Nutritional composition of potato (*Solanum tuberosum* L.) genetic resources

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Seventy-one germplasm lines comprising of commercial Indian potato cultivars, advanced clones exotic and indigenous cultivars were evaluated for nutritional compounds. We observed significant variability in the lines for anthocyanins (1.81–17.20 mg/100 g FW), carotenoids (4.75–27.75 μg/g FW), ascorbic acid (14.50–85.00 mg/100 g FW) and total phenolics (19.22–73.54 mg GAE/100 g FW). However, for zinc (10.62–27.58 ppm), iron (30.49–56.29 ppm), and tuber dry matter content (14–26%), only small variations were found. The anthocyanin, carotenoids, and total phenolic contents of indigenous cultivars and nutrient-rich advanced clones were generally much higher than those of the common variety. It is interesting to note that anthocyanin (r = –0.46; –0.43), total carotenoids (r = –0.47; –0.38), ascorbic acid (r = –0.27; –0.24) and tuber dry matter (r = –0.21, –0.24) all had negative correlations with marketable and total tuber yield respectively. Cluster analysis revealed that genotypes from clusters 1 and 3 can be used in bio-fortification breeding. The results of this study also reveal that two genotypes, viz. JEX/A-122 (Andigena line) and Kala Aloo (indigenous line) may be used as breeding material to develop nutrient-rich potato varieties.

Keywords: Cluster analysis, germplasm, nutritional compounds, potato, principal components.

POTATO (*Solanum tuberosum* L.) yields higher nutritious food per unit space and time in both conducive as well as harsh climates compared to other major food crops. Potatoes make up about 85% of plant parts suitable for human consumption, compared to just about 50% in cereals[1], increasing its bio-fortification use. Potato has evolved into a high-yielding, carbohydrate-rich crop as a result of domestication and selection. Potatoes are a good source of fibre, ascorbic acid, vitamin B6 and minerals like potassium and manganese. Keeping in view the vast genetic variations for these compounds present in diverse potato genetic background, fresh potatoes and their processed products can also be a rich source of bioactive compounds, including carotenoids, anthocyanin and phenolic. Carotenoids are a group of phytochemicals that impart different colours to foods, prevent human diseases, and maintain good health. They have health benefits for augmenting the immune system, provitamin A activity and antioxidative properties. The main functions of ascorbic acid are as an antioxidant, electron donor, collagen builder and iron absorber. Anthocyanins exhibit a wide range of pharmacological qualities, including the ability to regulate obesity, prevent cardiovascular disease and have antioxidant biological effects. In addition to aiding in wound healing, cell division, development and immune system function, zinc also plays a functional role in proteins containing the elements and enzymes that depend upon it. Zinc insufficiency accounts for 4.4% of under-five mortality in underdeveloped countries (5.3% in Africa and 3.7% in Asia)[2]. Anaemia, or iron deficiency, is a severe public health issue in India that affects all demographic groups (50–70%), but is most prevalent in newborns and young children, adolescent girls, women of reproductive age and pregnant women[3]. Both urban and rural areas experience the same degree of iron deficiency; however, gender disparities begin to appear around the age of 15 years as female gets more susceptible to this condition. The development of iron and zinc bio-fortified potatoes has been started by CIP (International Potato Center), Lima, Peru, under the aegis of the HarvestPlus Program (http://www.harvestplus.org/), which has been implemented at the national level by several countries across the world.

Potato is cultivated in all the states of India under diverse agro-climatic conditions varying from temperate high hills to subtropical plains. Since its introduction over 400 years ago at the beginning of the 17th century probably by Portuguese traders, potato has become a common household item in the country today. According to recent figures, India produced 51.30 million tonnes of potato in 2019–20 out of global potato production of nearly 359.07 million tonnes[4] covering approximately 13% of global potato acreage. Till 2022, the Indian potato breeding programme has resulted in the development and release of 66 varieties focusing mainly on the breeding strategy of high yield with

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Table 1. Tuber characters of 71 potato genotypes

