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STABILITY AND ADAPTABILITY OF KERNEL CAROTENOIDS IN MAIZE

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ABSTRACT
The study was conducted to investigate the adaptability and stability of kernel carotenoids (KC) and grain yield in 34 maize genotypes under various locations and to determine the relation between KC and grain yield, and between kernel colour and carotenoids content. Analysis of variance indicated significant genetic variance among the test materials for grain yield and kernel carotenoids. Results showed that none of the genotypes possessed general stability criteria either for the KC or grain yield. However, the germplasm identified to be promising for grain yield were 'PML-23', 'PML-10', 'PML-17', 'PML-11', 'PML-20' and 'PML-22' whereas 'PML-7', 'PML-3', 'PML-27', 'PML-31' and 'PML-29' were identified to be the five promising landraces for KC. On the other hand, PML-1, PML-6, PML-17, PML-27, PML-31 were found to be promising for both the traits and may serve as potential donor particularly for improvement of carotenoids in maize hybrids or composites. Relation between KC and grain yield emerged as non-significant with very low coefficient of determination. Similarly, kernel colour was found to be associated non-significantly with KC with low coefficient of determination. The present investigation also revealed that selection based on kernel colour is not reliable for selecting lines with higher carotenoids content.

INTRODUCTION

Maize (*Zea mays* L.) is the crop with highest genetic yield potential among cereals. Besides its diverse uses right from food and feed to industrial products such as ethanol, and adaptability to diverse ecological niches, it is the only carotenogenic crop among the major cereals. Presence of provitamin 'A' carotenoid in maize kernel makes this crop suitable for biofortification to supplement vitamin 'A' deficiency since most of the promising cultivars of maize have low and narrow range of kernel carotenoids (KC), improvement of carotenoid content in maize has received increased attention in recent years to overcome vitamin A deficiency there is a wide range of variability for KC (5.5 to 66 μg/g) has been reported in diverse maize germplasm (Harjes *et al.*, 2008 and Berardo *et al.*, 2009). The high concentration of KC in maize germplasm may be due to the presence of rare/desirable allele(s) or block of adapted genes influencing the biosynthesis of carotenoids. However the usefulness of maize varieties as a source of carotenoid in a breeding programmes depends on the stabile expression of these compounds across diverse growing environments (Menkir and Dixon, 2004). Thus, identification of lines with higher KC and further analysis of its behaviour across the different environmental conditions seems to be a key element in improvement of KC in maize. Sandmann and Albrecht (1994), Menkir and Dixon (2004) and Rios *et al.* (2009) have earlier reported that environmental factors influence carotenogenesis in maize. The differential response of the genotypes across the environments affects the selection gain as well as the development of cultivars with broad adaptability and stability. Literatures contain plenty of useful information about genotype-environment interaction (GEI), adaptability and stability in maize (Scapim *et al.*, 2000; Zivanovic *et al.*, 2004; Shrestha, 2013 and Shiri, 2013). However, most of the studies focus on yield-related traits, while limited attempts have been made to quantify GEI, adaptability and stability of carotenoid contents in maize. Therefore, the present investigation was planned to identify the promising germplasm showing adaptability and stability for carotenoids as well as grain yield. It was also decided to find out whether carotenoid content is related to grian yield and kernel colour or not.

MATERIALS AND METHODS

Thirty two maize collections from Uttarakhand (29 yellow and 3 white grained) were evaluated along with two check varieties namely 'Pant Sankul Makka-3' and 'Pragati' under three environments *i.e.* normal nitrogen dose and irrigated (E_1), low nitrogen and rainfed (E_2) and low nitrogen and excess soil moisture condition (E_3) in randomized complete block design during 2009-10 at the Crop Research Centre (CRC) of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Each plot consisted of two rows of 4 m. between rows and within row spacing was maintained at 75 cm and 25 cm, respectively. Low nitrogen dose means 40 kg/ha and excess soil moisture means ponding water of 5 cm continuously for 7 days preceding flowering. Grain yield was calculated (q/ha) at 15% moisture content. Each genotype was quantified for kernel carotenoids (mg/g dry matter basis) using Quick carotenoids extraction protocol given by Schaub *et al.* (2004). Behaviour of grain yield and kernel carotenoids across the environments was statistically analyzed using standard statistical methodologies proposed by Eberhart and Russell (1966). Linear regression was analysed to establish correlation between KC with grain yield and kernel colour. The Eberhart and Russell (1966) model is based on linear regression analysis, they defined a stable variety as one with a regression coefficient of unity (b = 1) and a minimum deviation from regression line ($S_d^2 = 0$).

