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Genetic analysis of tuber yield, processing and nutritional traits in potato (*Solanum tuberosum*)

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ABSTRACT

The present study was aimed to assess the genetic analysis of tuber yield, processing and nutritional traits in potatoes based on evaluation of 23 genotypes during the winter crop season in sub-tropical plains of India. Characters, viz. reducing sugars followed by chip colour score, phenols, soluble proteins, sucrose, total free amino acids and marketable tuber yield had high genotypic and phenotypic variation, heritability and genetic advance as percent of mean and can be improved by practising selection in potato breeding programme. The results revealed that table potatoes possessed high yield and high phenols content. Whereas, processing potatoes recorded moderate tuber yield, but had high soluble protein and high ascorbic acid, low reducing sugars, low sucrose, low phenols and low total free amino acids. Study suggests that genotypes with moderate to high tuber dry matter, high soluble protein and high ascorbic acid should be selected for improving nutritionally superior table potatoes.

Key words: Correlation, Genetic analysis, Nutritional traits, Potato, Processing, Tuber yield

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world after rice and wheat. Potato is nutritious food and provides carbohydrates, proteins, minerals, vitamin C, vitamin B complex, high quality dietary fibres and phenolic compounds (Woolfe 1987). Potato tubers are used for a wide variety of purposes such as table, processed, livestock feed and industrial uses. It has also gained recognition for antioxidant class of phyto-nutrient benefit (Brown *et al.* 2007). The information on nutritional composition of potato tuber is less understood than processing quality (Brown 2008). Sugar and free amino acids are precursors of color and flavor compounds in cooked potatoes (Khanbari and Thompson 1993). Excessive non-enzymatic browning caused by reaction between amino acids and reducing sugars produces an undesirable color and unacceptable bitter taste in fried potato products (Lisinska and Leszczynski 1990).

In India, at present nearly 68% potatoes are utilized for table purpose, 7.5% for processing, 8.5% for seed, and remaining 16% produce goes waste due to pre- and post-harvest handling. Since the establishment of Central Potato Research Institute, Shimla in 1949, concerted efforts of breeders have led to the development and release of 56 potato varieties suitable for different potato growing regions in the country. The main breeding focus has been to develop varieties with short duration, high yield, good keeping quality, resistance to biotic stress specially late blight and viral diseases, and suitable for table and processing purposes (Luthra *et al.* 2006). In potato, tuber yield is a complex polygenic trait (Killick 1977) and is the product of interactions of various factors. Information on the nature and magnitude of variability and association among different characters is a pre-requisite for an efficient breeding strategy. The information related on genetic parameters on tuber yield, processing and nutritional components in potato is meagre (Luthra *et al.* 2014). Hence, present investigation aimed to identify genetic factors such as variability, heritability, genetic advance and association between tuber yield, processing and nutritional traits to develop nutritionally superior potatoes.

MATERIALS AND METHODS

The experimental material comprised of 23 genotypes was evaluated during winter season (main crop) for two years (2013-14 and 2014-15) at CPRI, Regional Station, Modipuram, Meerut (29°N and 76°E; 222 m above mean sea level). Potato genotypes were table type: HT/7-804, HT/7-1105, MS/8-1148, MS/8-1565, MS/9-723, Kufri Bahar, Kufri Garima, Kufri Pukhraj and Kufri Sadabahar; and processing type: MP/6-39, MP/7-214, MP/8-57, MP/8-62, MP/8-172, MP/8-329, MP/8-1622, MP/8-1900, Atlantic, Kufri Chipsona-1, Kufri Chipsona-3, Kufri Chipsona-4, Kufri Frysona and Kufri Himsona. The trials were laid out in randomized complete block design with three replications.

