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GENETIC ANALYSIS OF NUTRITIONAL TRAITS IN TROPICAL CARROT (*Daucus carota* L.)

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Carrot has wide color range particularly purple, orange, red and yellow dependent upon anthocyanins, *β*-carotene, lycopene and lutein content. Due to recent awareness of nutritional health security, there is increasing consumption of carrot by consumers as well as nutraceutical based industry owing to huge bioavailability of dietary vitamins, phytonutrients and bioactive compounds of carrots. Though, breeding for multinutritional rich carrot varieties, there is need to study and understand the genetic mechanism of nutritional traits viz., moisture, total solids, total soluble solids, total carotenoids, *β*-carotene, lycopene and total anthocyanin content. Keeping these in view, the present investigation was designed to study the six genetic parameter in six generation of twelve cross combinations. The six digenic parameter model results clearly revealed that additive [*d*], dominance [*h*], additive × additive [*i*], additive × dominance [*j*] and dominance × dominance [*l*] interactions governed nutritional traits in the crosses studied. The positive sign of dominance [*h*] and dominance × dominance [*l*] resulted into complimentary epistatic interactions controlling moisture content and total solids, total soluble solids, total carotenoids and β-carotene, lycopene (in all crosses except PM × IPC-122) and total anthocyanin content. From the higher frequency of allele dispersal [*a*+*i*] between the parents, it is evident that the selection process should be delayed until homozygosity is attained in advance generation which can be obtained through inter-mating of parents followed by cyclic recurrent selection and mass selection for nutritional traits with consecutive cross combinations. This epistatic parameter

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of genetic analysis would be effectively utilized for breeding strategy for improvement of nutritional traits in carrot.

Keywords: tropical carrot, allele, recurrent selection, mass selection, nutritional traits enrichment

INTRODUCTION

Carrot (*Daucus carota* L.) is a cool weather crop grown in temperate and subtropical regions for its edible storage tap roots both for fresh as well as processed vegetable throughout the world. It is the most widely grown vegetable among root crops in India wherein it occupies an area of 64.27ha with a production of 1144.54MT and an average yield of 145.83q/ha (NHB, 2015). World carrot production has been four times increased during the past 45 years from 5.8 million MT in 1961 to 23.6million MT in 2014 (FAO, 2015). Among fruits and vegetables, carrot has been placed 7th in nutrition contribution (ALASALVAR *et al.*, 2001; SIMON, 2000). It is potential source of dietary nutrients (i.e. carotenoids, anthocyanins and flavonoids) which protect the human health and reduce the risk of cardiovascular disease by scavenging free radicals (STINTZING and CARLE, 2004; VAN DEN BERG *et al*., 2000). It has been classified as vitaminized functional food due to its richness in *β*-carotene and tocopherols as compounds with health promoting properties (HASHIMOTO and NAGAYAMA, 2004; HAGER and HOWARD, 2006). Eastern carrots of yellow and purple color were originated in Afghanistan during the mid-9th century. These were grown in Europe in the middle ages which were replaced by Western carrots of white and orange color due to selection and hybridization of yellow, purple and its wild relatives (RUBATZKY *et al*., 1999). Orange, red, yellow and purple color of carrot are formed by *α*- and *β*-carotene, lycopene and lutein and anthocyanins, respectively (KURILICH *et al*., 2005; MOLLDREM *et al*., 2004; NICOLLE *et al*., 2004; SIMON and WOLFF, 1987; SURLES *et al*., 2004; UMIEL and GABELMAN, 1972). Biometrics of generation mean analysis (GMA) is an efficient technique for estimating epistatic gene effects which are involved in the expression of structural, horticultural and biochemical traits in interacting and non-interacting crosses (MATHER and JINKS, 1971; SINGH and SINGH, 1992). These genetic analysis provides sufficient information of gene interaction effects of crosses of crops viz., additive [*d*], dominance [*h*], additive × additive [*i*] (fixable), additive × dominance [*j*] and dominance × dominance [*l*] (non-fixable). The additive [*d*], dominance [*h*] and epistatic [*i*, *j* and *l*] variance are closely associated with individual, intra-allelic and inter-allelic (non-allelic) genes, respectively and it decides the breeding value of genotype (MATHER and JINKS, 1971). The genetic additive [*d*] and dominance [*h*] variance favoured the intra-population selection and hybridization programme (GAMBLE, 1962). The relative magnitude and signs of the dominance [*h*] and dominance × dominance [l] gene effects are deciding the type of gene interaction and effects. The same signs of [*h*] and [*i*] indicated shows complimentary or recessive epistasis whereas the opposite signs of [*h*] and [*i*] suggested which shows duplicate dominant epistasis or recessive suppressor kind of interactions. These epistatic gene interactions were predominantly classified as complementary and duplicate type (MATHER and JINKS, 1971). The selection of suitable breeding strategies for different traits are mainly depends upon the genetic information on the nature and magnitude of type of non-allelic epistatic gene interactions and its effects present in the populations (HALLAUER and MIRANDA, 1988). Although, GMA have been widely studied for the gene action and interaction effects in many agricultural field and vegetable crops. However, genetic control mechanism of quantitative traits of tropical carrot has not been studied extensively and as a result very limited information is available in carrot. Therefore, the present study was designed consist of phenotypically contrasting carrot genotypes has been used to know the genetic mechanism of epistatic effects using biometrical analysis of generation mean analysis (WOLF and HALLAUER, 1977). The nature of fixable and non-fixable genetic information helps in the proper understanding of genetic components and selection of potential parental lines or crosses. Moreover, these will decide and help for selection programme in earlier and/or advanced generation and to choose best parental lines for hybridization programme with targeted traits. These best breeding strategies will accelerate generation of new cultivars/hybrids with high nutritional value. JINKS and JONES (1958) postulated that heterosis could be expressed when dispersion of favourable alleles coupled with complimentary epistasis occurs. There no alternative or substitute technology developed for conversion of duplicate epistatic interaction into complimentary epistatic interaction due to its intrinsic property of dispersal genes (CHAHAL *et al*., 1991). For the enhancement of nutritional traits like moisture content, total solids, total soluble solids, total carotenoids, β-carotene , lycopene and anthocyanin, a suitable breeding strategies have to be formulated with precise understanding of the magnitude of gene action and interaction effects. There are little research studies available on these traits. Therefore, an attempt was made in the present experiment to unravel the nature and magnitude of gene action and effects of the nutritional traits of tropical carrot. These genetic analysis studies could be useful to know the genetic information and best choice of sound carrot breeding strategies for these traits.

