for Indian conditions (Kaur *et al.,* 2020). Based upon above discussion, the breeding objectives for 61 table potato varieties are listed in **Table 2**.

Consumer preference for potato as a health food:The traditional Indian diet is cereal-centricwhere potato is mainly consumed as a vegetable which is contradictory to its wholesome carbohydrate rich nutritional profile, mostlyoblivious to the masses, and depending on its consumption as raw or cooked, and also on the method used for cooking ((Navarre *et al.,* 2010, Jayanty *et al.,* 2019). Its close association with fast food industry in recent years has further reiterated its image as a fatty food. Frying being the preferred method of consuming potato in the form of French fries, chips, aalu tikki, veg bullets

Table 2.Compiled breeding objectives for consumer preference of potato and potato products based on end use

Basic traits	Table potatoes	Nutritional value	Baby potatoes and fingerlings	Organic	Dehydrated	French fries	Chips	Canned	Feed for animals	Production of starch	Alcohol production
Skin colour	White, cream, yellow, red LP	Yellow, red, purple	White, cream, yellow, red, purple (visually attractive)	White, cream, yellow, red, LP	No preference	White or yellow	White or yellow	White or yellow	No preference	No preference	No preference
Flesh colour	Yellow, cream, white LP	Yellow, red, purple and their combinations	No preference	White, cream or yellow	White or yellow	White, cream or yellow	White, cream or yellow	White, cream or yellow	No preference	No preference	No preference
Tuber size	Medium	Medium	Small, uniformly produced	Medium	Medium	Large	Medium to large	Small	No preference	Large sized tubers for industrial processing	No preference
Tuber Shape	Round to oval	No preference	Round for baby potatoes and finger/ spindle for fingerlings	Oval to round	Round to oval	Oblong	Round to oval	Round to oval	No preference	Round or oval for industrial processing	No preference
Eye depth	Shallow to medium	Shallow to medium	Shallow	Medium to shallow	Shallow	Shallow	Shallow	Shallow	No preference	Shallow	Shallow
Skin smoothness	Smooth and shiny	Smooth and shiny	Smooth and shiny	Smooth and shiny	No preference	No preference	No preference	No preference	No preference	Smooth and shiny with	No preference
Organoleptic properties	Good taste, aroma, texture, mouth feel etc.	No preference	Good taste, aroma, texture, mouth feel etc.	Good taste, aroma, texture, mouth feel etc.	Good taste	Good taste, aroma, texture, mouth feel etc.	Good taste, aroma, texture, mouth feel etc.	Good taste, aroma, texture, mouth feel etc.	Desirable for fed animals based on animal feeding studies	No preference	No preference
Texture	Mealy or floury	Mealy or floury	Mealy or floury	NA	Fairly firm to mealy	Fairly firm	Fairly firm to mealy	Waxy	No preference	Floury	No preference
Reducing sugar, % fresh wt	No preference	No preference	No preference	NA	0.25	0.15	<0.1	0.5	No preference	No preference	No preference
Dry matter (%)	18-20 for boiled and >20 for baking	High dry matter preferred >18%	No preference	18-20 for boiled and >20 for baking	>20	>20	>20	<18	High dry matter preferred >18%	High	High
Cooking time	Less	Minimal to avoid losses in nutrition	Less	Less	Minimal after rehydration	Less	Less	Less	No preference	No preference	Less (facilitate hydrolysis of carbohydrates)
Disease resistance	AD	Preferably late blight resistance	AD	AD	AD	AD	AD	AD	AD	AD	AD
Tubers defect	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Table 2. Continued...