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Each genotype in a replication was planted in plot of 2.4 × 3 m^2 comprising four rows of each 3 m length at 60 (between rows) × 20 (within rows) cm^2 plants spacing. Sprouted seed tubers of 40-45 mm size were planted in the third week of October of respective year. The standard cultural practices of the regions were followed and crop was dehaulmed at 90 days after planting (DAP). The data was recorded on 16 characters, viz. germination at 45 days after planting, plant viogur at 60 days crop stage (1-5 scale: 1- very poor, and 5- very good), foliage maturity at 75 days crop stage (1-5 scale: 1- very late, and 5- very early), tubers/plant (marketable and total), marketable tuber yield (> 20 g) (t/ha), total tuber yield (t/ha), general impression (1-5 scale: 1- very poor, and 5- very good). The tuber dry matter content was estimated by oven drying of 50 g cut tuber samples (in three replications) to a constant weight at 80°C from the composite samples drawn from each genotype (Luthra *et al.* 2003). The chip colour (1-10 scale: 1- very light and desirable colour, and 10-dark and undesirable colour; up to 3 is desirable) is determined by frying of chips in hot oil at 180°C till the bubbling is over. The biochemical parameters, i.e. reducing sugars (Nelson 1944), sucrose (Van 1968), soluble protein (Lowry *et al.* 1951), phenols (Malik and Singh 1980), ascorbic acid (Sadashivam and Manikcam 1997) and total free amino acids (Lee and Takahashi 1960) were estimated following standard procedures.

The data were subjected to pooled analysis for estimating the variability (Panse and Sukhatme 1985), coefficient of variation (Burton and De Vane 1953), heritability in broad sense and genetic advance as a percentage of mean (Allard 1960) and correlation coefficients (Searle 1961). The data were analyzed using the software Windostat 8.5 (Ameerpet, Hyderabad, India).

RESULTS AND DISCUSSION

Genetic parameters

The analysis of variance revealed significant differences among the 23 genotypes for all the traits. The genotypic coefficient of variation (PCV), phenotypic coefficient variation (PCV), heritability and genetic advance for various traits are presented in Table 1. For all the characters PCV was higher than their corresponding GCV indicating the effect of environment on these traits. The highest values of PCV as well as GCV were observed for reducing sugars followed by chip colour score, phenols, soluble proteins, sucrose, total free amino acids and marketable tuber yield indicating that these characters would respond to selection. Singh *et al.* (2004) and Luthra *et al.* (2013) also found high GCV and PCV for average tuber weight, tuber number and tuber yield. Heritability values for various characters ranged between 0.25 (ascorbic acid) to 0.98 (chip colour/soluble protein/total free amino acids). Heritability estimates of all the traits excepting ascorbic acid (0.25) were high enough (> 0.69 to 0.98) for selection to be effective. The results on heritability for tuber yield and tuber number were in accordance with the findings of Chaudhary (1985), Gaur *et al.* (1985), Lynch and Kozub (1991) and Luthra *et al.*

Table 1 Estimates of coefficient of variation, heritability, genetic advance and genetic advance (5% of mean) in potato for yield, processing and nutritional components

Character	Coefficient of variation		h^2 (Broad sense)	Genetic advance	Genetic advance as % of mean
	Genotypic	Phenotypic			
Germination (%)	2.54	3.05	0.69	4.09	4.36
Plant vigour	6.44	7.01	0.84	0.56	12.18
Foliage maturity	16.50	17.23	0.92	0.88	32.53
Marketable tubers	12.09	12.48	0.94	1.59	24.12
Total tubers	12.10	13.41	0.81	1.96	22.49
Marketable yield (t/ha)	20.76	21.09	0.97	13.93	42.07
Total yield (t/ha)	19.31	19.66	0.96	13.88	39.06
General impression	13.33	13.67	0.95	1.14	26.79
Tuber dry matter (%)	9.35	9.79	0.91	3.59	18.39
Chip colour	46.49	47.08	0.98	3.71	94.56
Reducing sugars*	55.08	55.91	0.97	135.09	111.77
Sucrose*	22.38	24.06	0.87	97.79	42.88
Soluble proteins*	29.15	29.43	0.98	131.77	59.46
Phenols*	34.32	34.99	0.96	37.04	69.34
Ascorbic acid*	3.44	6.90	0.25	0.67	3.53
Total free amino acids*	23.63	23.88	0.98	272.29	48.18

Selection intensity at 5%. Chip colour score: 1-10 scale- 1 very light and desirable colour and 10 dark and undesirable colour following frying of chips in hot oil at 180°C till the bubbling is over, chip cololur score up to 3 is desirable; *mg/100g fresh weight of tubers.