Genotype	Skin colour/flesh colour
Table purpose/fresh consumption advanced clones	
MS/0-3740, MS/0-3808	WC/Y
MS/8-1148, MS/9-723, MS/9-2196, MS/13-110, MS/13-391	Y/Y
MS/10-1529, MS/12-2116	WC/Cr
MS/11-664	R/Cr
MS/13-148, MS/14-243, MS/14-935, MS/14-1063, MS/14-1305	WC/W
MS/13-27	R/W
MS/14-505, MS/14-1381	R/Y
MS/14-942	P/Cr
Nutrient-rich advanced clones	
MSP/15-26, MSP/15-56, MSP/15-60	R/Y with RPr VR
MSP/15-51	Pr/Rpr
MSP/15-64	P/Cr with RPr VR
MSP/16-004	R/Cr
MSP/16-150	Pr/DPr with Cr VR
MSP/16-216	RPr/RPr with Cr VR
MSP/16-272, MSP/17-007	Y/Y
MSP/16-300, MSP/16-307, MSP/16-375	DPrB/DPr
MSP/17-089	P/RPr
MSP/17-147	P/Y with RPr VR
MSP/17-212	P/Cr with RPr VR
MSP/17-241	P/Cr with Rpr
MSP/17-345	Pr/W with DPr
CIP-CPRI-bred advanced clones	
MCIP/9-11	Y/Y
MCIP/12-185, MCIP/14-211	WC/Cr
MCIP/13-64, MCIP/14-202	WC/W
Somatic hybrid advanced clones	
MSH/14-7, MSH/14-129, MSH/17-016, MSH/17-025	Y/Y
MSH/14-131	Y/Cr
CPRI-bred varieties	
Kufri Arun, Kufri Sindhuri	R/Cr
Kufri Bahar, Kufri Chipsona-3, Kufri Mohan	WC/W
Kufri Ganga, Kufri Lima, Kufri Surya	WC/Cr
Kufri Garima, Kufri Pukhraj	Y/Y
Kufri Lalima	R/W
Kufri Lalit	P/Y
Kufri Neelkanth	Pr/Y
Exotic varieties	
Atlantic	WC/W
Lady Rosetta	R/Y
Indigenous cultures	
Kala Aloo	DPrB/ Cr with mottled DPr
Laso Khasi	WC/Cr
CIP clones and JEX nos	
CP4175	Y/Y
CP4393	R/Y
CP4406, CP4496, CP4504	WC/W
CP4510	WC/Cr
JEX/A-122	DPrB/DPr

Tuber skin colour – WC, Whitish cream; Y, Yellow; P, Pink; R, Red; RPr, Reddish purple; Pr, Purple and DPrB, Dark purple black.
Tuber flesh colour – W, White; Cr, Cream; Y, Yellow; RPr, Reddish purple; DPr, Dark purple; Y with RPr VR, Yellow with reddish purple vascular ring; Cr with RPr VR, Cream with reddish purple vascular ring; DPr with Cr VR, Dark purple with cream vascular ring; RPr with Cr VR, Reddish purple with cream vascular ring; Cr with Rpr, Cream with reddish purple; W with DPr, White with dark purple; Cr with mottled DPr, Cream with mottled dark purple.

resistance/tolerance to biotic and abiotic stresses, and suitability for fresh and processing purposes[5], except for Kufri Neelkanth, India's first ever antioxidant (anthocyanin and carotenoids)-rich variety[6] and Kufri Manik, a micronutrient dense variety. However, work on developing nutrient and/or phytonutrient-dense populations through conventional breeding, i.e. hybridization, followed by phenotypic selection for nutritionally superior potatoes, began in the 2010s.