Basic traits	Table potatoes	Nutritional value	Baby potatoes and fingerlings	Organic	Dehydrated	French fries	Chips	Canned	Feed for animals	Production of starch	Alcohol production
After cooking discolouration	Absent	Absent	Absent	Absent	Slight	Slight	Absent or Slight	Absent		Absent	Absent
Glycoalkaloids	Low <15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<15mg/ 100 gm fresh weight	<200mg/ 100 gm	No preference	<200mg/ 100 gm
Phenols	High	High	Low (>0.02%)	High	Low (>0.02%)	Low (>0.02%)	Low (>0.02%)	Low (>0.02%)	No preference	Low (>0.02%)	Low (>0.02%)
Value added traits											
Nutrient efficiency	AD, Nutrient efficiency is desirable	No preference	No preference	Very high	No preference	No preference	No preference	No preference	No preference	No preference	No preference
Biotic stress	AD	AD	AD	Resistant to major diseases and insect pests prevalent in the area of cultivation. Should giveeconomical yield without any chemical spray (M)	AD	AD	AD	AD	AD	AD	AD
Heat stress	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD	*AD*
Nutritional value	Rich in antioxidants	Rich nutritive bioactive compounds	Rich in antioxidants	Rich in antioxidants (VA)	No preference	No preference	No preference	No preference	Higher protein content, minerals, rich in antioxidants	No preference	No preference
Keeping quality	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	Good keeping	No preference
Cold induced sweetening	Low/ resistant	Low/ Resistant	Low/ Resistant	Low/ resistant	Low/ resistant	Low/ resistant	Low/ resistant	Low/ resistant	No preference	No preference	High (for increased reducing sugar concentrations for processing to alcohols)
Greening	Low/ Resistant	Low/ Resistant	Low/ Resistant	No preference	No preference	No preference	No preference		Low/ Resistant		
Zn and Fe contents	Desirable	High									
Glycemic index	Desirable	Low	Low	No preference	No preference	No preference	No preference	Low	No preference	No preference	No preference
Starch quality	Not applicable	No preference	Very low amylose and high amylopectin content	No preference	No preference	No preference	No preference	No preference	No preference	Very low amylose and high amylopectin content	No preference

Objectives depicted in bold are major breeding objectives, un bold objectives are additional desirable . Abbreviations used AD: Agroclimate dependent and LP is local preference based on target population of a potato variety etc., increases the overall fat content of the fried product. Thereby creating a strong delusion about potato having a fattening effect to the consumers which is in stark contrast to its virtually fat and cholesterol free nature(Storey, 2007; Camire *et al.,* 2009).

Carbohydrate rich potatoes are valuable natural source of nutrients including a wide range of vitamins, minerals and dietary fibre (**Table 3**).Unlike the foods that provide "empty calories" (calories with less nutrition value), potatoes are rather nutrient dense. They provide equal or greater amount of recommended daily allowances of various vitamins (Vitamin C, B6 and B1, folate), minerals(potassium, phosphorus, calcium, and magnesium, iron and zinc) and proteins of a rich amino acid profile. They have been reported to contain 10% or more of the recommended dietary intake (RDI) of vitamin C, folate, thiamine, niacin, pantothenic acid and potassium. Besides being a rich source of dietary fibre,they contain diverse range of phytonutrients, antioxidants carotenoids and tocopherols especially when eaten unpeeled with its skin. Ithas a potential to improve food security and health, especially among women and children by contributing to improved diets and reduction in mortality rates caused by malnutrition. Coloured potatoes contain natural colorant, antioxidantsand other useful compounds which can be used as functional foods forbenefitting human health (Katan and De Roos 2004). Theirhearty consumption around the world, provides an opportunity for using them as vehicles to address health-related problems in humans(Ezekiel *et al.,* 2013).

The healing and medicinal properties of various components of potato have been reported by several workers (**Table 4)**. The concentration of nutrients in potatoes varies with species, location, crop year, maturity at harvest, soil and fertilizer contents. The discovery of anti-diabetic compounds in potato, which are being sought to be augmented through biofortification has added much interestamong the researchers. Increase in the anti-diabetic ingredients reported in potato such as biguanidine and metformin are expected to improve the insulin production to combat type II diabetes. Tubers of potato variety Kufri Surya have been found to lower the sugar levels of diabetic rats.

Phenolic contents and flavonols remain unaltered during the cooking process. Anthocyanin content in raw potatoes has been reported to be higher as compared to different processed products content mainly due toits alteration

Table 3 Nutritional value of potatoes

Nutrients (per 100 g fresh weight)	White flesh and skin, raw	Red flesh and skin, raw
Proximate composition		
Energy (kcal)	69	70
Protein (g)	1.7	1.9
Total lipid (fat) (g)	0.1	0.1
Carbohydrate, (g)	15.7	15.9
Total dietary fibre (g)	2.4	1.7
Total Sugars (g)	1.2	1.3
Minerals		
Calcium, Ca (mg)	9	10
Magnesium, Mg (mg)	21	22
Potassium, K (mg)	407	455
Phosphorus, P (mg)	62	61
Sodium, Na (mg)	16	18
Vitamins		
Total ascorbic acid (mg)	19.7	8.6
Thiamin (mg)	0.07	0.08
Riboflavin (mg)	0.03	0.03
Niacin (mg)	1.07	1.15
Vitamin B-6 (mg)	0.203	0.17
Folate (µg-DFE)	18	18
Vitamin E (mg)	0.01	0.01
Vitamin K (µg)	1.6	2.9
Vitamin A (IU)	8	8
Source: USDA, 2019		