(2013) suggesting that selection would be effective for these traits. High GCV and PCV associated with high heritability were observed for reducing sugars followed by chip colour score, phenols, soluble proteins, sucrose, total free amino acids and marketable tuber yield.

Expected genetic advance was converted into percentage of mean so that comparisons could be made among various characters, which had different units of measurement. The maximum genetic advance was observed for reducing sugars followed by chip colour score, phenols, soluble proteins, sucrose, total free amino acids and marketable tuber yield. Birhman *et al.* (1984), Luthra (2001) and Luthra *et al.* (2013) reported high genetic advance for marketable tuber yield, average tuber weight and total tuber yield. High heritability along with high genetic advance as percentage of mean is more reliable for selection to impose. Therefore characters, viz. reducing sugars followed by chip colour score, phenols, soluble proteins, sucrose, total free amino acids and marketable tuber yield had high genotypic and phenotypic variation, heritability and genetic advance as percent of mean and can be improved by practicing selection for required trait in potato breeding programme.

Performance of genotypes for yield, processing and nutritional traits

The results of tuber yield, processing and nutritional traits are presented in Table 2. In general, all the advanced stage hybrids and control varieties possessed high germination (86%), high plant vigour (4-5), moderate (3) to very high (5) general impression, and foliage maturity was medium (3) to very late (1).

Tuber yield traits

There was a wide variation with respect to marketable and total tuber yield in advanced hybrids and varieties. Marketable tuber yield ranged from 26 (Kufri Himsona) to 48 t/ha (MS/8-1565), whereas total tuber yield varied from 29 (Atlantic) to 51 t/ha (MS/8-1565). The highest marketable tuber yield was recorded in MS/8-1565 (48 t/ha) followed by MS/8-1148 (46 t/ha), Kufri Garima, Kufri Pukhraj (44 t/ha), Kufri Sadabahar, MS/9-723 (40 t/ha), MP/6-39 (36 t/ha), Kufri Bahar (33 t/ha), HT/7-1105 (33 t/ha), MP/8-1900 (31 t/ha), HT/7-804 (31) and Kufri Chipsona-3 (30 t/ha). Whereas highest total tuber yield was found in MS/8-1565 (51 t/ha) followed by MS/8-1148 (49 t/ha), Kufri Garima (47 t/ha), Kufri Pukhraj (46 t/ha), MS/9-723 (43 t/ha), Kufri Sadabahar (41 t/ha), MP/6-39 (39 t/ha), Kufri Bahar (37 t/ha) and HT/7-1105 (35 t/ha). For processing industry, processing grade tubers are important and indicative of economic suitability of potatoes for making chips (> 45mm) and French fries (>75mm). The ability of 14 genotypes suitable for processing varied between genotypes and highest processing grade potatoes were found in MP/8-62 and Atlantic (90%) followed by Kufri Chiposna-4 (89%), MS/8-1900 (86%), Kufri Frysona (85%), MP/6-39, MP8-172, Kufri Chipsona-1 (83%), MP8-1622 (82%), Kufri Chipsona-3 (80%), MP/8-214 (79%) and Kufri Himsona (76%).

Marketable tubers/plant ranged from 5 in Atlantic to 9 in Kufri Himsona, whereas total tubers/plant ranged from 7 in Atlantic to 11 in MP/7-214. The highest marketable tubers were recorded in Kufri Himsona (9) followed by MP/8-1900, MS/9-723, Kufri Chipsona-1, HT/7-804, Kufri Pukhraj, HT/7-1105, MS/8-1565, MP/7-214, MP/8-1622 and Kufri Garima (7). Total tubers/plant were high in MP/7-214, Kufri Himsona (11) followed by MS/9-723, Kufri Pukhraj, Kufri Chipsona-1 (10), Kufri Bahar, Kufri Garima, MS/8-1565, MP/6-39, Kufri Frysona, MS/8-1148 and HT/7-804 (9).

