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Assessment of stability and adaptability of carrot (*Daucus carota* sub spp. *sativus*) cultivars in North Karnataka

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Abstract
Carrot is the tenth most economically important vegetable crop in the world. Though, its production is limited across different ecological regions due to genotype instability and environmental variability. This research was carried out to examine the magnitude of environmental effect on performance of carrot genotypes and to investigate the stability and adaptability of genotypes under subtropical region of northern dry zone of Karnataka. As the performance of each cultivar tends to vary when grown in different seasons, hence, seven genotypes were evaluated in 2017, 2018 and 2019 during regular season of carrot from September-December. Eberhart and Russell model of stability analysis was carried out which revealed a significant effect of each season on the cultivars taken for all the seven morphological traits. None of the genotype was found stable for all the traits across seasons and stability of each trait was independent from one another. Thus, it emphasized the need for the development of trait specific cultivars that are stable across seasons.

Keywords: Adaptability, environment, Genotype, stability

Introduction
Carrots (*Daucus carota* L. subsp. *sativus*) are among top ten important vegetables grown in the world in terms of area, production and market value (Que *et al.*, 2019) [15]. Carrots occupy second most important vegetable in the world after potato due to its delicious taste, flavor and nutritive value (Spooner *et al.*, 2019) [20]. Carrots are extensively used in numerous cuisines, especially in the preparation of soups, stews, curries, pies, pickles and for salad purpose and in many regional cuisines. Cultivated carrot (*Daucus carota subsp. sativus*) is the utmost important member in the *Apiaceae* family (Peirce, 1987) [12], both in terms of economy and nutrition. Carotenoid content of carrot regulates its phloem and xylem colour either the white, yellow, orange or red root colour in the carrot (Nicolle *et al.*, 2004; Surles *et al.*, 2004) [12, 21]. Carrot is a major source of provitamin A, in which, the leaves of carrot plants with orange roots coupled with a higher α-carotene-to-β-carotene ratio than do leaves of plants with yellow roots (Arango *et al.*, 2014; Perrin *et al.*, 2016) [2, 13]. Carrot contains 495 mg of β-carotene, vitamins, and minerals and a good source of calcium, potassium and magnesium (Hager and Howard 2006) [7]. Moreover, carrot also contains phenolic compounds, and other antioxidant micronutrients (Que *et al.*, 2019) [15].
Central Asia is considered as a centre of origin of cultivated carrot. At present, large genetic variation is observed in cultivated carrot due to fast spread of carrot ancestors from their centre of origin to distant geographical regions, and additionally due to a lack of control of random cross pollination between cultivated and wild forms (Que *et al.*, 2019) [15]. Carrot domestication, early selection and then breeding programs resulted in creation of varieties differing in several root morphological traits, tolerance to diseases and pests, and nutritional composition. Domesticated traits are particularly well characterized for orange-coloured carrot roots, which contain a high level of beta-carotene, and being one of the main sources of pro-vitamin A in human diet. Orange carrots are thus of significant importance for human beings and are commonly grown in temperate, tropical and sub-tropical climate throughout the world (Simon *et al.*, 2008) [19]. Western (European) carrot is adaptable to temperate climate and Eastern (Asiatic) carrot is adaptable to tropical and sub-tropical climate (Kulkarni *et al.*, 2019) [8].

Environmental condition differs from year to year &/region to region. Hence, phenotypically stable genotypes are of great importance. Wide adaptation to particular environment and stable performance of genotypes is one of the primary objectives in breeding programs. Although number of carrot genotypes has been recommended for cultivation, yet the information on their stability for important root quality traits over different seasons is lacking for subtropical agro-climatic conditions in carrot. Hence, the present investigation was carried out to identify stable carrot genotype across seasons in northern dry zone of Karnataka described as sub-tropical climatic condition.