Table 4. Antioxidants and other componentsin potato reported to effect human health

Component	Effect	Reference
Vitamin C ascorbate	Increases bioavailability of ironacts as anantioxidant and cofactor in enzymatic reactions, protects folates from oxidative breakdown.	Yun *et al.* 2004; Hale *et al.* 2008; Andre *et al.* 2010
Vitamin E	Prevents lipid peroxidation and oxidation of poly unsaturated fatty acids and low-density lipoproteins from by free radicals	Valk and Hornstra 2000; Raederstorff *et al.* 2015
Carotenoids	Prevents age related macular degeneration	Griffiths *et al.* 2007
Polyphenols	Inhibits angiogenesis, cardiovascular and neurodegenerative diseases, carcinogenesis, apoptosis, and acting as a modulator in signalling cascades and apoptotic processes	Arts and Hollman 2005, Stevenson and Hurst 2007
Antioxidants: flavonoids, carotenoids, polyphenols anthocyanins, ascorbic acid, tocopherols, alpha-lipoic acid and selenium	Elevated antioxidant status, Reduction in oxidative stress and inflammation, DNA damage,radical scavenging action; decrease in plasma cholesterol and triglyceride levels, reduced hepatic lipid peroxidation and inhibition of carcinogenesis	Hakimuddin *et al.* 2004; Lachman and Hamouz 2004; Han *et al.* 2006; Robert *et al.* 2006, 2008; Thompson *et al.* 2009; Kaspar *et al.* 2011

at high temperature, enzyme activity, pH changes and presence of metallic ions and proteins changes during processing (Fang *et al.,* 2011, Patras*et al.,* 2010).

Indian potato varieties have been evaluated for presence of phytochemicals viz. anthocyanins, carotenoids and phenolics by Dalamu *et al.* (2015) who reported eight accessions*viz.* Desa Lal, Gulabia, Ultimus, CP4242, Barielly Red, Phulwa Red, Lal Mitti-2 and Pimpernel to be excelling in all these three phytonutrients. Dalamu *et al.* 2017 reported iron and zinc content in raw and peeled tubers showing a variation of 14.90–67.13 mg/kg (ppm) and 2.78–35.40 mg/kg (ppm) respectively on dry weight basis in tuber flesh. They also reported a significant and positive correlation between these two nutrients in some of theaccessions, indicating the feasibility of breeding for both these nutrients simultaneously. Studies by Luthra *et al.* (2018a) indicate that, for breeding nutritionally superior table potato genotypes moderate to high tuber dry matter, high soluble protein and high ascorbic acid may be selected in the hybrid progenies. Molecular analysis of the progenies of a cross between Bareilly Red (Red skin, round shape, deep eyes, cream flesh with red broad vascular ring) and CP3770 (Red skin, round shape, medium deep dark red eyes, yellow flesh) using a highly polymorphic and diagnostic SSR marker (STM2005) for tuber flesh colour showed segregating profiles in the progenies and five advanced generation clones could be identified having desirable nutritional profiles (Luthra *et al.,* 2018b). An Indian variety has also been released namely Kufri Neelkanth having high antioxidant levels (Luthra *et al.,* 2020).The identified breeding objectives of nutritionally superior potatoes has been depicted in **Table 2**.

Baby potatoes and fingerlings

Thesmall round uniformly sized tubers of baby potatoes and small and narrow tubers of fingerling tubers have much visual appeal and are sold in small packaging at premium prices. The small undersized tubers produced in ware potato varieties production are mostly sold separately as baby potatoes, while fingerlings are potato varieties that naturally grow specific long finger-like spindly shape. They are served as salad or as a side dish and do not require peeling, thereby retaining the phytonutrients in the skin and drastically reducing preparation and cooking time due to their small size. Presently, work on cultural conditions for enhancing baby potatoes of released varieties *viz.* Kufri Himasona, Kufri Shailja and Kufri Khyati are being evaluated in India. Besides cultural manipulation to enhance baby potato production, breeding efforts can be directed to getting large number of uniformly sized baby potatoes of organoleptic preference. However, varietal development has not reached much headway for baby potato production in India. Varieties for fingerling potatoes like Russian Banana, Purple Peruvian and Swedish Peanut Fingerling are popular in other countries, but such varieties areabsent in India at present.Simultaneously, certain indigenous cultures like Bareilly Red, Rangpuria, Badami Aalu etc.having low yield and small tuber shapes fetch premium prices in various pockets of India.