Processing traits

Dry matter content determines the suitability of genotype for processing purposes and thus affecting chips yields, texture, flavour, oil content and processing efficiencies. The tuber dry matter content ranged from 16 (Kufri Pukhraj and MS/8-1148) to 22 % (MP/8-62 and MP/8-57) followed by 21% (MP/8-1900, Kufri Himsona, Kufri Chipsona-4, MP/8-172, Kufri Chipsona-3, MP/8-329, Kufri Chipsona-1, Atlantic and Kufri Frysona). The genotypes with high tuber dry matter content (≥ 20 %) are considered suitable for processing.

The chip colour score of up to 3 is considered ideal for chip making. The chip colour score ranged from 2 (MP/8-62) to 8 (MS/8-1148). The acceptable chip colour score (3) was recorded in MP/8-62, Atlantic, Kufri Himsona, Kufri Chipsona-1, MP/8-57, Kufri Chipsona-3, MP/7-214 (2), MP/8-1900, Kufri Frysona, MP/8-1622, MP/6-39, MP/8-172 and Kufri Chipsona-4.

Reducing sugars are the major limiting factors in chip color development (Roe *et al.* 1990) and genotypes with low reducing sugars (≤ 150 mg/100 g FW) are considered to be suitable for processing. Reducing sugars ranged from 36 (Kufri Frysona) to 277 mg/100 g FW (Kufri Pukhraj). Genotypes such as Kufri Frysona (36), Kufri Himsona (48), MP/7-214 (49), Atlantic (56), Kufri Chipsona-3 (58), MP/8-57 (59), MP/8-62 (66), MP/8-1622 (73), Kufri Chipsona-1 (81), MP/6-39 (82), MP/8-172, Kufri Chipsona-4 (99), MP/8-329 (120), MP/8-1900 (132) recorded low reducing sugars and therefore found to be suitable for processing.

Sucrose content ranged from 135 (MP/8-1900) to 328 mg/100 g FW (MS/8-1565). Genotypes with low sucrose content (< 150 mg/100 g FW) are not only indicative of suitability for processing after harvest, but also signifies that acceptable processed product could be made from the tubers stored in cold storage at 2-4 °C. The lower value of sucrose content at harvest were recorded in MP/8-1900 (135), Kufri Chipsona-1 (148), Atlantic (160), Kufri Garima (180), Kufri Frysona (181), MP/6-39 (195), MP/8-329 (197) and HT/7-804 (198).

Nutritional traits

Protein is an important dietary requirement of human beings and known to perform a vast array of functions within the organisms. Soluble proteins content ranged from 132

Table 2 Phenotypes, tuber yield, processing and nutritional components traits in 23 potato genotypes

