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Relationship between chip colour and compositional characters in potato (*Solanum tuberosum*)

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ABSTRACT

A study was conducted during 2004-07 to evaluate 52, 72 and 72 germplasm accessions for relative importance of 5 compositional factors, namely, reducing sugars, dry matter sucrose, phenols and amino acids of tubers to chip colour. Correlation, path analysis and multiple regression studies showed that reducing sugars and dry matter were important constituents in determining the chip colour in freshly harvested potatoes. The correlation of reducing sugar content with chip colour was positive and significant. Tuber dry matter had a significant and negative correlation with the intensity of chip colour. Dry matter had a negative and significant correlation co-efficient with reducing sugars. The low reducing sugar and high tuber dry matter contents had both direct and indirect favourable effects on chip colour. As the low reducing sugars and high dry matter were associated with each other and both contributed to lighter chip colour, simultaneous selection for both of these parameters will better facilitate the development of potato varieties suitable for chipping. The multiple regression based on both these characters explained more variation in chip colour compared to either of these characters. Between the two, reducing sugar was more important and both reducing sugars and dry matter explained <50% variation in chip colour. The other three chemical constituents, viz sucrose, total phenols and free amino acids showed no consistent association with chip colour. Further studies are required to find out the other compositional factors contributing to the chip colour.

Key words: Chip colour, Correlation, Dry matter, Free amino acids, Path analysis, Potato, Reducing sugars, Regression, *Solanum tuberosum*, Sucrose, Total phenols

The colour of potato (*Solanum tuberosum* L) chips is an extremely important character affecting the marketability of chips. Excessive browning during frying produces is an undesirable colour and unacceptable bitter taste in chips due to Maillard reaction which results in the formation of brown melanoidin pigments involving compounds with amino and carbonyl group (Pritchard and Adam 1994). Levels of reducing sugars and sucrose have been used to predict the suitability of materials for chipping industries (Pritchard and Adam 1994, Rodriguez-Sanoa and Wrolstad 1997). Tuber dry matter has also been identified as a component determining the chip colour (Mazza 1983). Several other constituents including amino acids (Khanbari and Thompson 1993) and polyphenolic compounds (Cilliers and Singleton 1989) are also involved in non-enzymatic browning reaction.

The quantitative relationship among quality parameters of potatoes is not sufficiently stable to serve as a general measure of prediction under all conditions (Iritani and Weller 1976). Therefore, each potato production area of the world may have to develop relationships which best reflects their environmental conditions, production technologies, storage and utilization practices. Further, most of the previous studies (Ezekiel *et al*. 2005) on this aspect had been based on a few genotypes. In the present study, a large number of genotypes were evaluated for three seasons under the sub-tropical plains of India to investigate the relative importance of 5 compositional factors, viz reducing sugars, dry matter, sucrose, total phenols and free amino acids of tubers to chip colour. This information may be useful to the breeders in developing cultivars suitable for processing.

MATERIALS AND METHODS

The tuberosum germplasm accessions were planted in field during autumn crop seasons 2004–05, 2005–06 and 2006–07. In 2004–05 season freshly harvested tubers of 52

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Table 1 Range for chip colour (CC), reducing sugars (RS), dry matter (DM), sucrose (SUC), phenols (PHE), free amino acids (FAA) content of potatoes in the material studied

Crop season	Range					
	Chip colour score	Dry matter (%)	Reducing sugars (mg/100 g fr wt)	Sucrose (mg/100 g)	Total phenols (mg/100 g)	Free amino acids (mg N/100 g fr wt)
2004–05	1 – 9	14.3–23.7	58–788	86–198	36.5 – 91.4	28.8–66.2
2005–06	2 – 9	13.8–27.1	55–713	40–166	23.7 –156.6	13.7–97.1
2006–07	3 –10	13.8–24.6	40–582	111–246	32.6 – 71.2	47.0–82.1

germplasm accessions were evaluated for chip colour and 5 biochemical parameters. In 2005–06 season freshly harvested tubers of 72 germplasm accessions were evaluated for chip and biochemical characters. Similarly, in 2006–07 season 72 germplasm accessions were evaluated for chip colour and 5 biochemical parameters. Same 72 germplasm accessions were evaluated in both 2005–06 and 2006–07 crop seasons. For determination of dry matter, tubers were cut into small pieces and oven-dried to a constant weight at 80°C. For preparation of fresh fried chips, 10 tubers were hand-peeled and bisected longitudinally from stem to bud end. The exposed centre of each tuber was used to collect tissue for chip colour and chemical analysis. One-half of the tuber was used to collect 4 slices (1.8 mm thick) with an electricity operated rotary slicer, washed thoroughly with cold water, air-dried and immediately fried in groundnut oil at 180°C until bubbling ceased. The fried chips were subjectively scored for colour and assigned a value according to the 1–10 scale (lower number- better colour) of the PC/SFA (Gould *et al.* 1979). Chips up to a score of 3 were considered acceptable. The other half of the tuber was finely diced, mixed thoroughly and used for estimations of reducing sugars by the Nelson-Somogyi method (Pearson 1976), sucrose (Van Handell 1968), total phenols (Swain and Hillis 1959) and free amino acids (Moore 1968). Data were analyzed to estimate correlation co-efficients and their direct and indirect effects through path analysis (Dewey and Lu 1959). Various equations like linear, multiple regression, logarithmic and exponential were derived to know the one best explaining the relationship of chip colour with other constituents.