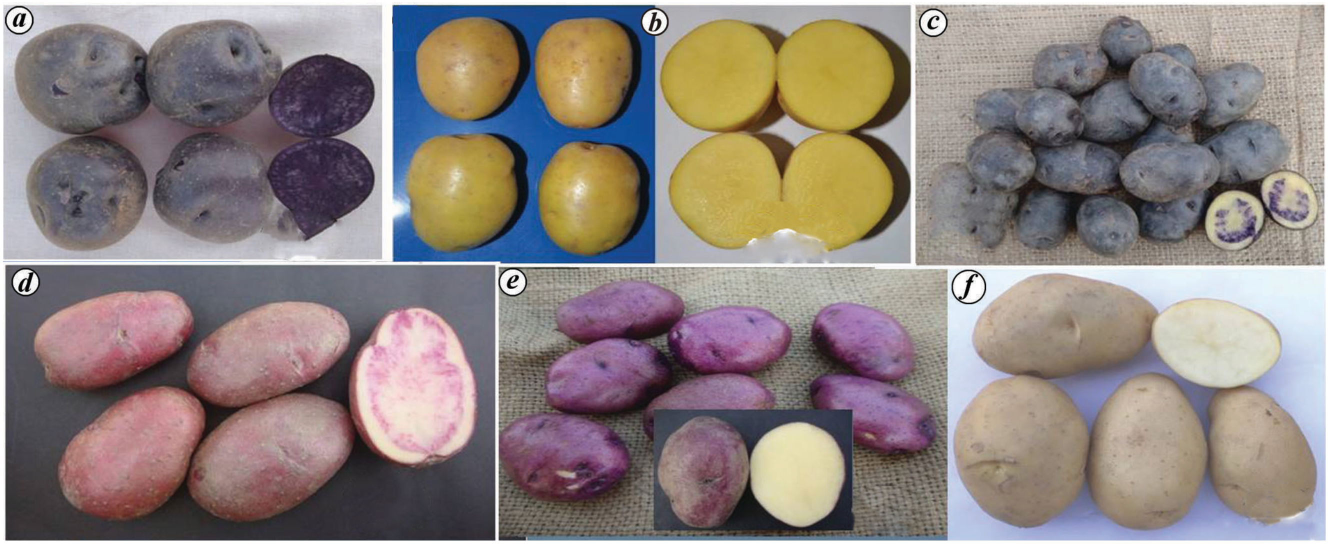

Figure 1. Tubers of (***a***) JEX/A-122, (***b***) MSP/16-272, (***c***) Kala Aloo, (***d***) MSP/16-216, (***e***) Kufri Neelkanth, (***f***) Kufri Bahar.

This involved screening potato genetic resources for different nutritional compounds, such as anthocyanin, carotenoids, and minerals such as iron, zinc, protein and ascorbic acid[7]. The aim of this study was to evaluate diverse potato lines for various nutritional parameters, which will be useful as parental lines for nutritionally rich potato breeding.

Materials and methods

Freshly harvested, medium-sized tubers of 71 diverse potato genotypes constituting CPRI-bred commercial varieties, exotic varieties, indigenous collections, advanced clones belonging to Tuberosum and Andigena groups grown under field conditions at ICAR-Central Potato Research Institute, Regional Station, Modipuram, Meerut (29°N and 76°E; 222 m amsl), Uttar Pradesh, India were included in the present study (Table 1). Majority of the genotypes were either white/cream fleshed (31 nos) or yellow (23 nos), while the novel accessions, i.e. variegated and purple-fleshed were 12 and 4 respectively, and a single genotype with red flesh (Figure 1).

The experimental design was randomized complete block with three blocks (replicates). The tubers had 60 cm inter-row spacing and 20 cm intra-row spacing, and the recommended agronomical techniques for plant nutrition and pathogen prevention, as well as intercultural operations were followed. Dehaulming was done 90 days after planting and subsequently the crop was harvested after 10 days of dehaulming.

The data were recorded on nine parameters on tuber flesh, anthocyanin[8], total carotenoids[9], ascorbic acid[10], total phenolics[11], tuber dry matter[12], iron and zinc[13], marketable (tuber yield >20 g; tonne/ha) and total tuber yield (tonne/ha) according to standard protocols.

Statistical analysis

The replicated (three replications) data were statistically analysed by one-way analysis of variance (ANOVA), and means were compared using post-hoc test (Duncan's multiple range test) at ($P < 0.05$) level using OPSTAT software. Statistical significance was accepted at a 95% confidence level. XLSTAT 2022 was used for principal component analysis, agglomerative hierarchical clustering and correlations test.

Results and discussion

In the present study, we performed nutritional value profiling of a diverse group of potato genotypes constituting germplasm (Tuberosum and Andigena groups), indigenous varieties, advanced clones, somatic clones and released varieties (Indian and exotic). Evaluation results in two crop seasons, 2017–18 and 2018–19, revealed that the genotypic effect was significant ($P \leq 0.01$) for all the traits, indicating sufficient variability among genotypes for the traits under study. The nutrition evaluation was done in the tuber flesh as most potato nutrients are concentrated in this part.

Coloured-flesh potatoes possess higher levels of anthocyanins than the yellow- and white-fleshed ones, making flesh colour a direct predictor of the total anthocyanin concentration. Anthocyanin in potatoes constitutes acylated petunidin glycosides (purple potatoes) and acylated pelargonidin glycosides (red/purple potatoes). In this study, anthocyanin content in the tuber flesh differed by 9.5-fold and ranged from 1.81 to 17.20 mg/100 g FW with an average value of 6.62 mg/100 g FW (Table 2). Anthocyanin content in the tuber flesh was highest in Andigena germplasm JEX/A-122 (17.20 mg/100 g FW), followed by bio-fortified advanced clone MSP/15-51 (17.05), indigenous variety Kala

Table 2. Selected nutrient profile of different potato genotypes based on average of two years (2017–18 and 2018–19)