Genotype	Germination (%)	Plant vigour	Foliage maturity	Tubers/plant		Tuber yield (t/ha)		General impression	Tuber dry matter (%)	Chip colour	Reducing sugars*	Sucrose*	Soluble protein*	Phenols*	Ascorbic acid*	Total free amino acids*
				Marketable	Total	Marketable	Total									
HT/7-804	94.17	4.27	2.71	7.26	8.72	30.60	31.84	4.19	17.63	6.12	170.91	197.52	159.79	48.91	17.92	579.64
HT/7-1105	94.25	4.73	3.03	7.03	8.35	33.18	35.24	4.58	19.18	4.67	175.55	282.01	145.94	89.20	18.31	563.69
MP/6-39	94.31	5.00	3.00	6.29	8.91	36.03	38.59	5.00	19.55	3.12	81.93	194.17	135.68	85.99	18.26	554.42
MP/7-214	86.42	4.42	2.33	6.74	11.31	28.86	34.04	3.75	19.52	2.43	48.74	220.71	192.20	40.04	19.16	458.43
MP/8-57	96.00	4.92	2.67	6.30	8.08	28.01	30.86	3.13	21.74	2.30	58.55	241.65	293.14	40.41	20.28	523.74
MP/8-62	91.83	4.03	2.67	6.31	7.79	27.76	29.86	3.21	21.94	1.67	65.61	257.28	266.33	51.75	19.29	447.38
MP/8-172	91.17	4.83	2.52	5.23	7.38	26.51	28.93	4.98	21.12	3.22	99.44	246.45	268.76	53.42	20.53	525.68
MP/8-329	94.67	4.75	2.58	6.38	7.73	29.34	32.48	3.33	20.87	3.97	120.45	197.44	261.69	49.45	18.68	397.41
MP/8-1622	94.30	4.25	2.75	6.68	8.31	28.11	30.24	4.11	20.35	2.87	73.00	237.22	266.24	36.23	18.34	438.92
MP/8-1900	94.61	4.83	2.59	7.49	8.38	30.98	34.11	4.96	21.36	2.67	131.85	134.80	268.72	23.81	19.70	407.86
MS/8-1148	95.97	4.50	2.67	6.44	8.85	46.44	48.51	4.17	15.68	7.70	216.79	240.17	154.17	79.97	18.32	894.80
MS/8-1565	99.11	5.00	3.00	6.88	9.16	48.05	50.90	5.00	17.26	5.15	152.27	327.52	165.56	65.47	15.11	698.70
MS/9-723	96.72	4.50	3.17	7.49	10.31	39.58	42.80	4.50	18.05	6.25	168.29	200.92	131.57	67.38	17.04	761.40
Atlantic	91.53	4.73	2.79	5.18	6.55	27.30	28.53	3.96	20.59	1.67	55.56	159.98	331.34	41.18	21.30	407.28
K. Bahar	93.61	4.50	3.50	6.37	9.26	33.23	35.62	3.83	18.12	4.88	208.26	310.21	196.50	84.67	18.97	800.51
K. Chipsona-1	94.00	4.38	2.67	7.31	9.59	28.54	31.05	4.29	20.78	2.05	80.62	148.38	322.60	53.88	21.06	468.26
K. Chipsona-3	91.95	4.83	2.67	5.48	8.39	29.81	31.94	4.33	21.02	2.43	57.56	310.96	191.27	44.97	19.77	481.42
K. Chipsona-4	93.83	4.46	2.71	6.18	7.73	28.51	30.15	4.38	21.13	3.42	99.45	210.25	255.90	36.02	18.82	510.38
K. Frysona	86.83	3.92	1.96	6.45	8.86	27.25	29.01	4.63	20.57	2.82	35.86	181.28	290.93	36.51	19.04	541.70
K. Garima	94.86	5.00	3.00	6.61	9.22	44.47	46.77	5.00	17.44	5.88	226.82	179.97	153.29	46.50	19.65	624.25
K. Himsona	94.50	4.21	1.13	8.82	11.05	25.86	29.23	3.75	21.30	1.97	48.14	201.32	296.69	27.39	19.74	558.71
K. Pukhraj	95.56	4.50	3.17	7.10	9.75	43.56	45.79	4.00	15.55	5.88	276.50	322.87	161.89	57.60	19.25	744.39
K. Sadabahar	95.97	5.00	3.00	5.54	7.12	39.74	41.01	4.83	18.29	7.07	127.82	242.67	186.89	67.89	18.84	610.95
CD (P=0.05)	4.45	0.36	0.38	0.57	1.41	3.48	3.70	0.36	1.59	0.82	32.54	56.51	25.42	10.20	-	54.27

*mg/100g fresh weight of tubers; K. = Kufri; Potato genotypes are: HT/7-804, HT/7-1105, MS/8-1148, MS/8-1565, MS/9-723, cvs. K. Bahar, K. Garima, K. Pukhraj and K. Sadabahar; Processing: MP/6-39, MP/7-214, MP/8-57, MP/8-62, MP/8-172, MP/8-329, MP/8-1622, MP/8-1900, cv. Atlantic, K. Chipsona-1, K. Chipsona-3, K. Chipsona-4, K. Frysona and K. Himsona.