Crop improvement activities success basically depends on identification of superior genotypes stable in performance across changing environment (adaptability) or performance against changing environmental factors over time within a given environment (stability) as suggested by Ayalneh *et al*., 2014 [4]. Stability of a variety is the consequent effect of its genotype and the environment in which the genotypes are tested. The genotype and environmental interaction decide the relationship between phenotype and genotype. Therefore, the genetic potential of every genotype survival is renewed in different environments, correspondingly, stability ranking of each genotype changes (Prabhakaran and Jain 1992) [14]. Hence, estimation of genotype environment interaction (GEI) is crucial for assessing the stability.

For analysis of GEI, among seven carrot genotypes, Linear Regression model (bi) and deviation from regression mean square (S^2di) of Eberhart and Russell (1966) [6] model was used to identify stable genotype across seasons in the present study.

Material and Methods

The experiment was conducted in main cropping season (second fortnight of September-December) in randomized block design with three replications. Plot sizes of 1m × 10 m and 10 cm x 30 cm spacing plant to plant and between rows were used respectively. Plants were evaluated in three seasons at the experimental farm of division of Biotechnology and Crop Improvement, UHS Bagalkote during 2017, 2018 and 2019. Bagalkote is situated at a latitude (N) 16º 12′ N - 16º 46′ N and longitude 74º 59′ E 76º 20′ E and has an elevation of 533 m above mean sea level. The place experiences hot, dry summer, hot and humid rainy season and cold winter months; the maximum temperature goes up to 38^0 C during summer (March to May) and minimum temperature falls to 18^0C during winters. The information on climatic conditions during the crop season was recorded in Division of Agrometeorology at each experimental site. All recommended agronomic practices and management were applied uniformly. Seven morphological traits *viz*., root length (cm), root width (mm), root weight (g), shoot length (cm), number of petioles, shoot weight (g) and shoulder width (g) were recorded from five randomly selected plants for each cultivar per replication. For fulfilling the objective of stability analysis, multi-season trial was conducted for seven elite genotypes of carrot and are listed in Table 1a and the list of traits for stability analysis are presented in Table 1b. Linear regression model of stability suggested by Eberhart and Russell (1966) [6] was employed and the data was analysed using OPSTAT software (Sheoran *et al*., 2010) [18] for stability parameters.

Table 1a: List of elite genotypes used for multi-location/multi-season evaluation

S. No	Name of genotype	Tropical/Temperate adapted
1.	UHSBC-32-2	Tropical
2.	UHSBC-17	Tropical
3.	UHSBC-117	Tropical
4.	UHSBC-67	Tropical
5.	UHSBC-23-1	Tropical
6.	UHSBC-34-1	Tropical
7.	UHSBC-100	Temperate

Table 1b: List of traits for stability analysis of carrot cultivars used for multi-location/multi-season evaluation

S. No	Trait
1	Root length (cm)
2	Root width(mm)
3	Root weight (g)
4	Shoot length (cm)
5	Number of petioles
6	Shoot weight (g)
7	Shoulder width (mm)

Results and Discussion

Analysis of variance revealed that mean sum of squares due to genotypes across the seasons (Table 2) were significant for all the seven traits *viz.*, shoot length, shoot weight, shoulder width, number of petioles, root length, root width and root weight indicating the presence of genetic variability among the genotypes involved in the study for these traits.

In stability analysis, environment and GEI component can also be subdivided into environment (linear), G x E (linear) and pooled deviations from regression. ANOVA (Table 2) showed that the sources of variation for Environment + (G x E) was found highly significant. Highly significant ($P< 0.01$) variation was observed in environment and genotype-environment interaction, while significant ($p< 0.05$) variations noted in genotypes. Significance of GEI is an indication for inconsistency of genotypes in response to changing environments across seasons due to genotype-environment interaction. Similar results were obtained by Das *et al*. (2010) [5], Tiawari *et al*. (2011) [22] and Zerihun (2011) [23].

The pooled analysis of variance for various traits in carrot over three seasonal conditions (Table 2) revealed that the variation due to G × E interaction has been partitioned into two, the predictable component due to linear regression and the unpredictable one due to pooled deviations from regression. Mean sum of squares due to Environment + (Genotype × Environment) was observed significant for shoot weight (g), shoulder width (mm), root length (cm) which depicted the existence of genotype × environment interaction. The linear contribution of environment on the performance of genotypes was significant for almost all the traits under study except for shoot length and number of petioles indicating that environmental effects were predominant.