Breeding objectives for these may be directed to evolving consumer-oriented traits, namely, superior taste, visual appeal, faster preparation and increased phytonutrients. It offers new opportunities outside of the traditional potato markets which can potentially relieve some of the overproduction issues faced by growers in traditional markets. With the growing number of consumers prioritizing nutrition, there is a need for the industry and nutritionists to increase information about the product profile of baby potatoes to the consumers. The breeding objective for baby potatoes are listed in **Table 2**.

Organic potatoes

Food grown organically is safe and nutritious. With the growing health consciousness among the consumers organic food has generated a high demand in the national and international markets, and have been related to a sense of food safety, reliability and trust among consumers (Greenway *et al.,* 2011). A large segment of the population has started preferring organic food over the chemical laden agricultural products available in the market. The organically produced food has stated fetching premium prices thereby makingit imperative to breed for organic potatoes or any crop consumed by mankind. Availability of organic potatoes will not only boost the consumption of potatoes in India but also its export toneighboring countries. Agrochemicals are utilized in agriculture in the form of fertilizers, insecticides, pesticides and fungicides, therefore varieties, which possesssuitable biotic stress resistance and the resilience to perform well under limited inputs thereby excluding the use of fertilizers are expected to perform better under organic cultivation systems perform better.Efforts on potato breeding for organic cultivationwill have to deviate itself from conventional production systems which use optimum fertilizer and pesticide. However organic cultivation has been reported to alter productivity, tolerance to abiotic and biotic stresses, storability and taste of genotypes, which would be a major consideration.In an evaluation of 54 potato genotypes includingadvanced hybrids and indigenous varieties evaluated with organic sources of nutrition,for their suitability for organic cultivation based upon their productivity Kufri Khyati and Kufri Mohan reportedly performed better (Luthra *et al.,* 2017).Leonel *et al.* (2017) reportedproduction of high-quality tubers with enhanced concentrations of phenolics, reduced nitrate and attractive tuber flesh colour for yellow-fleshed potato cultivars under organic cultivation. Adoption of suitable potato varieties in organic farming systems will go a long way in supporting a balanced agro-ecosystemand fetching remunerative prices to the growers in the market.

Consumer preference for potato as a processed food

Rapid urbanization, increase in women manpower, preference to convenience food, improved living standard, longer shelf life of processed products, tourism etc. have all led to a steadily expanding potato processing industry in India (Marwaha *et al.,* 2010). India's potato chips/crisps market was worth US$2.59bn in 2017, with an annual growth rate of 18.7%, which is expected to reach a value of $5.5bn in 2022.This has led to not only an increase in the number of entrepreneursand processing units but also in the capacity of existing processing units in the country. However, despite the increasing trends, only about 4% of the total potato produce in India is being processed as compared toestimated 30–67% in developed countries. (Rana and Pandey 2007).Which reveals that there is much untapped opportunity in this sector not only for development of new varieties but also for diverting the excess potato production and increasing profitability of potato stakeholders.To cater to the requirements of the processing industry, exotic processing varieties were initially introduced in the country, which however failed to perform well under the Indian agro climatic conditions. Subsequently, breeding programmes for processing varieties were initiated in the countryand fewpotato varieties have been bred and released in India since 1998 namely Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Himsona, Kufri Fyrsona, Kufri Fryom (French Fries) Kufri Chiposna-4 and Kufri Sangam (Chips).The varieties Kufri Chipsona-1, Kufri Chipsona-2 were bred in arecord time of merely 8 years (Pandey *et al.,*2003). These have>21% dry matter and contain low reducing sugars (<0.1% on fresh weight basis) and can be grown in most parts of the country to get processing grade potato tubers which may be consumed fresh or after storage at 10–12°C with CIPC ([Isopropyl N-(3-chlorophenyl) carbamate])(Pandey *et al.,* 2002, Kumar and Ezekiel 2006; Ezekiel *et al.,* 2007; Kumar *et al.,* 2007). Breeding of there varieties along with the standardization of processing potato storagetechnology haschanged the processing industry scenario in the country, effectively countering the glut situation by effective management of produce and increasing profitability of farmers.Processing varieties stored at 10–12°C are popular as 'low sugar potatoes' for table or ware consumption sell premium pricesin Indian market (Pandey *et al.,* 2008b). A few imported processing varieties like 'Atlantic' and 'Frito-Lay' hybrids are also cultivated in India.