Compound	Mean	Range	Best five performing genotypes
AN (mg/100 g FW)	6.62	1.81–17.20	JEX/A-122, MSP/15-51, Kala Aloo, MSP/17-345, MSP/16-300
TC (μg/g FW)	11.22	4.75–27.75	Kala Aloo, Kufri Neelkanth, MSP/15-56, MSP/15-64, MSP/17-212
AA (mg/100 g FW)	36.13	14.50–85.00	MS/8-1148, Kala Aloo, MSP/17-147, MSP/15-56, MSP/15-51
TP (mg GAE/100 g FW)	42.79	19.22–73.54	JEX/A-122, MS/9-723, MS/14-1305, MSP/15-64, MSP/17-345
Zn (ppm) on dry weight basis	19.83	10.62–27.58	MS/14-1381, MS/10-1529, Kufri Lima, Kufri Bahar, JEX/A-122
Fe (ppm) on dry weight basis	43.17	30.49–56.29	Kufri Lima, MS/0-3740, MCIP/14-211, MS/9-2196, CP4393
TDM (%)	19.31	13.82–25.64	MSP/16-272, MSP/17-345, Atlantic, MSP/16-216, Lady Rosetta
MTY (tonne/ha)	37.66	5.85–58.99	Kufri Mohan, MS/13-110, MS/9-2196, MS/14-942, Kufri Garima
TTY (tonne/ha)	40.87	18.41–60.67	Kufri Mohan, MS/9-2196, MS/13-110, MS/14-942, MS/14-1063

AN, Anthocyanin; TC, Total carotenoids; AA, Ascorbic acid; TP, Total phenolics; Zn: Zinc; Fe, Iron; TDM, Tuber dry matter; MTY, Marketable tuber yield; TTY, Total tuber yield.

Aloo (15.94) and bio-fortified advanced clones MSP/17-345 (13.45) and MSP/16-300 (12.79). Lowest anthocyanin content was found in Laso Khasi (1.81 mg/100 g FW), MS/14-1305 (2.49), MCIP/14-211 (2.89), Kufri Garima (3.00) and MSH/14-7 (3.06). Twenty-eight accessions had higher anthocyanin content compared to commercial check Kufri Neelkanth (6.32 mg/100 g FW). In earlier evaluations, a set of Indian potato germplasm collections depicted a narrower anthocyanin content range 0–11.88 mg/100 g FW in the tuber flesh[14], while commercially cultivated Indian potato varieties showed negligible values (up to 0.14 mg/100 g FW)[15], highlighting that potato breeding and varietal development was primarily focused on yield and related parameters. In the present group of genotypes, advanced clones, viz. MSP/15-51, MSP/17-345 and MSP/16-300 with high anthocyanin content are the result of recent introgression and selection for higher phytonutrients. However, higher content of total anthocyanin concentration in Andean potato genotypes (up to 16,330 μg/g DW/326 mg/100 g FW @ 20% tuber dry matter) was observed[16], signifying the scope of further enhancement.

Yellow pigmentation in potato tubers is related to the concentration of lipophilic phytonutrient carotenoids with health-promoting activities. Total carotenoid content ranged from 4.75 to 27.75 μg/g FW (5.84-fold variation) with a genotype mean of 11.22 μg/g FW. The maximum total carotenoids was in indigenous genotype Kala Aloo (27.75 μg/g FW), followed by Kufri Neelkanth (27.63), MSP/15-56 (24.80), MSP/15-64 (22.70) and MSP/17-212 (18.65). The genotypes with the least total carotenoids content were Kufri Lima (4.78 μg/g FW), Kufri Chipsona-3 (5.00), CP4504 (5.28), MS/0-3740 (5.28) and MCIP/12-185 (5.75). Much lower average total carotenoid content was recorded in previously analysed potato germplasm (0.98 μg/g FW)[14] and varieties (0.96 μg/g FW)[15].

Genotype, weather and soil conditions, and fertilization affect the ascorbic acid content in an accession. Moreover, ascorbic acid is highly water-soluble, thermo-sensitive and oxygen-labile. In the genotypic effect, ascorbic acid content was highest in advanced clone MS/8-1148 (85.00 mg/100 g FW), followed by Kala Aloo (78.00), MSP/17-147 (77.00), MSP/15-56 (60.50), MSP/15-51 (59.00). Kufri Neelkanth had ascorbic acid content of 29.50 mg/100 g FW and 48 accessions had higher ascorbic content than this. MSP/17-007 (14.5 mg/100 g FW), Kufri Lalit (15.5), MSH/17-025 (16.00), MSH/14-131 (17.00) and MS/10-1529 (18.00) had the lowest ascorbic acid content. The range of ascorbic acid content in the present set of genetic resources was much higher than that in the varieties, i.e. 17.65–47.80 mg/100 g FW (ref. 15), while Joshi *et al.*[17] reported ascorbic acid content up to 58 mg/100 g FW.