MATERIALS AND METHODS

Population generation

The four different phenotypic parental inbred lines which are yellow, purple, red and orange colored roots were used in this study. F_1 progenies (F_1) were generated from these four inbred lines were selfed to produce F_2 progenies and backcrossed to both the parental lines to get back cross of B_1 and B_2 progenies, respectively for gene interaction analysis. For nutritional analysis, the 20 plants of parental inbred lines, 25 F_1 progenies, 300 of F_2 progenies and 50 each of back cross progenies (B_1 and B_2) were taken for nutritional analysis.

Crossing programme

Four different genotypes of tropical carrot maintained in the Division of Vegetable Science, IARI, New Delhi, India were utilized in this genetic study. These parental ($P_{1,}$ P_2) carrot seeds were sown during 2011-12 at Vegetable Research Farm, IARI, New Delhi, India. The carrot inbred lines were selected on the basis of different morphological characters such as root shape, size, uniform colour of root epidermal, phloem and xylem. Each of these carrots inbred lines were selfed and seeds were harvested to get homozygous inbreds. Hybridization were done during 2012-13 by using harvested carrot inbred seeds The carrot inbreds which has four genetic backgrounds with uniform root epidermal, phloem and xylem colour, size and shape of roots were selected for crossing purpose. These chosen inbred lines were hybridized in a diallel fashion including reciprocals. The F_1 progeny seeds were harvested and sown during October, 2013. The roots from F_1 progenies were harvested and planted for producing F_2, B_1 and B_2 progenies by selfing of F_1 plants crossing with female and male parents, respectively. The seeds of all this six populations namely P_1, P_2, F_1, F_2, B_1 and B_2 were grown during October, 2014-15 for raising these generations for fresh market roots.

Experimental design

The carrot experimental field was laid out in Randomized Block Design with three replications. The six generations viz., P_1, P_2, F_1, F_2, B_1 and B_2 were sown for genetic observation at the Vegetable Research Farm of Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi, India located at an elevation of about 228m above MSL, 20°40′ North latitude and 77°13′ East Longitude during the winter of 2013-14 and 2014-15. Each of these carrot generations consist of 50 parental inbred lines (P_1 and P_2), 50 F_1 progenies (3 block), approximately 500 F_2 progenies and 100 of each backcross progenies (B_1 and B_2). The different phenotypical data of roots were observed on an individual plant of six generations for each cross where 20, 20, 25, 300, 50 and 50 plants were chosen from P_1, P_2, F_1, F_2, B_1 and B_2 generations of twelve combinations, respectively.

Horticultural operations

The experimental plot of parents, F_1, F_2, B_1 and B_2 consisted of two, two, ten, three and three rows of 2.5m length each with spacing of 45 and 10cm between rows and plants, respectively. Before growing of different carrot progeny seeds on the ridges, Pendimethalin herbicide at 3L a.i/ha was applied for suppression of weed growth, after proper checking of moisture in the soil and optimum moisture was maintained by irrigation up to half of the ridges in the experimental plots. The recommended dose of NPK fertilizer (40:60:60kg/ha) were applied during field preparations in the experimental plots. After thirty days of carrot sowing with earthing up and thinning, 40kg N/ha dose was applied.

Biochemical analysis

The research experiments involved the six basic generations P_1, P_2, F_1, F_2, B_1 and B_2 of twelve crosses which are White Pale × IPC-126, White Pale × IPC-122 and White Pale × PM, IPC-126 × White Pale, IPC-126 × IPC-122, IPC-126 × PM, PM × White Pale, PM × IPC-126 and PM × IPC-126 . The harvested carrot progenies were collected for biochemical analysis viz. moisture content (%), total solids (%), total soluble solids (ºBrix), total carotenoids (mg/100g fresh weight (FW)), β-carotene (mg/100g FW), lycopene (mg/100g FW) and total anthocyanin content (mg/100 g FW). This biochemical analysis was done by AOAC (1990) standard methods.

Statistical analyses and biometrical analysis

The data collected from biochemical analytical methods for above mentioned nutritional traits were subjected into biometrical analysis through plant breeder tools software (PBT, 2013) to study the genetic components in tropical carrot.

Generation mean analysis

The genetic components were estimated from mean values and standard errors for all generations by MATHER and JINKS (1971) and '*t*' test were used for significance of the scales and gene interactions effects. The test of adequacy of three and six parameter model was done by joint scaling test and individual scaling test of six generations. The scaling test of A, B, C and D were done by HAYMAN and MATHER (1955) and MATHER (1949) method in which significance of 'A' and 'B' scale indicate that presence of three non-allelic interaction effects (additive × additive [*i*], additive × dominance [*j*] and dominance × dominance [*l*]), 'C' scale indicate the dominance × dominance [*l*] epistatic interaction effects and 'D' scale indicate the additive × additive [*i*] epistatic interaction effects. When the joint scaling test or three parameter model (mean [*m*], additive [*d*] and dominance [*h*]) of CAVELLI (1952) were significant, a six parameter were successfully used to test of fitness of appropriate genetic model as per HAYMAN (1958), MATHER and JINKS (1982) and MATHER and JINKS (1971). The six parameter or digenic interaction model consist of additive × additive [*i*] additive × dominance [*j*] and dominance × dominance [*l*] in addition to three parameter model. The significance of m, [*d*], [*h*], [*i*], [*j*] and [*l*] genetic effects were done by '*t*' test at the 0.05 and 0.01 levels of probability (SINGH and SINGH, 1992). The type of epistatic gene interaction were determined by KEARSEY and POONI (1996) as presence of similar sign of dominance [*h*] and dominance × dominance [*l*] effects when it is noted as complimentary epistasis while dissimilar sign of [*h*] and [*l*] effects then it is duplicate type of epistatic gene interaction. Genetic analysis were carried out separately for each cross using the plant breeder tools (PBT, 2013) software developed by International Rice Research Institute, Department of plant breeding, genetics and biometrics, Philippines.