RESULTS AND DISCUSSION

The range observed for various characters (Table 1) showed wide variation in the genotypes studied. Tuber dry matter had a significant and negative correlation with the intensity of chip colour in all the three seasons (Table 2). The correlation of reducing sugar content with chip colour was positive and significant in all the seasons. Dry matter had a negative and significant correlation co-efficient with reducing sugars in all the 3 seasons.

Path analysis showed that reducing sugar had maximum direct positive effect on chip colour in all the 3 seasons

Table 2 Correlation of chip colour with biochemical contents in potato

Character	Crop season	Dry matter	Reducing sugars	Sucrose	Total phenols	Free amino acids
			Correlation co-efficient			
Chip colour	2004–05	–0.4732**	0.5077**	0.0520	0.1085	–0.2136
	2005–06	–0.4892**	0.4504**	–0.0759	0.0656	0.0104
	2006–07	–0.4775**	0.7175**	–0.0765	0.2596*	–0.0644
Dry matter	2004–05		–0.4403**	0.0044	0.1224	0.1143
	2005–06		–0.3147**	0.4366**	–0.3329**	–0.0885
	2006–07		–0.5866**	0.5141**	–0.1229	0.0605
Reducing sugars	2004–05			–0.0699	–0.2443	–0.2023
	2005–06			0.0565	–0.1835	0.0079
	2006–07			–0.0975	0.1824	–0.2610*
Sucrose	2004–05				0.1326	–0.1911
	2005–06				–0.376**	–0.1219
	2006–07				0.1831	0.2003
Total phenols	2004–05					0.1772
	2005–06					–0.0417
	2006–07					0.4558**

Table 3 Direct and indirect effects of biochemical contents of potatoes on chip colour

Character	Crop season	Character				
		Dry matter	Reducing sugars	Sucrose	Total phenols	Free amino acids
Dry matter	2004–05	–0.3096	–0.1806	0.001	0.0329	–0.0159
	2005–06	–0.4298	–0.0984	0.0428	–0.0053	0.0015
	2006–07	–0.0679	–0.3986	–0.0040	–0.0116	0.0046
Reducing sugars	2004–05	0.1363	0.4102	–0.0013	–0.0657	0.0282
	2005–06	0.1352	0.3127	0.0055	–0.0029	–0.0010
	2006–07	0.0398	0.6795	0.0008	0.0172	–0.0197
Sucrose	2004–05	–0.0013	–0.0287	0.0184	0.0370	0.0266
	2005–06	–0.1876	0.0177	0.0979	–0.0060	0.0021
	2006–07	–0.0349	–0.0662	–0.0077	0.0173	0.0151
Total phenols	2004–05	–0.0379	–0.1002	0.0025	0.2688	–0.0247
	2005–06	0.1431	–0.0570	–0.0368	0.0160	0.0007
	2006–07	0.0083	0.1239	–0.0014	0.0943	0.0345
Free amino acids	2004–05	–0.0354	–0.083	–0.0035	0.0476	–0.1393
	2005–06	0.0380	0.0025	–0.0119	–0.0007	–0.0175
	2006–07	–0.0041	–0.1774	–0.0016	0.0430	0.0756
Residuals:	2004–05	0.5833				
	2005–06	0.6555				
	2006–07	0.4595				

Table 4 Multiple correlation co-efficients and regression equations for chip colour dependence on dry matter and reducing sugars

Year	Regression equation	Multiple correlation	
		R^2	r
2004–05	CC=10.401–0.2597 DM + 0.003359 RS	0.340	0.580
2005–06	CC=10.337–0.2274 DM + 0.0034 RS	0.337	0.580
2006–07	CC=6.375–0.06721 DM + 0.009516 RS	0.520	0.721
2004–05	CC=5.1979 + 0.004592 RS	0.258	0.508
2005–06	CC=5.604 + 0.004679 RS	0.203	0.450
2006–07	CC=5.00 + 0.010237 RS	0.515	0.717
2004–05	CC=14.1778–0.3969 DM	0.234	0.473
2005–06	CC=12.48–0.288 DM	0.239	0.489
2006–07	CC=13.8586–0.37217 DM	0.228	0.477

CC, Chip colour score; DM, dry matter (%); RS, reducing sugars (mg/100 g fresh wt)

(Table 3). Dry matter had direct negative effect on chip colour in all the seasons. Reducing sugars had indirect positive effect on chip colour through dry matter. Dry matter also had negative indirect effect on chip colour through reducing sugars.