Potatoes are the third most significant source of phenols after apples and oranges based on daily consumption data of 34 fresh fruit and vegetables in the American diet[18]. In the present group of potato genotypes, total phenolics ranged from 19.22 to 73.54 mg gallic acid equivalents (GAE)/100 g FW (3.82-fold difference) between the lowest and highest performing genotype content with a mean value of 42.79 mg GAE/100 g FW. JEX/A-122 (73.54 mg/100 g FW) had the highest total phenolics content, closely followed by MS/9-723 (73.50), MS/14-1305 (63), MSP/15-64 (60.81) and MSP/17-345 (58.50). Majority of genotypes had higher total phenolics (67 nos) than Kufri Neelkanth (24.6 mg/100 g FW). In earlier studies, total phenolics in potato germplasm ranged from 20.26 to 63.05 in the tuber flesh with a mean value of 31.17 mg GAE/100 g FW (ref. 14). However, high levels of total phenolics (191–1864 mg/100 g DW were recorded) in the peeled potato samples of native Chilean potatoes[19].

Tuber dry matter is an important trait for potato varieties to be suitable for processing. The present genotypes have moderately higher mean tuber dry matter content, i.e. 19.31% with 1.85-fold variations. The highest tuber dry matter was recorded in MSP/16-272 (25.57%), followed by MSP/17-345 (24.65), Atlantic (23.90), MSP/16-216 (23.85) and Lady Rosetta (23.85). Least dry matter concentrations were recorded in potato varieties/advanced clones for fresh consumption, namely MS/14-935 (13.86%), Kufri Ganga (15.10), MS/10-1529 (15.29), MS/08-1148 (15.57) and MSP/16-300 (15.65). In another study, in a group of advanced clones plus varieties, tuber dry matter to the tune of 16–22% was recorded[12], while a wider range, i.e. 13.71–27.80% dry matter was observed in potato germplasm[20].

Table 3. Correlation coefficients for nine traits in potato germplasm

Variables	AN	TC	AA	TP	Zn	Fe	TDM	MTY	TTY
AN	**1**								
TC	**0.46**	**1**							
AA	**0.39**	0.21	**1**						
TP	0.13	–0.15	0.09	**1**					
Zn	–0.01	–0.02	–0.23	0.05	**1**				
Fe	**–0.36**	–0.19	–0.13	0.04	0.08	**1**			
TDM	0.18	0.16	0.05	–0.06	**–0.28**	–0.07	**1**		
MTY	**–0.46**	**–0.47**	**–0.27**	–0.05	–0.01	0.05	–0.21	**1**	
TTY	**–0.43**	**–0.38**	**–0.24**	0.02	0.00	0.04	**–0.24**	**0.97**	**1**

Values in bold are different from 0 with significance level $\alpha = 0.05$.

Potatoes have, in general, relatively low levels of zinc and iron. However, higher consumption quantity and high bioavailability render it as an excellent source of these minerals compared to cereal and legume crops[21]. More-over, the negligible content of anti-nutrients, viz. oxalates and phytates that hamper micronutrients, particularly iron absorption and ascorbic acid that enhances nutrient absorption, render potatoes a potent source of micronutrients. Zinc content in the tuber flesh ranged between 10.62 and 27.58 parts per million (ppm) by dry weight (DW) (2.59-fold difference), with a mean value of 19.83 ppm DW. Genotypes high in zinc content were MS/14-1381 (27.58 ppm), MS/10-1529 (27.10), Kufri Lima (26.56), Kufri Bahar (24.79) and JEX/A-122 (24.40). CP4175 (10.62 ppm), MS/13-148 (14.32), MS/0-3740 (14.59), MS/14-1305 (15.03) and MS/12-2116 (15.13) had the lowest zinc content. In earlier studies, zinc content had a higher range in the tuber flesh of potato germplasm (2.78–35.40 ppm DW)[22]. However, the zinc content range in the tuber flesh of another lot of potato germplasm constituting tuberosum, Andigena and commercial varieties[20] and varieties[13] was at par with the present study.

Iron content ranged from 30.49 to 56.29 ppm (DW), and the difference was 1.84-fold. The best-performing genotypes were Kufri Lima (61.56 ppm), MS/0-3740 (60.10), MCIP/14-211 (56.29), MS/9-2196 (55.45) and CP4393 (53.96). MSP/16-300 (30.49 ppm), MSP/17-212 (31.56), MSP/16-307 (32.45), MSP/17-089 (32.64) and Laso Khasi (33.54) had the lowest iron content. Previously reported potato germplasm had a wider range of iron content[20,22] compared to the varieties[13].