Morphological characters like tuber shape, eye depth, skin and flesh color are of immense importance for processing varieties. There is much impetus on breeding of varieties with oblong shape type suitable for making French fries. Besides these minimum quality standards required for varieties in processing industry have been summarized in detail by Marwaha *et al.* (2010). High dry matter of the processing varieties in most crucial for ensuring higher weight and recovery of processed product, low oil absorption, lower energy consumption and crispy texture of the product. Specific gravity estimation is reportedly an easy and quick method for dry matter estimation (Grewal and Uppal 1989). Similarly, higher levels of reducing sugars (< 0.1% on fresh weight basis) in tubers impart unacceptable dark colour and bitter taste on frying due to 'Maillard reaction' between reducing sugars and free amino acids of tubersleading to the formation of acrylamide (Marwaha 1997; Marwaha *et al.,* 2008). It not only affects the colour and flavour of the processed product but is a potent toxic compound having carcinogenic properties (Lo Pachin 2004).

Development of early maturing processing varieties,varieties resistant to cold induced sweeteningand antioxidant rich processed products for the consumers, are the future scopes for this flourishing industry. Additional internal quality traits like glycoalkaloids, enzymatic discoloration, nutritional quality, greening(>3%), total tuber defects and tuber dormancy also need to be considered(> 15%) (Storey, 2007, Jansky 2009, Werij 2011, Luthra *et al.,* 2018a and Luthra and Gupta, 2019). Beyond its consumption mainly as human food, potato is consumed as raw material in various industries like starch and alcohol and also as feed for animals.

Potato as a feed for reared animals

Potatoes can be fed to reared animals in raw, cooked, culled ormashed form and aspeels and processed form as starch or pellets in combination with other feed products. It is an efficient strategy to manage potato tubers which do not meet market standards, are in oversupply or produced as waste from processing industry (Schroeder 2012). Ensilage of potato has been reported with dry hay, maize stover or strawthis not only improves the fibre content of the feed but also increases its shelf life and reduces choking hazard (Okine 2005, Schroeder 2012).Culled potatoes are a good, succulent feed for farm animals having higher biological value of proteins and favorable amino acid composition, but with very less protein content. It can be fortified with protein supplements and minerals (calcium and magnesium)based on the diets of the animal(Lisinska and Leszczynski, 1989, Halliday 2015). Much of potato production in the Russian Federation and east European countries is used as animal feed, where cattle are reportedly fed upto 20 kg raw potatoes and pigs 6 kg of potatoes a day.Feeding of fresh potatoes mixed as a part of the total ration or chopped had reportedly no adverse effects on acceptability, palatability and the performance of animals while the phenolics present in the peels have the potential to act as antibioticagents (Anonymous 2012, Guil-Guerrero *et al.,* 2016, Sharma *et al.,* 2016). However, Due care needs to be exercised to avoid feeding of potato sprouts, greened potatoes, fungal infested which contain elevated levels of toxic alkaloids (α-solanine and α-chaconine).

Identification of greening resistant varieties will be of much value for developing varieties for specifically animal feed as itallows their easy storage under farm conditions. Variations in greening reactions indicate variation in components of greening (external color, internal color, and depth of color) among varieties(Reeves 1998). The depth of greening has been reported to be less in russetted varieties as compared to white varieties, while red varieties showed less discoloration for all three components, indicating independent inheritance. Resistance to greening isstrongly linked to suberin content in the periderm,number of phellem cell layers and light-induced carotenoids and anthocyanins(Tanios *et al.,* 2020).However, there is much scope for research for not only in development of varieties suitable for feed but also for strategies to prolong shelf life of potato feed products ensuring environmental and financial sustainability.