RESULTS AND DISCUSSION

The combined analysis of variance revealed the existence of significant genetic variance in the maize collections evaluated for both KC and grain yield (Table 1). Significant GEI for KC and grain yield indicated that the expressions of both the traits are influenced by the environment, highlighting the need for a detailed study to identify genotypes for greater adaptability and phenotypic stability (Sandmann and Albrecht, 1994; Rios *et al.* 2009).

The range of variation for grain yield was found to vary from 21.76 to 63.97 q/ha with population mean of 36.71 q/ha in E_1, from 19.10 to 54.88 q/ha with population mean of 36.52 q/ha in E_2, and from 16.69 to 59.94 q/ha with population mean of 37.95 q/ha in E_3. Estimates on KC varied from 2.07 mg/g in white grained genotype to 42.29 mg/g with population mean of 31.52 mg/g, from 2.47 mg/g in white genotypes to 44.59 mg/g with population mean of 28.93 mg/g and from 4.12 mg/g in white grained genotypes to 41.98 mg/g with population mean of 29.58 mg/g in E_1, E_2 and E_3, respectively (Table 2). In the present investigation, the highest carotenoid content was observed to be 44.59 mg/g. However, Harjes *et al.* (2008) reported KC up to 66 mg/g in 282 maize germplasm and Based on analysis of 1245 samples of maize, Berardo *et al.*, (2009) reported range of total carotenoids from 1.09 ìg/g to 61.10 ìg/g dry weights. Rios et al. (2009) found 19.32 ìg/ g to 26.43 ìg/g KC in 10 maize cultivars. Lower concentration of KC observed in the present investigation could be due to type of materials used.

Based on performance pooled over the environments, 'PML-23' (52.13 q/ha) followed by 'PML-10' (51.68 q/ha) exhibited higher grain yield than the best check composite variety Pragati (Table 3). However, these three genotypes were statistically *on par* in yield performance. Local collection 'PML-9' gave minimum yield of 22.90 q/ha. The kernel of 'PML-7' consisted of highest amount of KC (39.96 mg/g) which was significantly superior over the carotenoids levels of the best check Pant Sankul Makka-3 (37.85 mg/g). The other promising genotypes for KC were 'PML-3' (37.95 mg/g), 'PML-27' (36.91 mg/g), 'PML-31' (36.48mg/g), 'PML-29' (36.47mg/g), 'PML-17' (36.25 mg/g). These landraces may be used to constitute a population with high kernel carotenoids and can be used directly as varieties or can be used for development of inbred lines with high carotenoid content as suggested by Wong et al. (1998), Egesel *et al.* (2003) and Menkir and Dixon (2004). Moreover, Burt *et al.* (2006) have developed maize lines with a mean KC between 43.6 and 88.3 mg/g evidencing the possibility of successfully increasing the KC levels in maize grains. Three genotypes namely 'PML-13' (2.93mg/g), 'PML-19' (4.06 mg/g) and 'PML-21' (4.54 mg/g) with white grain colour had meager amount of carotenoids.