Tuber yield is important for any advanced potato clone to be released as a variety and for further success in the farmer's field. Enhancing the nutritional profile is necessary for bio-fortification while minimizing the impact on tuber yield. In the present study, the bio-fortified advanced clones had average marketable and total tuber yield ranging from 33.00 to 38.45 tonne/ha (data not shown). Nutrient-dense advanced genotypes, viz. MSP/16-150, MSP/16-300, MSP/16-307, MSP/17-147 and MSP/17-345 had >40 tonne/ha marketable tuber yield and >45 tonne/ha total tuber yield. However, Kufri Mohan had the highest marketable tuber yield (58.99 tonne/ha) followed by MS/13-110 (51.76), MS/9-2196 (50.43), MS/14-942 (48.42) and Kufri Garima (47.45). The lowest marketable tuber yield was recorded in MSP/15-64 (5.85 tonne/ha), MSP/15-51 (14.25), Kala aloo (15.58), MSP/15-56 (15.85) and JEX/A-122 (16.49). A similar trend was also observed for total tuber yield. Kufri Mohan recorded the highest total tuber yield (60.67 tonne/ha), followed by MS/9-2196, MS/13-110 (53.37), MS/14-942 (50.39) and MS/14-1063 (49.56). The lowest performing genotypes for total tuber yield were Kala Aloo (Himachal Pradesh), JEX/A-122 (18.41 tonne/ha each), followed by MSP/15-56 (23.56), MSP/15-51 (24.07) and Kufri Surya (24.56).

Significant positive correlations were observed between anthocyanin and total carotenoids as well as anthocyanin and ascorbic acid (Table 3). Thus, simultaneous improvements of these nutritional traits are possible by focusing on improving any of them. However, anthocyanin was negatively correlated with iron, signifying that selecting one trait results in negating the other. Marketable and total tuber yield had negative associations with anthocyanin, total carotenoids, ascorbic acid and tuber dry matter, while micronutrients, i.e. zinc and iron, had no significant links with yield. A negative correlation was also observed between marketable and total tuber yield with tuber dry matter content[12], while non-significant associations with tuber zinc and iron content were reported in previous studies[13,23].

In the content of anthocyanin, a compound imparting red/purple/blue hue to potato tubers, was highest in red-fleshed genotypes, followed by purple- and variegated-fleshed genotypes (Table 4). White/cream- and yellow-fleshed genotypes had the lowest anthocyanin content. The trend for total carotenoids was highest in variegated fleshed genotypes, followed by yellow-fleshed genotypes. The average total carotenoid content in white/cream, red and purple-fleshed genotypes was the same. In general, genotypes high in anthocyanin are low in total carotenoids, and vice versa. However, breeding efforts have overcome this negative correlation[24]. Thus, variegated-fleshed genotypes with higher levels of anthocyanin as well as total carotenoids are available. Ascorbic acid content was highest in red-fleshed accession, followed by purple and variegated ones. White/cream- and yellow-fleshed genotypes had the lowest ascorbic acid content. Total phenolics content value was equivalent in all genotypes irrespective of flesh colour. Among micronutrients,

Table 4. Effect of flesh colour on nutritional composition in potato tubers

Flesh colour	AN	TC	AA	TP	Zn	Fe	TDM	MTY	TTY
White/cream	5.07[c]	8.84[b]	32.82[cd]	41.85[a]	20.47[ab]	45.97[a]	19.07[b]	40.15[a]	42.57[a]
Yellow	5.10[c]	11.84[ab]	31.87[d]	42.07[a]	19.29[ab]	44.54[a]	19.10[b]	40.18[a]	42.70[a]
Red	17.05[a]	8.75[b]	59[a]	46.10[a]	20.87[a]	47.20[a]	19.24[b]	14.58[d]	24.19[d]
Purple	12.85[b]	10.46[b]	42.38[bc]	51.37[a]	20.76[a]	35.09[b]	16.86[c]	36.67[b]	39.67[b]
Variegated	10.63[b]	15.35[a]	48.83[b]	46.91[a]	18.70[b]	38.77[b]	21.18[a]	30.48[c]	36.52[c]