RESULTS AND DISCUSSION

Moisture content

The estimates of generation means and their standard error are presented in Table 1. The scaling test and joint scaling test are presented in Table 2. Significance of A, B, C and D individual scaling test was observed in White Pale × IPC-126 cross, A, B and D in White Pale × IPC-122, White Pale × PM, IPC-122, B and D in IPC-122 × IPC-126 cross, A and B scale in IPC-122 × PM, PM × White Pale, PM × IPC-126 and PM × IPC-126 crosses. Three genetic parameter model are highly significant with chi-square value. These scaling and joint scaling results are presented in Table 2. Digenic six parameter model were adequate to explain the gene interaction and effects for moisture content (Table 3). The positive effects of dominance [*h*] and additive × dominance [*l*] gene interaction were highly influencing moisture content in the IPC-126 × PM, PM × White Pale, PM × IPC-126, PM × IPC-122 and IPC-122 × PM crosses. HALLAUER and MIRANDA (1988) highlighted in similar lines of maize that higher effects of dominance [h] was often expressing heterosis phenomenon than additive [*d*] effects. The positive dominance [*h*], additive × additive [*i*] and negative dominance × dominance [*l*] gene interactions were significant in governing this trait in the White Pale × IPC-126, IPC-126 × White Pale and IPC-122 × White Pale cross combinations whereas along with these gene interactions, additive × dominance [*j*] gene interactions were negatively expressing for moisture content in White Pale × IPC-122 and White Pale × PM crosses. The additive [*h*], dominance [*h*] and dominance × dominance [*l*] type of gene interactions were governing this trait in IPC-126 × IPC-122 cross. The negative effects of dominance [*h*], additive × additive [*i*] and positive effects of dominance × dominance [*l*] were significant in IPC-122 × IPC-126 cross for moisture content. This similar genetic component effects was reported by SINGH *et al*. (1992) and SINGH and SINGH (1985) in chickpea and tomato, respectively. The duplicate type of gene interactions was observed in all the crosses except White Pale × IPC-126 wherein complimentary epistatic interactions were observed due to similar gene effects of [*h*] and [*l*]. In the F_2 generations of these crosses, the interaction were conditioned by negative effects of [*j*]s and [*i*]s and [*l*]s similar sign to each other but opposite of dominance [*h*] effects. Thus, this interaction will decrease the variation of F_2 and its derived population (MATHER, 1967b). Thereby, HOLLAND (2011) stated that duplicate non-allelic gene interactions can be exploited by restriction of selection in earlier selection and till attaining of homozygosity of genes in advanced generations.

Table 1. Generation means of nutritional traits of the tropical carrot (Daucus carota L.)

Traits	Cross	**Mean**±SE					
		P$_1$	**P$_2$**	**F$_1$**	**F$_2$**	**B$_1$**	**B$_2$**
Moisture content (%)	White Pale × IPC-126	89.37±0.0	88.17±0.15	87.96±0.26	85.30±0.28	86.54±0.37	86.99±0.49
	White Pale × IPC-122	89.30±0.05	88.06±0.13	87.39±0.21	85.34±0.24	86.53±0.32	87.04±0.40
	White Pale × PM	89.25±0.05	88.04±0.12	87.17±0.20	85.35±0.23	86.57±0.30	87.05±0.37
	IPC-126 × White Pale	86.05±0.1	86.06±0.10	86.82±0.46	85.39±0.22	86.52±0.30	87.09±0.36
	IPC-126 × IPC-122	86.49±0.25	86.62±0.14	88.05±0.22	87.32±0.11	86.94±0.21	88.08±0.14
	IPC-126 × PM	87.98±0.45	86.11±0.22	86.95±0.34	87.16±0.15	88.38±0.10	86.34±0.16
	PM × White Pale	88.06±0.70	86.16±0.36	87.00±0.49	87.17±0.19	88.42±0.12	86.37±0.17
	PM × IPC-122	88.04±0.49	86.09±0.24	86.90±0.33	87.17±0.15	88.34±0.09	86.32±0.15
	PM × IPC-126	87.80±0.34	86.18±0.18	87.09±0.37	87.13±0.14	88.32±0.09	86.33±0.15
	IPC-122 × White Pale	89.09±0.07	88.00±0.10	86.52±0.23	85.38±0.21	86.66±0.25	87.07±0.30
	IPC-122 × IPC-126	86.51±0.27	86.56±0.15	88.02±0.24	87.34±0.11	86.93±0.21	86.84±0.16
	IPC-122 × PM	88.02±0.39	86.01±0.15	86.80±0.33	87.17±0.14	88.38±0.10	86.33±0.16
Total Solids (%)	White Pale × IPC-126	10.62±0.0	11.82±0.15	12.03±0.26	14.70±0.28	13.45±0.37	13.00±0.49
	White Pale × IPC-122	10.69±0.05	11.93±0.13	12.60±0.21	14.65±0.24	13.46±0.32	12.95±0.40
	White Pale × PM	10.74±0.05	11.95±0.12	12.82±0.20	14.64±0.23	13.43±0.30	12.94±0.37
	IPC-126 × White Pale	13.94±0.1	13.93±0.10	13.17±0.46	14.60±0.22	13.47±0.30	12.90±0.36
	IPC-126 × IPC-122	13.50±0.25	13.37±0.14	11.94±0.22	12.67±0.11	13.05±0.21	11.91±0.14
	IPC-126 × PM	12.01±0.45	13.88±0.22	13.04±0.34	12.83±0.15	11.61±0.10	13.65±0.16
	PM × White Pale	11.93±0.70	13.83±0.36	12.99±0.49	12.82±0.19	11.57±0.12	13.62±0.17
	PM × IPC-122	11.95±0.49	13.90±0.24	13.09±0.33	12.82±0.15	11.65±0.09	13.67±0.15
	PM × IPC-126	12.19±0.34	13.81±0.18	12.90±0.37	12.86±0.14	11.67±0.09	13.66±0.15
	IPC-122 × White Pale	10.90±0.07	11.99±0.10	13.47±0.23	14.61±0.21	13.33±0.25	12.92±0.30
	IPC-122 × IPC-126	13.48±0.27	13.43±0.15	11.97±0.24	12.65±0.11	13.07±0.21	13.15±0.16
	IPC-122 × PM	11.97±0.39	13.98±0.15	13.19±0.33	12.82±0.14	11.61±0.10	13.66±0.16
TSS (ºBrix)	White Pale × IPC-126	5.23±0.25	9.39±0.20	8.27±0.31	8.35±0.13	7.30±0.32	8.93±0.37
	White Pale × IPC-122	5.23±0.25	9.14±0.43	6.49±0.56	7.80±0.21	7.04±0.349	8.51±0.40
	White Pale × PM	5.23±0.25	8.46±0.12	6.83±0.42	7.13±0.28	7.18±0.29	8.63±0.34
	IPC-126 × White Pale	9.39±0.20	5.23±0.25	7.28±0.51	8.76±0.14	8.24±0.29	8.71±0.32
	IPC-126 × IPC-122	9.39±0.20	9.14±0.43	8.76±0.31	7.97±0.29	9.25±0.37	8.86±0.38
	IPC-126 × PM	9.39±0.20	8.46±0.12	8.34±0.44	7.94±0.20	8.56±0.39	8.48±0.51
	PM × White Pale	8.46±0.12	5.23±0.29	7.79±0.35	7.84±0.22	8.04±0.31	8.69±0.33