Stability analysis indicated that 'PML-23' had highest grain yield and non-significant deviation from linearity and therefore 'PML-23' seems to stable across the environments. However, regressions value more than unity revealed that it is adapted to favourable environmental conditions. The stability of 'PML-10', the second highest yielding genotype was found to be poor due to significant deviation from regression. The four local collections namely 'PML-11', 'PML-17', 'PML-20' and 'PML-22' having numerically less but statistically *on par* yield with the best check exhibited differential response in terms of stability and adaptability. The PML-17 was identified to be unstable due to significant deviation from regression. The PML-11 and PML-22 were found to be stable but adapted to better environment whereas PML-20 was found to have adaptability to less favourable environment. The composite varieties namely 'Pant Sankul Makka-3, and 'Pragati' were found to be stable and best adapted to favourable environment. The remaining genotypes did not qualify the stability criteria as they were either low in yield potential or had significant deviation from regression. None of the genotypes fulfill the requirement of average stability i.e. high grain yield, unit regression and non-significant deviation from regression indicating variation in yield in different environmental conditions. Similar findings were also reported by Scapim *et al.* (2000), Signor *et al.* (2001), Primomo *et al.* (2002), Shiri (2013), Shrestha (2013) and Silva *et al.* (2014). A reported remarkable variation in yield under high and low nitrogen levels was also reported by Kumar *et al.* (2013) and Singh *et al.* (2013).

The 'PML-7' was identified to be significantly superior over the best check variety 'Pant Sankul Makka-3' and other test genotypes for KC. Due to significant deviation from unity, 'PML-7' did not qualify as stable genotype. Two collections namely 'PML-3' and 'PML-27' having KC numerically superior over the best check were found to be stable due to non-significant deviation from regression but better adapted to unfavourable and favourable environments due to regression coefficient less and more than unity, respectively. Out of seven genotypes found *on par* in term of carotenoids content with best check, four genotypes namely, 'PML-29', 'PML-17', 'PML-6' and 'PML-1' were found to be unstable due to significant deviation from

Table 1: Pooled analysis of variance for kernel carotenoids and grain yield in maize

Source of variation	Mean square Degree of freedom	Kernel carotenoids (mg/g)	Grain yield (q/ha)
Genotype	33	245.92**	235.39**
Environment	2	61.96**	20.34
G × E	66	17.14**	51.27*
E + (G × E)	68	18.46	50.36
E (linear)	1	123.94**	40.68
G × E (linear)	33	24.32**	53.47
Pooled deviation	34	9.66**	47.63**
Pooled error	198	1.46	27.86

'*' and '**'-Significant at 5% and 1% probability level

Table 2: Environment-wise grain yield and kernel carotenoids in maize

Genotypes	E1		E2		E3	
	Grain yield(q/ha)	Carotenoids(mg/g)	Grain yield(q/ha)	Carotenoids(mg/g)	Grain yield(q/ha)	Carotenoids(mg/g)
PML-1	38.65	31.53	46.31	41.67	35.99	31.58
PML-2	27.03	41.81	25.77	31.59	39.98	33.78
PML-3	49.31	33.69	36.87	39.35	20.88	40.80
PML-4	37.32	38.38	34.65	35.36	41.79	29.05
PML-5	38.65	32.93	39.98	21.49	26.02	21.13
PML-6	39.98	42.29	42.65	28.84	39.69	35.33
PML-7	35.99	42.21	29.77	35.68	30.11	41.98
PML-8	37.32	33.47	35.99	28.97	24.43	28.5
PML-9	32.91	31.66	19.10	26.91	16.69	25.79
PML-10	63.97	28.05	44.43	26.18	46.65	26.42
PML-11	46.65	32.05	42.39	23.20	55.75	27.57
PML-12	21.76	30.38	23.99	32.94	28.88	36.51
PML-13	31.99	2.07	19.99	2.47	23.99	4.25
PML-14	31.99	24.88	23.95	29.08	39.21	26.62
PML-15	34.65	22.06	26.66	32.68	27.06	28.71
PML-16	30.65	35.82	23.99	33.49	28.88	30.57
PML-17	30.65	37.07	54.88	33.28	59.94	38.39
PML-18	26.66	34.67	38.21	22.63	31.09	24.61
PML-19	45.32	4.67	34.65	3.4	22.21	4.12
PML-20	46.65	40.39	52.42	30.34	44.43	33.47
PML-21	41.32	5.42	34.65	3.36	39.98	4.83
PML-22	47.98	36.24	44.87	26.27	49.87	36.09
PML-23	49.31	27.48	49.31	38.34	57.75	35.91
PML-24	33.32	34.81	50.20	25.78	51.09	37.91
PML-25	23.99	29.57	30.65	31.66	43.10	29.11
PML-26	29.32	35.50	31.09	27.96	39.09	28.6
PML-27	35.99	41.39	44.43	34.51	51.09	34.83
PML-28	26.66	35.32	26.21	26.65	22.66	26.3
PML-29	33.32	30.88	26.66	44.59	30.03	33.93
PML-30	23.99	38.72	23.99	35.73	26.66	30.40
PML-31	33.32	37.23	45.77	35.8	51.87	36.42
PML-32	30.65	31.19	35.54	31.65	37.32	30.03
Pragati (c)	45.54	28.55	52.42	27.77	53.31	34.72
Pant Sankul Makka-3 (c)	45.32	39.35	49.31	33.91	52.66	37.28
GM	36.71	31.52	36.52	28.93	37.95	29.58