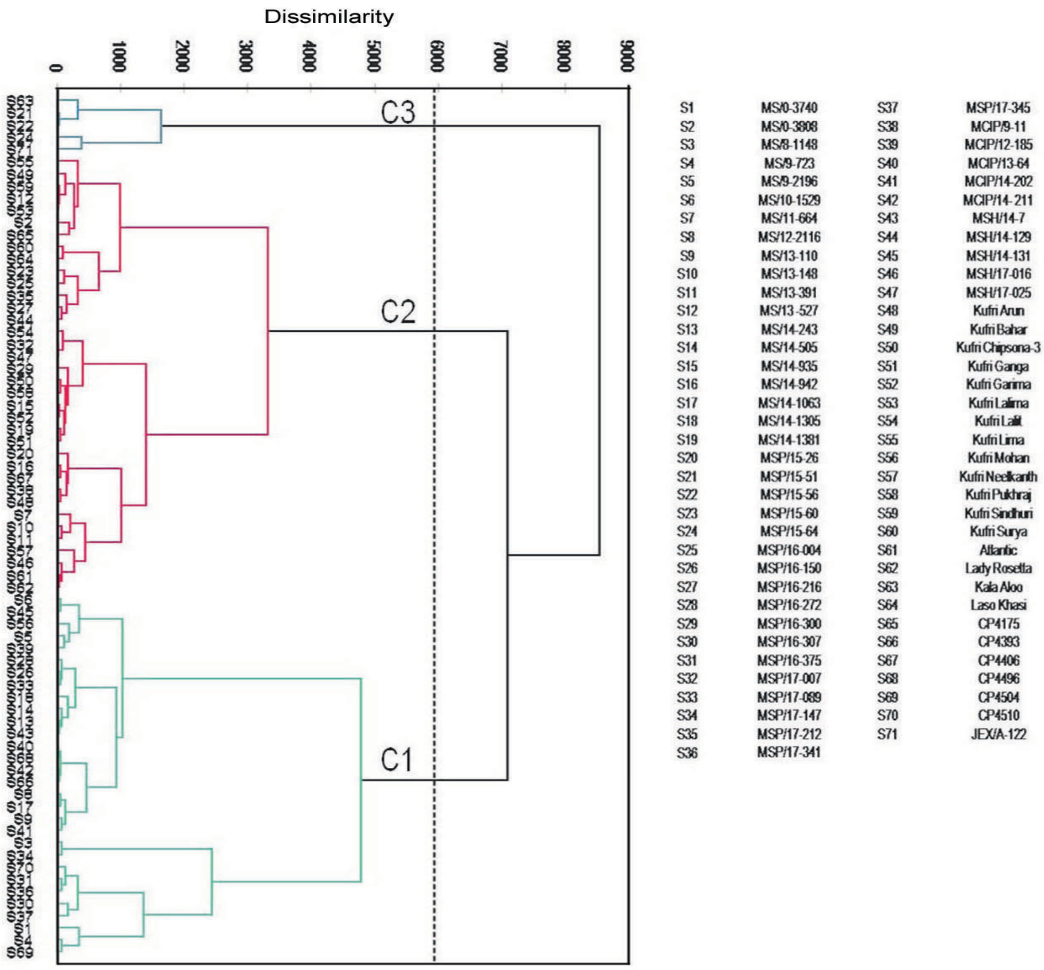

Figure 2. Grouping of 71 potato genotypes based on nutritional parameters and yield.

zinc was significantly higher in red and purple-fleshed tubers, followed by white/cream and yellow-fleshed tubers. The distribution trend of iron content in the tuber flesh was nearly equivalent in both coloured and non-coloured tubers. Tuber dry matter was highest in variegated-fleshed genotypes, while purple-fleshed genotypes had the lowest dry matter content. Marketable and total tuber yield was highest in white/cream- and yellow-fleshed accessions. Significant effect of the tuber flesh colour of genotypes was observed for anthocyanin[25], carotenoids[25,26], phenols[27] and ascorbic acid[28] contents. The distribution pattern of nutrients indicates that consumption of coloured (purple, red, variegated) flesh genotypes may provide dietary supplements of higher anthocyanin, total carotenoids, ascorbic acid and zinc, while another micronutrients of health significance, iron content, irrespective of tuber flesh colour is present in both coloured and white fleshed tubers. However, the nutritional profile of the red-fleshed genotype needs further evaluation as only a single accession of red flesh was available for the present study.