	PM × IPC-122	8.46±0.12	9.14±0.43	7.46±0.62	8.20±0.19	7.98±0.35	8.47±0.39
	PM × IPC-126	8.46±0.12	9.39±0.20	5.75±0.64	8.26±0.17	8.58±0.46	8.33±0.35
	IPC-122 × White Pale	9.14±0.43	8.46±0.12	6.49±0.92	7.98±0.17	9.31±0.42	9.20±0.37
	IPC-122 × IPC-126	9.14±0.43	5.23±0.25	6.30±0.66	8.79±0.31	8.53±0.43	8.70±0.40
	IPC-122 × PM	9.14±0.43	9.39±0.20	5.73±0.98	8.26±0.24	7.95±0.53	8.45±0.41
TCC (mg/100g FW)	White Pale × IPC-126	1.19±0.00	3.14±0.01	7.65±0.02	6.41±0.34	6.17±0.59	6.942±0.53
	White Pale × IPC-122	1.19±0.00	7.89±0.02	19.76±0.04	9.69±0.50	9.85±0.92	9.65±0.89
	White Pale × PM	1.19±0.00	13.78±0.06	15.11±0.02	10.55±0.64	10.52±1.16	10.34±1.13
	IPC-126 × White Pale	3.14±0.01	1.19±0.00	7.77±0.01	7.36±0.50	6.99±0.76	8.46±0.74
	IPC-126 × IPC-122	3.14±0.01	13.78±0.06	19.33±0.01	11.76±0.59	11.68±1.02	11.40±0.94
	IPC-126 × PM	3.14±0.01	7.89±0.02	12.20±0.04	10.16±0.56	10.43±1.04	10.28±1.00
	PM × White Pale	7.89±0.02	3.14±0.01	12.2±0.05	10.17±0.5	9.79±0.95	9.6±0.91
	PM × IPC-122	7.89±0.02	13.78±0.06	19.73±0.03	14.16±0.47	14.23±0.80	14.09±0.80
	PM × IPC-126	7.89±0.02	1.19±0.00	19.74±0.02	9.98±0.49	9.99±0.89	9.92±0.87
	IPC-122 × White Pale	13.78±0.06	1.19±0.00	15.30±0.03	10.42±0.64	10.40±1.20	10.56±1.25
	IPC-122 × IPC-126	13.78±0.06	7.89±0.02	19.81±0.49	13.97±0.47	13.97±0.82	13.777±0.78
	IPC-122 × PM	13.78±0.06	3.14±0.01	21.88±0.01	11.67±0.63	11.72±1.12	11.30±1.10
β-CC (mg/100g FW)	White Pale × IPC-126	0.91±0.00	2.46±0.03	5.90±0.02	4.94±0.26	4.76±0.46	5.35±0.41
	White Pale × IPC-122	0.91±0.00	10.63±0.04	11.65±0.02	8.13±0.50	8.11±0.90	7.97±0.87
	White Pale × PM	0.91±0.00	6.08±0.01	15.25±0.03	7.48±0.39	7.60±0.71	7.44±0.69
	IPC-126 × White Pale	2.46±0.03	0.91±0.00	5.99±0.01	5.68±0.38	5.39±0.59	6.52±0.57
	IPC-126 × IPC-122	2.46±0.03	10.63±0.04	14.91±0.01	9.07±0.45	9.01±0.78	8.80±0.72
	IPC-126 × PM	2.46±0.03	6.08±0.01	9.41±0.031	7.84±0.43	8.05±0.80	7.93±0.77
	PM × White Pale	6.08±0.01	10.63±0.04	15.22±0.02	10.92±0.36	10.97±0.62	10.87±0.62
	PM × IPC-122	6.08±0.01	0.91±0.00	15.23±0.02	7.70±0.37	7.70±0.69	7.65±0.67
	PM × IPC-126	6.08±0.01	2.46±0.03	9.47±0.04	7.84±0.45	7.55±0.73	7.45±0.70
	IPC-122 × White Pale	10.63±0.04	0.91±0.00	11.80±0.02	8.03±0.50	8.02±0.92	8.14±0.96
	IPC-122 × IPC-126	10.63±0.04	6.08±0.01	15.28±0.37	10.78±0.36	10.77±0.63	10.627±0.60
	IPC-122 × PM	10.63±0.04	2.46±0.03	16.87±0.01	9.00±0.49	9.04±0.86	8.71±0.85
LC (mg/100g FW)	White Pale × IPC-126	0.21±0.00	1.08±0.01	1.01±0.05	0.94±0.02	0.96±0.02	0.86±0.02
	White Pale × IPC-122	0.23±0.00	10.79±0.08	13.21±0.01	4.47±0.30	4.67±0.48	4.63±0.47
	White Pale × PM	0.21±0.00	1.17±0.01	3.18±0.01	1.62±0.10	1.42±0.17	1.51±0.18
	IPC-126 × White Pale	1.08±0.01	0.21±0.00	1.22±0.00	0.89±0.03	1.21±0.10	1.35±0.15
	IPC-126 × IPC-122	1.15±0.01	10.79±0.08	14.08±0.02	4.60±0.26	4.69±0.46	4.17±0.43
	IPC-126 × PM	1.08±0.01	1.17±0.01	4.05±0.00	1.55±0.11	1.50±0.18	1.09±0.07
	PM × White Pale	1.26±0.01	10.79±0.08	5.73±0.05	3.41±0.22	3.40±0.40	3.52±0.38