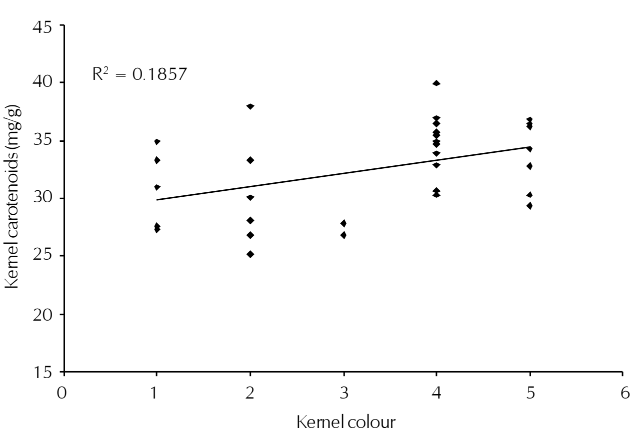

Figure 1: Relation of kernel colour and total carotenoids in maize (0- white, 1- Dark yellow, 2- Yellow, 3- light yellow, 4- Orange, 5- Light orange).

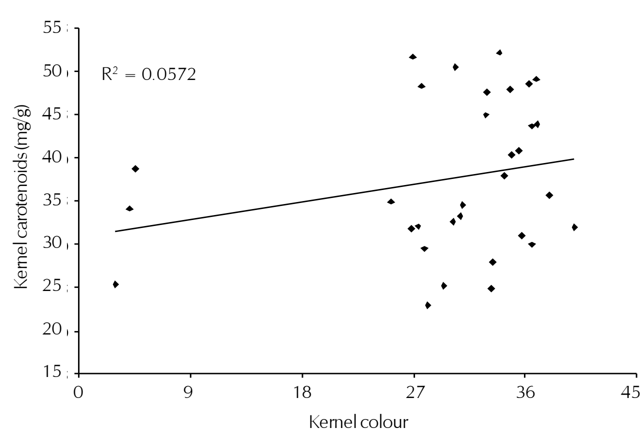

Figure 2: Relation between grain yield and kernel carotenoids in maize

regression. The remaining three genotypes were found to be stable but 'PML-31' was adapted to un-favourable environment because of regression less than unity, and 'PML-20' and 'PML-2' were found to be adapted under favourable environmental condition because of regression value higher than unity. Composite variety 'Pragati' was found to be unstable because of significant deviation from regression whereas the other check variety namely 'Pant Sankul Makka-3' was identified to be