Preference of potato for industrial uses

***Potato starch industry*:** Starch is commercially produced from maize, wheat, tapioca, and potato while in India maize and tapioca are its major sources. It is used in the manufacture of a variety of products. Its increasing demand in the country offers scope for improvement in production efficiencies and product quality. Traditionally, the starch was mainly used for thickening and adhesion, but with development of modern applications and processing methods has led to an increasing need for further product refinement for specific uses. In recent years starch has found applications as a feeder to the paper industry, stability agent in food, warp sizing and fabric printing in textile industry, fluid loss control during deep-well drilling for oil and gas and flocculation in the purification process for drinking-water. It is also an environment friendly biodegradable substitute for several polymers like disposable plates etc. Starch extraction can be an effective strategy to manage overproduction and crashing potato prices. Simultaneously flow process waters from other potato processing industries may be directed for extraction of reclaimed potato starch.

Extraction of starch requires special potato varieties, which may not have very high food value but rich starch content. Since dry matter has a major correlation with starch content of the tuber, which is mostly genetically determined, such varieties would be important.

In several starch applications its amylose componentgelatinizes to form crystals which reduces paste claritythereby acting as a hinderance to the process.Chemical modification of amylose to prevent gelatinization is an expensive process and therefore development of suitable varieties of potato containing only amylopectin or its higher proportions as compared to amylose can be an important objective for breeding starch specific varieties. An amylose free potato variety Elaine has been commercially bred by Avebeusing traditional breeding techniques, while genetically modified Amylopectin potato variety Amflora has been developed by BASF company and commercialized in Europe. The GBSS (granule bound starch synthase) enzyme which is necessary for amylose production has been deactivated using co-suppression in this GM variety (Tilocca *et al.,* 2014). Development of such amylopectin varieties would help in getting high quality starch at lower cost and in an eco-friendly manner.

***Ethanol production*:**Ethanol can be produced from hydrolysis of starch and its fermentation to produce alcohol. It finds its use as a chemical and a beverage, but most importantly as a biofuel, which is being promoted for its use in combination with petrol in transport. Many countries have implemented, or are in the process of implementing, programs providing for the addition of ethanol to gasoline. Promotion of biomass energy offsets fossil fuel consumption,reduces greenhouse gas emissions and increases sustainability(Lynd 1996). Potatoes can be directly used in the process, besides the use of agro-industrial waste from potato processing plants. Ethanol is mostly produced from fermentable monosaccharides and some non-fermentable disaccharides like sugar cane. Disaccharides can be naturally and easily hydrolysed to produce ethanol by action of invertase enzyme produced by yeasts.However, alcohol production from non-fermentable carbohydrates like lignocellulose and starch present in potato require additional treatment before fermentation(Lima 2001). They are firstly hydrolysed into glucose, maltose and other carbohydrates which can readily befermented. In recent years biotechnological interventions have paved the way for new enzyme and fermentation technologies for its efficient fermentation of potato and its byproducts. Several reports of potato as a substrate for production of other fermentation products besides ethanol like acetone, butanol, lactic acid, α-amaylase, β-mannanase etc. are also available (Nimcevic *et al.*, 1998, Jin *et al.,* 2003, 2005, Oda *et al.,* 2002, Saito *et al.,* 2003, Shukla and Kar 2006, Mabrouk and El Ahwany 2008).

Similarly, specific breeding programmes may be initiated in India to develop varieties suitable for ethanol production.

Targeting of varieties to different agro-climatic regions: Requirement of potato varieties for different purpose have been compiled by Luthra *et al.*(2004) andLuthra and Gupta, (2019). In view of the present review these have been further elaborated in Table 2, in moving withthe emerging new consumer-based uses of potato. However, the consumer-oriented breeding cannot be considered independent of the conventional breeding objectives, which affect the productivity and profitability of a variety and more importantly the overall food security of a nation. In breeding field crops, the ultimate goal is to improve yield per se, which may encompass important traits of interest like resistance etc., which affect yield (Kaur, 2017). In view of these the varietal production areas for the different consumer-oriented varieties need to be given due emphasis based on market/ consumer demand. Since 90 % of the total potato produced in the country comes from the north-western plains, most of the consumer-oriented potato varieties can be bred for in this agroclimate. Whereas table potatoes may be targeted to the different agro climatic regions to enable their easy availability based on food preference and prevalent important agro climate linked traits like abiotic and biotic resistance. Similarly processed potato varieties may be targeted for cultivation inNorth Indian plains as well as the Gujrat, Maharashtra, Andhra Pradesh and Karnataka regionswhere there is a predominance of several potato processing companies, to enable higher profitability for the farmers as well as these industries. Global climate is affecting weather patterns, resulting in extremes of heat, drought, frequent frost and snow fall in high altitudes (Dahal *et al.*, 2019) and poses a major challenge for sustainable potato production. These tend to negatively impact plant growth, survival and crop yield and are likely to be aggravated in future because of continued greenhouse gas emissions which will intensify crop plant's exposure to abiotic and biotic stresses (Lesk*et al.*, 2016). In potatoes tuberization is reduced at night temperatures above18°C with complete inhibition of tuberization above 25°C. High temperature stresses adversely affect plant growth, tuberization, tuber bulking, quality and tuber yield. The magnitude of loss depends on the duration, severity and plant growth stage (Minhas, 2012; Wang-Pruski and Schofield, 2012 and Evers *et al.*, 2010). In India work on heat tolerance breeding, morphological, and physiobio-chemical parameters associated for heat stress by ICAR-CPRI has led to the release of four varieties having heat tolerance (Table 1). (Luthra *et al.*, 2020; Chaudhary *et al.*, 2021).