Cluster analysis results grouped the potato genotypes into three major clusters (Figure 2). Cluster 1 comprised of 30 genotypes (42.25%). Values of ascorbic acid, total phenolics, iron, marketable and total tuber yield in this cluster were greater than the total mean (Table 5), whereas it had lower anthocyanin, total carotenoids and tuber dry

Table 5. Average of traits for each cluster (difference between each cluster with the total mean)

Cluster	AN	TC	AA	TP	Zn	Fe	TDM	MTY	TTY
1	5.84	9.29	38.21	52.12	19.91	44.51	19.19	43.24	46.12
	(–0.77)	(–1.92)	(2.08)	(9.33)	(0.07)	(1.34)	(–0.11)	(5.58)	(5.25)
2	6.17	11.36	31.73	34.66	19.74	43.27	19.39	36.92	39.67
	(–0.45)	(0.14)	(–4.39)	(–8.12)	(–0.08)	(0.10)	(0.08)	(–0.73)	(–1.19)
3	14.57	21.66	55.20	53.49	19.66	41.79	19.42	13.82	22.13
	(7.95)	(10.44)	(19.07)	(10.70)	(–0.16)	(–1.38)	(0.11)	(–23.83)	(–18.73)

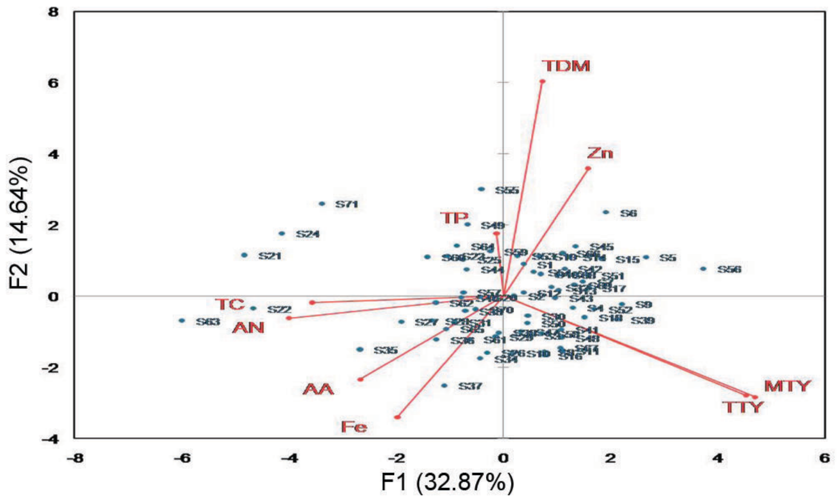

Figure 3. Biplot between principal components 1 and 2 showing contribution of different traits to variation.

matter than the total mean of these parameters. The highest number of genotypes, i.e. 36 (50.70%), constituted cluster 2. In this group, the mean of ascorbic acid, total phenolics and total tuber yield was less than the total average, while for other traits, it was approximately less than or equivalent to the total mean. Five genotypes (7.04%) were classified in cluster 3. The average content of anthocyanin, total carotenoids, ascorbic acid and total phenolics was higher than the total mean, while iron content, marketable and total tuber yield were much less compared to the total average. Intra-cluster distances define the magnitude of diversity between genotypes within a cluster. The dissimilarity with respect to Euclidean distance was highest for clusters 3 and 1. Thus, utilizing the potato genotypes from cluster 1 for higher yield and from cluster 3 for nutritional value in breeding will be advantageous to get the desired combinations.

In the present study, the first three principal components (PCs) constituted 32.67%, 14.64% and 13.12% of the total variation, accumulating to 60.43% of the total variability among the evaluated potato genotypes. In PC1, the largest positive loadings were ascribed to marketable (0.50) and total tuber yield (0.49), whereas characters such as anthocyanin (–0.43), total carotenoids (–0.38) and ascorbic acid (–0.29) contributed to negative loading of the first component. In PC2 micronutrients, viz. zinc (0.65) and iron (0.39) had positive loadings and thus, contributed maximum to variation, while tuber dry matter (–0.37), marketable (–0.30) and total tuber yield (–0.30) accounted for the most negative value. Likewise, anthocyanin, ascorbic acid and total phenolics contributed the maximum to PC3. The angle of vectors is important in a biplot diagram (Figure 3), i.e. smaller the angle, the higher the correlation between the traits. Marketable and total tuber yield entirely contrasted with total carotenoids, anthocyanin, ascorbic acid, iron, zinc and tuber dry matter content, indicating negative associations. The biplot clearly distinguishes genotypes with two or more combined nutrient values.

Conclusion

Tremendous progress in Indian agriculture, including potato has been achieved with respect to production. Now the focus is slowly being shifted to nutritional value while keeping yield stable at current levels. Evaluation of the present set of potato genotypes highlights the progress made till now in potato bio-fortification in the Indian scenario. The identified potential accessions, especially indigenous varieties, may be utilized as donors in the potato bio-fortification breeding programme.

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