Table 3. Stability parameters for kernel carotenoids and grain yield in maize

Genotypes	Kernel carotenoid (mg/g)	Bi	$\bar{X}$ S^2d_i	Grain yield (q/ha)	Bi	$\bar{X}$ S^2d_i
PML-1	34.93	-3.01*	34.67**	40.32	-5.41	13.16
PML-2	35.73	3.98	-0.40	30.93	10.17	-9.08
PML-3	37.95	-2.52*	4.56	35.69	-15.49*	110.04*
PML-4	34.26	2.00	30.27**	37.92	4.51	-7.60
PML-5	25.19	4.79*	5.89*	34.89	-9.96	-9.15
PML-6	35.49	4.81*	5.58*	40.77	-1.42	-6.36
PML-7	39.96	1.96	12.93**	31.95	-1.57	12.23
PML-8	30.31	1.92	1.07	32.58	-8.95	-4.70
PML-9	28.12	2.10	2.79	22.90	-5.83	103.31*
PML-10	26.88	0.75	-0.45	51.68	-4.07	199.99**
PML-11	27.61	3.15	2.39	48.26	8.66	-5.75
PML-12	33.28	-1.49	10.41**	24.88	4.27	-4.66
PML-13	2.93	-0.38	1.69	25.32	-0.54	64.96
PML-14	26.86	-1.45	0.75	31.71	8.96	11.26
PML-15	27.82	-3.94*	0.59	29.46	-2.04	26.33
PML-16	33.29	1.31	7.08*	27.84	1.67	11.18
PML-17	36.25	0.97	10.19**	48.49	10.84	340.25**
PML-18	27.30	4.76*	0.17	31.99	-1.89	54.33
PML-19	4.06	0.44	-0.39	34.06	-12.34*	76.05
PML-20	34.74	3.80	-0.25	47.83	-4.24	3.31
PML-21	4.54	0.68	0.08	38.65	2.00	10.79
PML-22	32.87	2.97	32.68**	47.57	2.79	-5.89
PML-23	33.91	-4.22**	-0.44	52.13	6.26	-8.59
PML-24	32.83	2.31	59.56**	44.87	5.59	153.80**
PML-25	30.11	-0.57	2.05	32.58	11.17	29.59
PML-26	30.69	3.06	0.46	33.17	6.45	-4.78
PML-27	36.91	2.82	0.72	43.83	7.41	39.70
PML-28	29.42	3.64	3.40	25.18	-2.76	-8.82
PML-29	36.47	-4.43**	31.68**	30.00	0.55	12.56
PML-30	34.95	1.87	22.18**	24.88	1.98	-9.22
PML-31	36.48	0.52	-0.44	43.65	8.16	89.77
PML-32	30.96	0.00	0.91	34.51	2.75	5.51
Pragati (c)	30.35	-0.52	27.64**	50.42	2.67	18.40
Pant Sankul Makka-3 (c)	36.85	1.86	2.01	49.1	3.65	1.83
Mean	30.00	0.99		37.06	1.00	
SE(±)	2.2	1.63		4.88	6.31	

stable with better adaptation to favourable environments. It is interesting to note that none of the genotypes fulfill the criteria of general adaptability for KC. The result of the present investigation necessitates the need for further research on the adaptability and stability of KC since maize is cultivated throughout the year under different cultural practices and environmental. Since there are very few published literatures on this aspect, the present work is therefore seems to be important for understanding GEI for carotenoids in maize. Information on stability and adaptability of carotenoids in maize cultivars and germplasm is also essentially required for spread and/or exchange of plant materials and technologies of cultivation and processing (Rios *et al.* 2009).

Maize kernel colour of each line was recorded and broadly grouped into dark yellow, yellow, light yellow, orange, light orange and white colour to assess relation between kernel colour and carotenoids content. Five genotypes with dark yellow kernel colour had KC from 27.30 to 34.93 ìg/g, six lines with yellow kernel colour varied in KC from 25.19 to 37.95 ìg/g whereas two lines with light kernel colour had 26.82 and 27.82 ìg/g of KC. Eleven orange kernel colour genotypes varied in KC from 30.31 to 39.96 ìg/g whereas seven genotypes with light orange colour had KC from 29.42 to 36.85 ìg/g.

The kernel colour score generated from 1 to 5 were regressed over to carotenoids content. The regression analysis revealed non-significant relation between kernel colour and carotenoids content. The coefficient of determination of kernel colour on carotenoids content was also found to be low (R^2 = 0.186, Fig. 1). The results of the present investigation, therefore, indicated that kernel colour cannot be used reliably for selection of genotypes with higher carotenoids content. Similar observations were also noted earlier by Harjes *et al.* (2008) and Mishra and Singh (2010). The relation of KC levels was also analysed with grain yield. Regression analysis revealed very low correlation between KC level and grain yield. The coefficient of determination was also found to be very low (R^2 =0.06, Fig. 2). Thus, it is evident from the present investigation that grain yield and KC is not correlated and they need to be selected independently in improvement programme.

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