The mean square due to genotype × environment (Linear) when tested against pooled deviation, were significant for shoot weight (g). This indicated significant rate of linear response of the genotypes to environmental changes for this trait. Non-significant effect of genotype × environment (linear) for shoot weight (g), shoulder width (g), number of petioles, root length (cm), root weight (g) and root width (mm) indicated that the different genotypes did not differ genetically in their response to different environments in seasonal conditions. The pooled deviation when tested against pooled error was found significant for shoot length (cm), root length (cm) and root width (mm) under studied indicating the important contribution of non-predictable component. Hence, ANOVA for Eberhart and Russell model revealed highly significant E+ (G×E) for all the characters against pooled error and indicated distinct nature of seasons and GxE interactions in the phenotypic expression. Very significant values for environment (linear) variance exposed significant additive environmental variance for all the traits. Similar works were done by Matin *et al.* (2017) [10]. High source of variation was observed in environment similarly as reported by Letta (2009) [4] and Das *et al*. (2010) [5]. The high degree of variation originated by environment reveals that complex external factors (biotic and abiotic) are number one challenges in crop improvement. A greater number of environmental factors is difficult to manage in the superlative attention of breeder during field experiment. The higher extent of variation was observed in GEI which discriminate the correlation between phenotype and genotype making it difficult to assess the genetic potential of particular genotype whose relative ranking changed in different environments across seasons.

The mean square due to environments (Lin) were significant for all the traits namely shoot length, shoot weight (g), shoulder width (g), root length (cm), root width (mm), root weight (g) which indicated the presence of variable environments in expression of all the traits across seasons (Table2). Significant environment mean sum of squares were observed across the seasons for all the three productivity traits and number of petioles. The presence of genotypes × environment interaction was also significant for shoot weight whereas, it was found non-significant for shoot length (cm), shoulder width (mm), number of petioles, root length (cm), root width (mm) and root weight (g) that indicated the differential response of genotype to all seasonal conditions.

The mean performance, regression (bi) and squared deviation (s^2di) for seven morphological traits are presented in Table 3 and 4 across seasons. According to Eberhart & Russell (1966) [6] model a stable genotype has high mean yield, bi = 1 and S^2di = 0.

For shoot length, genotypes UHSBC_117 (G3) and UHSBC_67 (G4) had higher mean yield, unit regression coefficient (bi=1) and non-significant S^2di. Thus, they were stable, high yielding genotypes which can be adapted to all the environments. Genotype UHSBC-34-1 (G6) had higher mean than overall mean, bi significantly greater than 1, non-significant S2di. Therefore, UHSBC-34-1 (G6) was stable and well adaptable to favourable environment. Genotypes UHSBC_32-2 (G1), UHSBC_17 (G2), UHSBC_23-1 (G5), UHSBC_100 (G7) was found unstable due to their significant S^2di values (Seboksa *et al.*, 2001; Akcura *et al.*, 2005 and Arshad *et al.*, 2003) [17, 1,].

For number of petioles, UHSBC_ 17 (G2) had higher mean yield and regression co-efficient around unity and non-significant S^2di. Thus, it is found to be adaptable to all the environments across seasons. UHSBC_32-2 (G1), UHSBC_34-1 (G6) had regression coefficient greater than unity with non-significant deviation from regression line which indicates its adaptation to favourable environment. These results are in conformity with Mane *et al.*, (2010). UHSBC_117 (G3), UHSBC_67 (G4), UHSBC_23-1 (G5) and UHSBC_100 (G7) showed regression coefficient lesser than unity (bi<1) with non-significant deviation from regression line so are suitable under unfavourable environment. Genotype UHSBC_32-2 (G1) and UHSBC_34-1 (G6) which are comparable to average mean showed regression coefficient greater than one (bi>1) with non-significant deviation from regression line reflecting its preference under favourable environments.