TAC(mg/100g FW)	PM × IPC-122	1.17±0.01	0.21±0.00	3.64±0.01	1.47±0.10	1.09±0.10	1.06±0.07
	PM × IPC-126	1.17±0.01	1.08±0.01	4.26±0.01	1.63±0.12	1.46±0.19	1.53±0.20
	IPC-122 × White Pale	10.79±0.08	1.15±0.01	14.18±0.00	4.54±0.27	4.53±0.46	4.52±0.47
	IPC-122 × IPC-126	10.79±0.08	1.26±0.01	6.16±0.00	4.74±0.34	4.40±0.50	5.33±0.51
	IPC-122 × PM	10.79±0.08	0.23±0.00	13.54±0.00	5.60±0.30	5.39±0.42	5.89±0.41
	White Pale × IPC-126	0.02±0.00	86.53±0.17	132.22±0.20	41.61±1.87	25.67±4.50	26.26±4.30
	IPC-126 × White Pale	86.53±0.17	0.02±0.00	134.08±2.09	19.28±2.27	19.30±3.68	20.57±4.33
	IPC-126 × IPC-122	86.53±0.17	0.02±0.00	151.11±1.87	19.00±1.99	18.84±3.41	19.34±3.68
	IPC-126 × PM	86.53±0.17	0.03±0.00	150.24±1.63	19.75±2.22	23.19±4.74	21.77±4.52
	PM × IPC-126	0.03±0.00	86.53±0.17	154.79±0.92	36.25±3.74	34.46±5.74	42.88±8.92
	IPC-122 × IPC-126	0.02±0.00	86.53±0.17	153.08±1.57	39.25±4.25	37.73±7.02	38.63±7.46

TCC-total carotenoids content; β-CC- β-carotene content; LC- Lycopene content; TAC- Total anthocyanin content

Table 2. Estimates of scaling test and Joint scaling test of twelve carrot crosses for nutritional traits in tropical carrot (Daucus carota L.)

Nutritional traits	Cross	Scaling Test				Joint Scaling Test		
		A ± SE	B ± SE	C ± SE	D ± SE	m ± SE	d ± SE	h ± SE
Moisture content (%)	White Pale × IPC-126	4.24**±0.79	2.14**±1.04	12.27**±1.25	-2.94**±0.83	88.66**±0.08	-0.69**±0.08	-2.12**±0.24
	White Pale × IPC-122	3.62**±0.67	1.36±0.84	10.76**±1.06	-2.88**±0.70	88.57**±0.07	-0.68**±0.07	-2.27**±0.20
	White Pale × PM	3.29**±0.64	1.11±0.78	10.22**±1.02	-2.90**±0.67	88.55**±0.06	-0.65**±0.06	-2.39**±0.19
	IPC-126 × White Pale	-0.17±0.79	-1.30±0.86	4.17**±1.32	-2.82±0.65	86.02**±0.10	0.03±0.10	0.30±0.32
	IPC-126 × IPC-122	0.65±0.54	-1.48**±0.39	-0.07±0.69	-0.37±0.34	86.51**±0.12	0.34**±0.12	1.81**±0.24
	IPC-126 × PM	-1.84**±0.61	0.37±0.52	-0.64±1.05	-0.41±0.36	87.57**±0.18	-1.69±0.14	-0.46±0.38
	PM × White Pale	-1.79±0.89	0.41±0.70	-0.45±1.49	-0.45±0.44	87.67**±0.28	-1.85**±0.17	-0.59**±0.57
	PM × IPC-126	-1.75**±0.54	0.61±0.52	-0.35±1.02	-0.39±0.34	87.43**±0.15	-1.51**±0.12	-0.15±0.34
	PM × IPC-122	-1.74**±0.63	0.34±0.51	-0.75±1.07	-0.32±0.36	87.62**±0.19	-1.76**±0.14	-0.57±0.39
	IPC-122 × White Pale	2.29±0.57	0.37±0.66	8.59±0.97	-2.96±0.57	88.47±0.06	-0.54±0.06	-3.04±0.20
	IPC-122 × IPC-126	0.68±0.56	0.89*±0.43	-0.23±0.73	0.90**±0.35	86.51**±0.13	-0.01±0.13	1.35**±0.26
	IPC-122 × PM	-1.93**±0.56	0.15±0.49	-1.03±0.98	-0.37±0.3	87.56**±0.15	-1.66**±0.13	-0.46±0.33
	White Pale × IPC-126	-4.24**±0.79	-2.14**±1.04	-12.27**±1.25	2.94**±0.83	11.33±0.08	0.69**±0.08	2.12**±0.24
	White Pale × IPC-122	-3.62**±0.67	-1.36±0.84	-10.76**±1.06	2.88**±0.70	11.42**±0.07	0.68**±0.07	2.27**±0.20
	White Pale × PM	-3.29**±0.64	-1.11±0.78	-10.22**±1.02	2.90**±0.67	11.44**±0.06	0.65**±0.06	2.39**±0.19
	IPC-126 × White Pale	0.17±0.79	1.30±0.86	-4.17**±1.32	2.82**±0.65	13.97**±0.10	-0.03±0.10	-0.30±0.32
	IPC-126 × IPC-122	-0.65±0.54	1.48**±0.39	0.07±0.69	0.37±0.34	13.49**±0.12	-0.34**±0.12	-1.81**±0.24
	IPC-126 × PM	1.84**±0.61	-0.37±0.52	0.64±1.05	0.41±0.36	12.42**±0.18	1.69±0.14	0.46±0.38