(MS/9-723) to 331 mg/100 g FW (Atlantic). The higher values of soluble proteins (mg/100 g FW) were recorded in Atlantic (331) followed by Kufri Chipsona-1 (323), Kufri Himsona (297), MP/8-57 (293), Kufri Frysona (291), MP/8-172 (269), MP/8-1900 (269), MP/8-62 (266), MP/8-1622 (266), MP/8-329 (262) and Kufri Chipsona-4 (256).

Phenolic compounds are known to exhibit health-promoting effects in humans. Potato peels is a great source of phenolic compounds, almost 50% of phenolics are located in the peel and adjoining tissues (Albishi *et al.* 2013, Al-Weshahy *et al.* 2009). Phenol content ranged from 24 (MP 8-1900) to 89 mg/100 g FW (HT/7-1105). The genotypes with high phenols were HT/7-1105 (89) followed by MP/6-39 (86), Kufri Bahar (85), MS/8-1148 (80), Kufri Sadabahar (68), MS/9-723 (67), MS/8-1565 (65), Kufri Pukhraj (58), Kufri Chipsona-1 (54), MP/8-172 (53), MP/8-62 (52) and MP/8-329 (49).

Potato is rich source of ascorbic acid (vitamin C), which is an antioxidant playing an important role against many human diseases especially scurvy. In this study, ascorbic acid content ranged between 15 (MS/8-1565) to 21 mg/100 g FW (Atlantic). The high content of ascorbic acid is good for nutrition point of view, was observed in Atlantic, Kufri Chipsona-1, MP/8-172 (21), MP/8-57, Kufri Chipsona-3, Kufri Himsona, MP/8-1900 and Kufri Garima (20). Brown (2005) also reported an average level of 20 mg/100 g FW that account for up to 13% of the total antioxidant capacity of tuber.

Potato genotypes with low free amino acids are known to be suitable for processing purpose. In this study, free amino acids content ranged between 327 (MP/8-397) to 895 mg/100 g FW (MS/8-1148). Based on the lower free amino acid content, processing genotypes were identified such as MP/8-329 (397), Atlantic (407), MP/8-1900 (408), MP/8-1622 (439), MP/8-62 (447), MP/7-214 (458), Kufri Chipsona-1 (468), Kufri Chipsona-3 (481), Kufri Chipsona-4 (510), MP/8-57 (524), MP/8-172 (526), Kufri Frysona (542), MP/6-39 (554), Kufri Himsona (559). Free amino acids and reducing sugars participate in the Maillard reaction during high-temperature cooking and processing (Muttucumaru *et al.* 2014) causing formation of undesirable contaminants such as acrylamide by participation of asparagine in the reaction.

Correlation among different traits

Correlations among the different traits studied (phenotype, yield, processing and nutritional components) are summarized (Table 3).

Phenotypes

Early and uniform germination is known to contribute toward tuber initiation, tuber bulking and finally yield at harvest. Germination (%) was positively associated with plant vigour (0.46*), marketable tuber yield (0.61**), total tuber yield (0.59**), chip colour (0.52*) and total free amino acids (0.44*) and negative association with tuber dry matter (-0.41*) and ascorbic acid (-0.45*). Plant vigour is known to have positive impact on productivity. Plant vigour possessed positive and significant association with germination (0.46*), foliage maturity (0.44*), marketable tuber yield (0.41*), total tuber yield (0.42*) and general impression (0.42*). Plant vigour did not have impact on processing and nutritional components.

Foliage maturity possessed positive and significant correlation between plant vigor *(*0.44**), marketable tuber yield (0.52*), total tuber yield (0.49*), chip colour (0.49*), reducing sugars (0.60*), phenols (0.63**) and negative association with tube dry matter (-0.49*) and soluble proteins (-0.53**). This indicates that late maturing genotypes with low reducing sugars and high tuber dry matter lead to acceptable chip score, the major criterion of breeding processing varieties.