For shoot weight, genotypes UHSBC_ 17 (G2), UHSBC_67 (G4), UHSBC_23-1 (G5), UHSBC_34-1 (G6) displayed unit regression coefficient (bi=1) and non-significant S^2di. Therefore, they are regarded as stable genotypes across all seasons. UHSBC_100 (G7) showed regression coefficient less than unity (bi<1) with non-significant S^2di. Hence, they are suitable under unfavourable environments. UHSBC_32-2 (G1), UHSBC_117 (G3) had significant S^2di values and found unstable.

For shoulder width, UHSBC_ 17 (G2) and UHSBC_23-1 (G5) showed regression coefficient (bi=1) and non-significant S^2di and regarded as stable genotypes across seasons. Genotypes UHSBC_32-2 (G1) and UHSBC_100 (G7) had bi>1 and non-significant S^2di indicating adaptable to favourable environment. UHSBC_117 (G3), UHSBC_67 (G4) and UHSBC_34-1 (G6) had significant positive S^2di and found unstable across seasons in varying environment.

For root length, UHSBC_117 genotype was superior over average mean, showed regression coefficient bi=1 with non-significant deviation from regression line (S^2di) reflecting its stability over changing environments. Whereas, remaining all genotypes showed significant S^2di and found unstable across seasons.

For root width, UHSBC_117 (G3) and UHSBC_34-1 (G6) showed superior yield and with regression coefficient close to one with non-significant deviation from regression line indicates its adaptation to all the environments. UHSBC_ 100 had bi<1 with non-significant S^2di, so are suitable under unfavourable environments. Remaining genotypes were considered to be unstable as they had significant S^2di.

For root weight, UHSBC_67 (G4) was the only genotype showed unit regression coefficient (bi=1) and non-significant S^2di indicating its adaptation to all the environments across seasons. UHSBC_32-2 (G1), UHSBC_23-1 (G5) and UHSBC_100 (G7) exhibited superior performance coupled with regression coefficients lesser than unity (bi<1) with non-significant deviation from regression line so are suitable under unfavourable environment. However, UHSBC_117 (G3) and UHSBC_67 (G4) had (bi>1) with non-significant deviation from regression line reflecting its adaptation under favourable environments. However, UHSBC_ 17 (G2) and UHSBC_34-1 (G6) possess regression co-efficient close to unity but display significant S^2di. Hence, are regarded as unstable across seasons.

Table 2: Mean Squares due to different source of variation for various quality traits in carrot (*Daucus carota L*)-ANOVA for Eberhart and Russel Model across seasons

Source of Variation	DF	Shoot length	Shoot weight	Shoulder width	Number of petioles	Root length	Root width	Root weight
Replication within Environment	6	19.552	493.104 *	4.065	0.617	1.772	19.268	133.806
Genotypes	6	302.499 **	2822.874 ***	85.523 ***	1.016	14.47	25.515	605.795*

Environment+ (Genotype × Environment)	14	38.522	824.704 **	103.668 ***	0.871	32.994 *	45.804	378.82
Environments	2	3.27	1897.922 ***	702.296 ***	1.06	173.458 ***	122.207	1246.041 *
Genotype × Environment	12	44.397	645.834 **	3.897	0.84	9.583	33.07	234.283
Environments (Lin.)	1	6.539	3795.844 ***	1404.592 ***	2.12	346.917 ***	244.415 *	2492.082 **
Genotype × Environment (Linear)	6	50.387	1206.584 ***	5.133	1.196	12.738	21.905	296.989
Pooled Deviation	7	32.920 *	72.93	2.28	0.415	5.510 ***	37.916 **	147.067
Pooled Error	36	13.125	184.71	3.543	0.432	1.128	9.091	99.868
Total	20	117.715	1424.155	98.224	0.915	27.437	39.718	446.913

* Significant at 5% level of significance, ** significant at 1% level of significance