	PM × White Pale	1.79±0.89	-0.41±0.70	0.45±1.49	0.45±0.44	12.32**±0.28	1.85**±0.17	0.59**±0.57
	PM × IPC-126	1.75**±0.54	-0.61±0.52	0.35±1.02	0.39±0.34	12.56**±0.15	1.51**±0.12	0.15±0.34
	PM × IPC-122	1.74**±0.63	-0.35±0.51	0.75±1.07	0.32±0.36	12.37**±0.19	1.76**±0.14	0.57±0.39
	IPC-122 × White Pale	-2.29**±0.57	-0.37±0.66	-8.59**±0.97	2.96**±0.57	11.52**±0.06	0.54**±0.06	3.04**±0.20
	IPC-122 × IPC-126	-0.68±0.56	-0.89**±0.43	0.23±0.73	-0.90**±0.35	13.49**±0.13	0.01±0.13	-1.35**±0.26
	IPC-122 × PM	1.93**±0.56	-0.15±0.49	1.03±0.98	0.37±0.35	12.43**±0.15	1.66**±0.13	0.46±0.33
TSS (ºBrix)	White Pale × IPC-126	-1.10**±0.76	-0.20±0.83	-2.26**±0.90	0.48±0.56	7.47**±0.15	2.00**±0.15	1.34**±0.31
	White Pale × IPC-122	-2.37**±0.93	-1.39±1.07	-3.86**±1.50	0.04±0.67	7.38**±0.23	1.95**±0.22	0.41**±0.49
	White Pale × PM	-2.31**±0.77	-1.97**±0.81	-1.17**±1.44	-1.55**±0.72	6.95**±0.13	1.52**±0.13	0.72**±0.35
	IPC-126 × White Pale	0.17±0.80	-4.91**±0.87	-5.89**±1.21	0.57±0.52	7.59**±0.15	-1.72**±0.15	1.68**±0.35
	IPC-126 × IPC-122	-1.35**±0.83	0.18±0.94	4.16**±1.41	-2.17**±0.79	9.08**±0.21	-2.25**±0.21	-0.60**±0.38
	IPC-126 × PM	2.60**±0.92	-0.16±1.12	2.75**±1.21	-1.15±0.76	8.87**±0.11	-1.43**±0.11	-1.17**±0.32
	PM × White Pale	0.15±0.72	-4.36**±0.79	-2.10**±1.16	-1.05±0.63	7.08**±0.13	-1.34**±0.13	1.40**±0.31
	PM × IPC-126	-2.95**±1.13	-1.53±0.98	-3.71**±1.47	-0.38±0.68	8.96**±0.11	2.46**±0.11	-1.67**±0.3
	PM × IPC-122	-2.05**±0.95	-0.35±1.09	-2.29**±1.54	-0.05±0.65	8.83**±0.20	2.37**±0.20	-1.26**±0.45
	IPC-122 × White Pale	-1.62±1.17	-5.87**±1.07	-8.22**±1.90	0.36±0.86	7.39**±0.23	-1.76**±0.23	1.56**±0.54
	IPC-122 × IPC-126	-1.03±1.52	-1.78**±1.30	-3.05**±2.25	0.11±0.84	9.30**±0.22	0.12**±0.22	-2.30**±0.55
	IPC-122 × PM	-2.99**±1.32	-3.46**±1.19	-1.36**±2.02	-2.54**±0.66	8.81**±0.20	-0.32**±0.20	-1.05*±0.48
TCC (mg/100g FW)	White Pale × IPC-126	-3.50**±1.19	-3.09**±1.06	-6.02**±1.36	-0.28**±1.05	2.16**±0.00	0.97**±0.00	5.49**±0.03
	White Pale × IPC-122	-4.74*±2.33	8.20**±2.26	2.99*±2.59	0.23±2.08	7.48**±0.03	6.29**±0.03	7.62**±0.04
	White Pale × PM	1.24±1.84	8.35**±1.79	9.83**±2.02	-0.11±1.63	4.54**±0.01	3.35**±0.01	15.21**±0.04
	IPC-126 × White Pale	-3.0**6±1.53	-7.96**±1.48	-9.58**±2.00	-0.72±1.46	2.16**±0.00	3.97**±0.00	5.61**±0.02
	IPC-126 × IPC-122	-0.89*±2.04	10.30**±1.88	8.53**±2.38	0.43±1.83	8.45**±0.03	5.31**±0.03	10.88**±0.03
	IPC-126 × PM	-5.53**±2.08	-0.47±2.00	-5.22*±2.26	-0.39±1.83	5.51**±0.01	2.37**±0.01	6.69**±0.04
	PM × White Pale	7.66**±1.79	1.09±1.74	8.62**±1.96	0.06±1.59	4.54**±0.01	-3.35**±0.01	15.20**±0.03
	PM × IPC-126	0.59±1.90	-3.91*±1.82	-5.08*±2.37	0.88±1.77	5.51**±0.01	-2.37**±0.01	6.77**±0.05
	PM × IPC-122	-0.84±1.60	5.31**±1.61	4.47*±1.90	-0.00±1.48	10.83**±0.03	2.93**±0.03	8.89**±0.05
	IPC-122 × White Pale	8.27**±2.40	-4.62±2.50	3.89*±2.59	-0.12±2.16	7.48**±0.03	-6.29**±0.03	7.82**±0.04
	IPC-122 × IPC-126	12.22**±2.25	2.41±2.20	13.99**±2.54	0.32±2.02	8.45**±0.03	-5.31**±0.03	13.42**±0.03
	IPC-122 × PM	5.65**±1.71	0.15±1.65	5.40*±2.14	0.20±1.48	10.83**±0.03	-2.93**±0.03	8.14**±0.40
β-CC (mg/100g FW)	White Pale × IPC-126	-2.70**±0.92	-2.34**±0.82	-4.60**±1.05	-0.22±0.81	1.69**±0.01	0.77**±0.01	4.21**±0.02
	White Pale × IPC-122	-3.66*±1.80	6.32**±1.74	2.30*±2.00	0.17±1.60	5.77**±0.02	4.85**±0.02	5.88**±0.03
	White Pale × PM	0.96±1.42	6.44**±1.38	7.58**±1.56	-0.09±1.26	3.50**±0.01	2.58**±0.01	11.73**±0.03
	IPC-126 × White Pale	-2.32*±1.18	-6.14**±1.14	-7.34**±1.54	-0.56±1.13	1.69**±0.01	-0.77**±0.01	4.30**±0.02
	IPC-126 × IPC-122	-0.64±1.57	7.94±1.45	6.62±1.83	0.33±1.41	6.54**±0.02	4.07**±0.02	8.37**±0.03
	IPC-126 × PM	-4.22**±1.60	-0.36±1.54	-3.98*±1.74	-0.30±1.41	4.27**±0.01	1.80**±0.01	5.13**±0.03