Tuber yield traits

Marketable tuber yield was significantly high positively associated with germination (0.61**), plant vigour (0.41*), foliage maturity (52*) and total tuber yield (0.99**) indicating the importance of these traits for improvement of tuber yield in potato. Luthra *et al.* (2013) also reported positive association between tuber yield components for improvement in potato. The pattern of correlation of total tuber yield with other traits was similar like association between marketable tuber yield and other traits. It indicated that higher tuber yield with high phenols and amino acid is suitable for table potatoes. Free amino acids are known to produce heterocyclic flavour in potato (Hwang *et al.* 1995). Phenols as anti-oxidants, proteins and vitamin C are required for healthier development of human beings. The negative association of yield with protein and ascorbic acid suggests to compromise between these traits while making selection for nutritional superior genotypes. Whereas, processing potatoes should have acceptable chip colour score, low reducing sugars and high tuber dry matter. Marketable tubers/plant showed positive association (0.74*) with total tubers/plant. Gopal *et al.* (1994), Luthra (2001), Luthra *et al.* (2013) suggested that a standard may be fixed for the maximum number of tubers required in the selected genotype before employing selection for tuber yield and average tuber weight.

Processing traits

Tuber dry matter content is very important to most processors because yield of processed products (chips and French fries) is directly related with it. Tuber dry matter content (%) showed significant positive association with soluble protein (0.76**) and ascorbic acid (0.51*), and significantly negative association with germination (-0.41*), foliage maturity (-0.49*), marketable tuber yield (-0.87**), total tuber yield (-0.85**), chip colour (-0.88**), reducing sugars (-0.84**), soluble proteins (-0.76**), phenols (-0.56**) and total free amino acid (-0.83**). Feltran *et al*. (2004) observed positive correlation of specific gravity with starch content, texture, pulp pH and soluble solids and negative correlation with reducing sugars.

Table 3 Inter-relationship between tuber yield, processing attributes and nutritional components in potatoes

Character	Plant vigour	Foliage maturity	Mark-etable tubers	Total tubers	Mark-etable yield (t/ha)	Total yield (t/ha)	General imp-ression	Tuber dry matter (%)	Chip colour	Reducing sugars	Sucrose	Soluble protein	Phenols	Ascorbic acid	Total free amino acids
Germination (%)	0.46*	0.40	0.27	-0.06	0.61**	0.59**	0.15	-0.41*	0.52*	0.53	0.22	-0.34	0.34	-0.45*	0.44*
Plant vigour		0.44*	-0.37	-0.31	0.41*	0.42*	0.42*	-0.14	0.23	0.23	0.13	-0.32	0.29	-0.05	0.05
Foliage maturity			-0.36	-0.26	0.52*	0.49*	0.21	-0.49*	0.49*	0.60**	0.37	-0.53**	0.63**	-0.28	0.38
Marketable tubers				0.74**	0.07	0.12	-0.08	-0.13	0.05	0.17	-0.18	-0.08	-0.15	-0.26	0.16
Total tubers					0.19	0.27	-0.05	-0.30	0.07	0.14	0.03	-0.30	0.00	-0.23	0.34
Marketable yield (t/ha)						0.99**	0.42*	-0.87**	0.81**	0.76**	0.35	-0.74**	0.54**	-0.58**	0.76**
Total yield (t/ha)							0.39	-0.85**	0.77**	0.74**	0.35	-0.75**	0.52*	-0.59**	0.75**
General impression								-0.28	0.33	0.23	-0.11	-0.38	0.22	-0.27	0.18
Tuber dry matter (%)									-0.88**	-0.84**	-0.37	0.76**	-0.56**	0.51*	-0.83**
Chip colour										0.82**	0.28	-0.75**	0.56**	-0.54**	0.79**
Reducing sugars											0.34	-0.66**	0.51*	-0.35	0.73**
Sucrose												-0.43*	0.45*	-0.39	0.46*
Soluble proteins													-0.66**	0.65**	-0.64**
Phenols														-0.41*	0.63**
Ascorbic acid															-0.47*

Significant at P=0.05 (*) and P= 0.01 (**). Chip colour on 1-10 scale, 1 very light and desirable colour and 10 dark and undesirable colour following frying of chips in hot oil at 180˚C till the bubbling is over, chip cololur score up to 3 is desirable); *mg/100 g fresh weight of tubers.