The correlation co-efficients in the present study showed that only low reducing sugars and high dry matter were important for getting light chip colour. A number of studies indicating correlation between chip colour and various components in potato have been reported (Rodriguez-Sanoa and Wrolstad 1997, Marwaha 1999). However, there appears to be no report on the direct and indirect effects of various compositional factors on chip colour. Path analysis showed that low reducing sugars and high dry matter, besides, having desirable direct effect, also had desirable indirect effect through each other. Our results on the effect of reducing sugar and high tuber dry matter on chip colour are in agreement with the earlier reports (Rodriguez-Sanoa and Wrolstad 1997, Marwaha 1999). Our results showed that sucrose was not associated with chip colour in freshly harvested potatoes and this was in agreement with earlier reports (Rodriguez-Sanoa and Wrolstad 1997) that the role of sucrose in chip colour in fresh harvested potatoes is marginal/limited.

Individual amino acids like lysine, glycine, glutamine and arginine have been reported as components responsible for the colour development in fried potatoes (Khanbari and Thompson 1993). However, in the present study individual amino acids were not analysed and total amino acids showed no association with chip colour.

There are reports that browning may result from non-

enzymatic auto-oxidation of polyphenolic compounds favoured by alkaline *p*H (Cilliers and Singleton 1989) and ascorbic acid reacting with amino acids during frying (Smith 1987).

Most of the genotypes with reducing sugars less than 80 mg/100 g fresh weight produced light-colour chips. None of the genotype having dry matter less than 16.3% produced chips of light colour. Some genotypes with light chip colour associated with low reducing sugars were 'A 97-22' (chip colour 3; reducing sugar 40.0 mg/100 g, dry matter, 19.2%), 'A 98-181' (chip colour 3; reducing sugar 44.0 mg/100 g, dry matter 20.6%), 'NJ 17' (chip colour 3; Reducing sugar 40.0 mg/100 g, dry matter 24.5%), 'NJ 68' (chip colour 3; reducing sugar 49.0 mg/100 g, dry matter 19.7%), 'CP 1940' (chip colour 2; reducing sugars 69.0 mg/100 g, dry matter 24.1%), 'CP 1945' (chip colour 1; reducing sugar 76.0 mg/100 g, dry matter 21.6%).

The co-efficient of determination of multiple regression based on both the reducing sugars and dry matter were 0.340, 0.337 and 0.520 for the seasons 2004–05, 2005–06, 2006–07 respectively (Table 4). The corresponding co-efficients of determination based on either reducing sugar or dry matter were comparatively low, except for regression based on reducing sugar in the season 2006–07, where co-efficient of determination (R^2=0.515) was comparable to that based on both reducing sugars and dry matter. The relationship between reducing sugars and chip colour was best described by the logarithmic function, except in the season 2006–07, where linear function was also equally good (Table 5). Mazza (1983) reported that although sucrose content was significantly correlated with chip colour in freshly harvested potatoes, it had little importance in predicting chip colour as the multiple correlation co-efficients obtained by incorporating the sucrose were not significantly higher than those obtained by regression analysis of chip colour, on dry matter and reducing sugar. The co-efficient of determination for regression equations based on chip colour, dry matter and reducing sugars were lower than those observed by Mazza (1983). His study was based on multiple observations on individual cultivars. Whereas in the present study, regression equations were based on a large number (52, 72 and 72) of genotypes with a wide range for the characters studied.

Best fit logarithmic equations between chip colour and reducing sugar showed that reducing sugars did not completely explain chip colour quality when present in low concentrations. Similar results were also reported earlier (Rodriguez-Sanoa and Wrolstad 1997, Ezekiel *et al*. 2003). Ezekiel *et al.* (2003) also reported an exponential relationship between chip colour and reducing sugars (with reducing sugars as independent variable) with a high value of R^2 (0.78). The study conducted by them was based on a few genotypes including both fresh and stored tubers of different sugar levels and chips of different colour intensities, which may be the reason for obtaining higher R^2 value. Logarithmic relationship obtained by us and the exponential relationship reported by Ezekiel *et al.* (2003) between chip colour and reducing sugar content were the same, the difference being only in the character taken as dependent variable in the relationship.

Table 5 The logarithmic equations for dependence of chip colour on reducing sugars

Crop year	Equation	R^2	r
2004–05	CC=2.0335Ln (RS)–3.0895	0.45	0.67
2005–06	CC=1.6693Ln (RS)–1.9666	0.37	0.61
2006–07	CC=1.8477Ln (RS)–2.7275	0.50	0.71

CC, Chip colour score; RS, reducing sugars (mg/100 g fresh wt)

As the low reducing sugars and high dry matter were associated with each other and both contributed to lighter chip colour, simultaneous selection for both of these parameters will better facilitate the development of potato varieties suitable for chipping. High tuber dry matter (>20%) is also desirable to obtain high chip yield, low oil uptake and better texture of fried products (Marwaha *et al*. 2005). However, the residuals in path analysis and co-efficient of determination in multiple correlation analysis showed that characters analyzed in the present study explained only less than 50% of the variation in chip colour. This suggests the need to further investigate the role of other compositional factors like ascorbic acid and chlorogenic acid on chip colour (Rodriguez-Sanoa and Wrolstad 1997).

The present study being based on a large number of genotypes with large variation for various quality characters in freshly harvested potatoes, may prove useful to the breeders as they handle large populations and base their selection on freshly harvested potatoes. The potato industries also prefer fresh potatoes for chipping.

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