	PM × White Pale	5.91**±1.38	0.84±1.34	6.65**±1.51	0.05±1.22	3.50**±0.01	-2.58**±0.01	11.72**±0.02
	PM × IPC-126	0.45±1.46	-2.97**±1.40	-3.87**±1.83	0.68±1.36	4.27**±0.01	-1.81**±0.01	5.20**±0.04
	PM × IPC-122	-0.65±1.24	4.10**±1.24	3.45*±1.46	-0.00±1.14	8.35**±0.02	2.26**±0.02	6.86**±0.03
	IPC-122 × White Pale	6.38**±1.85	-3.56±1.93	3.00*±2.00	-0.09±1.67	5.77**±0.02	-4.85**±0.02	6.03**±0.03
	IPC-122 × IPC-126	9.42**±1.73	1.90±1.70	10.83**±1.96	0.24±1.56	6.53**±0.02	-4.07**±0.02	10.33**±0.03
	IPC-122 × PM	4.36**±1.32	0.12±1.27	4.17**±1.65	0.15±1.14	8.35**±0.02	-2.26**±0.02	6.28**±0.31
LC (mg/100g FW)	White Pale × IPC-126	-0.69**±0.07	0.36**±0.08	-0.44**±0.16	0.05±0.07	0.62**±0.00	0.41**±0.00	0.56**±0.03
	White Pale × IPC-122	4.09**±0.96	14.73**±0.95	19.56**±1.22	-0.36±0.91	5.39**±0.04	5.16**±0.04	7.80**±0.04
	White Pale × PM	0.55±0.34	1.32**±0.37	1.27**±0.43	0.30±0.33	0.69**±0.00	0.48**±0.00	2.48**±0.01
	IPC-126 × White Pale	-0.12±0.20	-1.28**±0.31	0.16±0.14	-0.78**±0.20	0.64**±0.00	-0.43**±0.00	0.57**±0.01
	IPC-126 × IPC-122	5.86**±0.93	16.53**±0.87	21.68**±1.08	0.35±0.83	5.81**±0.04	4.66**±0.04	8.23**±0.05
	IPC-126 × PM	2.13**±0.36	3.04**±0.15	4.15**±0.47	0.51±0.31	1.11**±0.01	0.04**±0.01	2.92**±0.01
	PM × White Pale	2.63**±0.20	1.72**±0.15	2.75**±0.43	0.80**±0.253	0.68**±0.00	-0.48**±0.00	2.92±**0.01
	PM × IPC-126	2.51**±0.39	2.28**±0.41	4.27**±0.50	0.26±0.38	1.12**±0.01	-0.05**±0.01	3.13**±0.01
	PM × IPC-122	0.19±0.80	9.47**±0.77	9.84**±0.91	-0.09±0.71	5.91**±0.04	4.65**±0.04	-0.28**±0.06
	IPC-122 × White Pale	13.54**±0.85	1.98*±0.82	15.69**±1.23	-0.08±0.85	5.39**±0.04	-5.16**±0.04	8.13**±0.04
	IPC-122 × IPC-126	8.13**±1.00	-3.24**±1.02	5.40**±1.36	-0.25±0.98	5.98**±0.04	-4.72**±0.04	0.18**±0.04
	IPC-122 × PM	15.90**±0.92	6.28**±0.94	22.12**±1.11	0.02±0.86	5.82**±0.04	-4.67**±0.04	8.35**±0.04
TAC (mg/100g FW)	White Pale × IPC-126	80.89**±9.01	166.24**±8.60	184.54**±7.52	31.29**±7.27	43.20**±0.08	43.17**±0.08	88.61**±0.22
	IPC-126 × White Pale	182.00**±7.66	92.95**±8.91	277.59**±10.01	-1.31±7.28	43.20**±0.08	-43.17**±0.08	54.30**±1.80
	IPC-126 × IPC-122	199.95**±7.08	112.45**±7.60	312.78**±8.80	-0.18±6.41	43.17**±0.08	-43.15**±0.08	66.06**±1.61
	IPC-126 × PM	190.39**±9.62	106.73**±9.18	308.03**±9.47	-5.45±7.91	43.20**±0.08	-43.17**±0.08	82.11**±1.49
	PM× IPC-126	85.89**±11.52	155.56**±17.88	251.14**±15.09	-4.84±12.99	43.26**±0.08	43.23**±0.08	108.73**±0.91
	IPC-122 × IPC-126	77.63**±14.14	162.35**±15.00	235.71**±17.31	2.13±13.32	43.26**±0.08	43.23**±0.08	103.36**±1.53

Total solids

The dominance [*h*], additive × additive [*i*] and dominance × dominance [*l*] gene interactions was conditioning this trait in White Pale × IPC-126, IPC-126 × White Pale and IPC-122 × White Pale cross combinations with negative and positive, respectively, whereas along with these gene interactions, positive effects of [*j*] gene effects were expressed for total soluble solids in White Pale × IPC-122 and White Pale × PM crosses. The additive [*h*], dominance [*h*] and dominance × dominance [*l*] type of gene interactions were governing this trait in IPC-126 × IPC-122 cross. Higher values of [*h*] effects than [*l*] effects may be due to heterozygosity of genes present in the parents (Kearsey and Pooni 1996). The effects of [*h*], [*i*] and [*l*] were positive and significant in IPC-122 × IPC-126 cross for total solids. The dominance [*h*] and additive × dominance [*l*] gene interaction were significant and negatively influencing total solids in IPC-126 × PM, PM × White Pale, PM × IPC-126, PM × IPC-122 and IPC-122 × PM crosses. Wilson *et al.* (2000)

conceptualized that the additive genetic component are undermined due to less phenotypical information of parental differences The duplicate type of gene interactions was observed in all the crosses except White Pale × IPC-126 wherein complimentary epistatic interactions due to similar gene effects of [*h*] and [*l*]. The undesirable linkage of [*i*] and [*l*] effects in the duplicate epistatic interaction can be broken by inter-mating of selector followed by earlier selection which resulted into rare useful recombinants (ALVAREZ-CASTRO *et al*., 2008). The greater expression of positive heterosis reinforced dominance effects by [*i*] and [*l*] gene interaction in White Pale × IPC-126 as supported by JINKS and JONES (1958). Similarly these total solids gene effects were reported in okra (SOHER *et al*., 2013), tomato (CAUSSE *et al*., 2007; DA SILVEIRA and MALUF, 2002; RODRIGUEZ *et al*., 2004), pea (DIXIT *et al*., 2006) and temperate carrot) (SELVAKUMAR *et al*., 2017; 2018).