Chip colour score possessed significant and positive relationship with germination (0.52*), foliage maturity (0.49*), marketable yield (0.81*), total tuber yield (0.77**), reducing sugars (0.82**), phenols (0.56**) and total free amino acids (0.79**). The chip color score showed negative relationship with tuber dry matter (-0.88**), soluble protein (-0.75**) and ascorbic acid (-0.54**). The potatoes suitable for chip industry should produce acceptable chips colour (up to 3) and should possess high tuber dry matter and low reducing sugars. Reducing sugars had positive association with foliage maturity (0.60**), marketable yield (0.76**), total tuber yield (0.74**), chip colour score (0.82**), phenol (0.51*) and total free amino acid (0.79**) and negative association with tuber dry matter (-0.84**) and soluble proteins (0.66**). Takada *et al*. (2005) found strong correlation between the reducing sugar content and acrylamide level, R^2 = 0:87 for fructose and R^2 = 0:84 for glucose.

Nutritional traits

Soluble protein showed positive relationship with tuber dry matter (0.76**) and ascorbic acid (0.65**) and negative association with phenols (-0.66**) and total free acids (-0.64**). The positive association of sucrose with phenols (0.45*) and total free acids (0.46*) suggests that genotypes with high sucrose are not suitable for chips after long-term cold storage (2-4 °C), however they can be used as table purpose. The negative association of sucrose with soluble protein (-0.43*) indicated that table potato varieties possessed low protein as compared to processing varieties.

Phenols showed positive association with foliage maturity (0.63**), marketable tuber yield (0.54**) and total tuber yield (0.52*), chip colour (0.56**), reducing sugar (0.51*), sucrose (0.45*) and total free amino acids (0.66**), but showed significantly negative association with tuber dry matter (-0.65**), soluble protein (0.66**) and ascorbic acids (-0.41*). This indicates that while making selection compromise needs to be made between ascorbic acid and phenols as both are important for nutrition point of view. Ascorbic acid exhibited significantly negative association with germination (-0.45*), marketable tuber yield (-0.58**), total tuber yield (-0.59**), chip colour (-0.54**), phenols (-0.41*) and total amino acid (-0.47*). Positive association of ascorbic acid was recorded with tuber dry matter (0.56**), and soluble proteins (0.65**) was recorded.

Total free amino acid showed positive relationship with germination (0.44*), marketable (0.76**) and total (0.75**) tuber yield, chip colour (0.79**), reducing sugars (0.73**), sucrose (0.46*) and phenols (0.63**). The negative correlation was found with total free amino acid and tuber dry matter (-0.83**), soluble protein (-0.64**) and ascorbic acid (-0.47*). In table potato, where criterion is to breed for high tuber yield, high total free amino acids would have positive role. However, genotypes with high total free amino acids along with high reducing sugars are not suitable for processing owing to their negative role in formation of dark and undesirable chips colour.

Conclusions

The results revealed that table potato genotypes possessed high yield and high phenols. Whereas, processing potato though possessed moderate tuber yield, but high tuber dry matter, high soluble protein and high ascorbic acid, low reducing sugars, low sucrose, low phenols and low total free amino acids. The processing genotypes with high dry matter (> 20%), low reducing sugars (<150 mg) and acceptable chip colour score (up to 3) needs could be utilized for processing purposes to avoid the periodic gluts resulting wastage of precious produce. For improving the nutritional values of table potatoes, genotypes with high yield, high tuber dry matter, high soluble protein and high ascorbic acid should be selected. Although, this finding would strengthen potato research and development program of the country, it would be a challenging task to breed such nutritionally superior genotypes for the consumers.

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