Futureconsumer-orientedbreeding

In the present era Precision breeding has taken a center stage in almost all breeding programmes all over the world. Potato genetics have been described as complex,mainly due to its tetraploid nature and high heterozygosity. Although in past years several genesrelated to simple traits like tuber shape, flesh colour, eye depth etc. and resistance genes for late blight, root knot nematodes have been identified but genes for complex quantitatively inherited traits like yield, starch, processing attributes or bruising susceptibility need to be clearly evaluated (Slater *et al.*, 2014). The resistance genes identified from wild relativeshave been successfully incorporated in commercial potato varieties to impart disease and pest resistance (Gebhardt *et al.,* 2014). The availability of the potato genome in the public domain has accelerated gene annotations, linkage mapping, SNP assays, GWAS (Genome wide association studies) and QTL analysis. Major achievements using Illumina Infinium 8303 SNPs Potato Array (Hamilton *et al.,* 2011; Schreiber *et al.,* 2014; Sharma *et al.,* 2014) genome wide association mapping (D'Hoop *et al.,* 2008; Ramakrishnan *et al.,* 2015)is gradually enhancing our knowledge of several complex traits like tuber dormancy, after baking darkening, maturity and starch metabolism. The new age technologies have become more accessible to breeders offering are cheaper, faster and accurate results, and can be coupled with the other omics technologies for identification of candidate genes (Gebhardt 2013).Transgenics for resistant to cold induced sweetening, late blight, starch have been produced (Clasen *et al.,* 2016).

The availability of the potato genome(Xu *et al.,* 2011) in the public domain has accelerated development of gene annotations and linkage maps, opening avenues to new genetic resources (e.g., single nucleotide polymorphisms arrays, SNPs arrays; genome-wide association studies, GWAS) for analysing the regulation of complex traits and QTLs (quantitative traits loci).

Gene editing technologies based on CRISPR-associated (Cas) endonucleases hold great promisefor precision breeding(Symington and Gautier 2011). Potato has in time emerged from a vegetable to a serious food security option with multifarious consumer preferences being cultivated under different agro-climatic conditions. There is immense pressure on firstly increasing the potato productivity under the limited land resources and changing climatic conditions, projected to further reduce the potato growing periods in India. Secondly, to improve the overall quality of potato as preferred by the industry as well as potato consumers various needs in the era of economic development, higher purchasing power and the willingness to pay more for the desired quality. This would be an important step towards increasing the overall profitability of the farmers, where premium prices for the produce may be sought, and simultaneously promoting export of the commodity.The involvement of all stakeholders involved in potato value chain for selecting the desired traits would be highly fruitful in delineating the breeding objectives for various purpose potatoes and making it more consumer supported. Similar trials referred as the Mother and baby trials (MBT) have been conducted by CIP in South America which yielded positive results (Rusike *et al.,* 2004).

The future research in this direction would focus on developing consumer driven varieties like rich in anti-oxidants, low glycemic index, high in amylase, low cold induced sweetening, good keeping, high starch for the industry etc. New and varied uses for potato besides food are being described viz. edible films, Biodegradable packaging (Guilbert *et al.,* 1997, Kawasumi, 2004) which open newer avenues and consumer arenas for utilization of potato. The breeding programmes need to be diversified, superimposing of both agroclimatic and consumer-based objectives.

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