Table 3: Mean value, regression coefficient (bi) and variation due to deviation (s^2di) for seven carrot genotypes across seasons

	Genotypes	Shoor length			Number of petioles			Shoot weight			Shoulder width		
		μ Mean	βi	σ²di	μ Mean	βi	σ²di	μ Mean	βi	σ²di	μ Mean	βi	σ²di
1	UHSBC_32-2	68.609	0.62	25.67	82.776	2.76*	-78.25	28.533	0.91	0.66	7.808	2.39	-0.46
2	UHSBC_ 17	68.092	-2.59	56.25*	118.589	1.94*	-99.62	32.061	1.27	-1.86	8.583	1.74	-0.46
3	UHSBC_117	66.35	1.37	-13.87	97.6	0.43	-221.92	28.654	0.9	5.08	8.511	-0.52	0.03
4	UHSBC_ 67	63.962	1.31	-7.19	70.614	-0.86	-167.95	24.477	1.06	-3.62	7.949	1.062*	0.53
5	UHSBC_23-1	59.454	13.08	23.3	74.459	-0.14	-212.07	25.733	1.06	-3.19	7.56	1.25	-0.45
6	UHSBC_34-1	60.911	4.53	-10.53	104.148	2.83	-99.41	28.223	1.03	-2.89	9.089	1.13	0.72
7	UHSBC_ 100	39.622	-11.33	58.52*	23.806	0.04	-211.64	15.339	0.76	-3.54	7.578	3.53	-0.23
	Population Mean	61			81.713			26.146			8.154		

*Significant at 5% level of significance, ** significant at 1% level of significance

Table 4: Mean value, regression coefficient (bi) and variation due to deviation (s^2di) for seven carrot genotypes across seasons

	Genotypes	Root length			Root width			Root weight		
		μ Mean	βi	σ²di	μ Mean	βi	σ²di	μ Mean	βi	σ²di
1	UHSBC_32-2	18.8	1.16	3.5	31.8	2.3	112.86**	89.267	-0.14	-28.31
2	UHSBC_ 17	18.392	1.43	0.05	27.847	0.75	50.64*	72.608	1.48	124.03
3	UHSBC_117	16.417	1.26	-0.41	30.038	1.27	-3.54	72.744	2.5	-90.16
4	UHSBC_ 67	16.632	1.33	0.27	26.867	1.1	30.99	60.8	1.26	-62.08
5	UHSBC_23-1	19.878	0.91	21.02***	26.241	0.12	21.71	74.34	0.62	-77.62
6	UHSBC_34-1	18.133	0.98	1.41	33.247	1.45**	-10.54	63.956	1.26	534.14*
7	UHSBC_ 100	13.183	-0.07	4.19*	25.712	0.02*	-10.52	43.356	0.02*	-103.55
	Population Mean	17.348			28.822			68.153		

*Significant at 5% level of significance, ** significant at 1% level of significance

Conclusion

Considering the overall performance, UHSBC_67 (G4) was found to be promising and well adapted to all environments across seasons for shoot length, root weight, shoot weight. Therefore, UHSBC_67 can be used for cultivation across seasons for these traits. UHSBC_117 (G3) was stable for root length and root width. But both UHSBC_117 (G3), UHSBC_67 (G4) was found to be unstable for shoulder width. UHSBC_32-2 (G1), UHSBC_117 (G3), UHSBC_23-1 (G5) and UHSBC_100 (G7) exhibited suitability under unfavourable environment for root width, root weight, number of petioles traits. Genotype UHSBC_34-1 (G6) was found to be stable genotype for shoot length, shoot weight and number of petioles and root width under favourable environment but we could observe that same genotype was found to be unstable for root length, root weight and shoulder width. None of the carrot cultivars were stable across changing environments across seasons of northern dry zone of Karnataka evaluated under present study. The change in monsoon and weather environments during crop growth period could be the major reason for instability of carrot performance across seasons. Hence, the present work highlights the necessity of understanding ecological effect on carrot crop growth and emphasizes the need for development of environment specific cultivars to tropical climates.

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