Total soluble solids

The significant estimates showed in A, B, C and D scales in White Pale × PM and IPC-122 × PM, in A and C scales in IPC-126 × IPC-122 IPC-126 × PM, PM × IPC-126, PM × IPC-122 and scales B and C in IPC-126 × White Pale, PM × White Pale, IPC-122 × White Pale, IPC-122 × IPC-126 crosses (Table 2). The additive [*h*] gene and dominance × dominance [*l*] type of gene interaction expressed negative directions in White Pale × IPC-126, White Pale × IPC-122 and White Pale × PM cross combinations but the dominance [*h*] gene effects were positive in these crosses for total soluble solids. The dominance [*h*] and additive × additive [i] gene effects were expressing along with the effects of [*h*] and [*l*] gene in White Pale × PM cross. The positive effects of dominance [h], additive × additive [l] gene and negative effects of dominance × dominance [*l*] were influencing this trait in IPC-126 × IPC-122 and IPC-122 × PM crosses. The dominance [*h*] and dominance × dominance [*l*] gene interactions were negatively governing the total soluble solids in PM × IPC-126, PM × IPC-122 and IPC-126 × IPC-122 cross combinations. The negative effects of dominance [*h*], additive × dominance [j] and dominance × dominance [*l*] gene interactions were significantly expressing for this trait in the IPC-126 × White Pale and IPC-122 × White Pale crosses. CUKADAR-OLMEDO and MILLER (1997) and EDWARDS *et al*. (1975) stated in sunflower and wheat, respectively, in that the additive [*d*] gene of positive and negative sign depend on the female parent (P_1). The positive dominance [*h*] and negative dominance × dominance [*l*] gene were significantly controlling this trait in IPC-126 × PM cross in addition of these gene effects, additive × dominance [*j*] gene interactions were negatively influencing in PM × White Pale cross. The complimentary type of non-allelic gene interactions was observed in the White Pale × IPC-122, IPC-126 × White Pale, PM × IPC-126, PM × IPC-122, IPC-122 × White Pale and IPC-122 × IPC-126 where it had similar signs of dominance [*h*] and dominance × dominance [*l*] gene effects. The magnitude of dominance [*h*] effects and its sign imparted the enhancing performance of targeted total soluble solids. The effects of [*h*] varied with parents used for targeted traits, thus, the absence of significance in [*h*] effects indicated no dominance or bidirectional dominance between parents. The sign of [*h*] and [*l*] effects and duplicate type of epistatic interactions was observed in the White Pale × IPC-126, White Pale × PM, IPC-126 × IPC-122, IPC-126 × PM, PM × White Pale and IPC-122 × PM crosses. Similar findings were reported by CAUSSE *et al*. (2007) and RODRIGUEZ *et al*. (2004) in tomato for total soluble solids.

Total carotenoids and β-carotene content

The three parameter mode was found inadequate in all cross combinations as revealed by significant values of A, B and C in White Pale × IPC-126, IPC-126 × White Pale, A and B scales in White Pale × IPC-122, A and C scales in IPC-126 × PM, PM × White Pale, IPC-122 × White Pale, IPC-122 × IPC-126 and IPC-122 ×PM and scales B and C in White Pale × PM, IPC-126 × IPC-122, PM × IPC-126 and PM × IPC-122 crosses (Table 2). The positive genetic effects of dominance [*h*], additive × dominance [*j*] and dominance × dominance [*l*] gene interaction was significantly controlling total carotenoids and carotene content in White Pale × IPC-122, White Pale × PM, IPC-126 × IPC-122 and PM × IPC-122 crosses. The nature and magnitude of dominance [*h*], dominance × dominance [*l*] was positively than additive × dominance [*j*] in PM × White Pale, IPC-122 × White Pale, IPC-122 × IPC-126 and IPC-122 × PM crosses for these traits. The positive effects of [*h*] and [*l*] increase the frequency of favourable alleles (Jinks and Jones 1958). The dominance [*h*] gene was governing the total carotenoids and β-carotene content in the White Pale IPC-126 and IPC-126 × White Pale crosses with positive directions whereas additive × dominance [*j*] and dominance × dominance [*l*] gene interactions were negatively influencing for these traits. The negative sign of [*l*] show bidirectional dominance in the parents whereas the positive values of [*j*] increases showed the variation in F_2 and its derived generations (MATHER, 1967). The dominance gene [*h*] and dominance × dominance [*l*] gene interactions exhibited significance with positive and negative directions, respectively in the IPC-126 × PM and PM × IPC-126 crosses for total carotenoids and *β*-carotene content. These findings were contrary to those of results of CHANDEL *et al.* (1994) who worked on gene action studies in temperate carrot. The positive signs of [*h*] and [*l*] gene effects and complimentary type of epistatic interactions plays an vital role for these trait in all crosses except in the White Pale × IPC-126, IPC-126 × White Pale, IPC-126 × PM and PM × IPC-126 crosses. Heterosis method of breeding will be more useful in these crosses for carotenoids rich varieties due to association and accumulation of [*h*] and [*l*] gene effects as similar gene estimates have been observed by LI *et al*. (2006) in tomato. In White Pale × IPC-126, IPC-126 × White Pale, IPC-126 × PM and PM × IPC-126 crosses, duplicate type of non-allelic gene interactions were noticed due to dissimilar effects of [*h*] and [*l*] gene interactions. The negative effects of [*h*] and [*l*] decrease the frequency of favourable alleles in the phenotype as revealed by MA (2007). Therefore, in this cross, biparental mating or diallel parental mating system followed by recurrent selection will be more precise breeding methodology for selection of carotenoid rich genotypes as suggested by HOLLAND, 2011; HILL *et al*., 2008; HOLLAND, 2007; HANSEN and WAGNER, 2001; KAMMERLOHR and PETERSON, 1980.

Lycopene content

The estimates of simple scale depicted in Table 2 revealed that A, B and C scales are significant in White Pale × IPC-126, White Pale × IPC-122, IPC-126 × IPC-122, IPC-126 × PM, PM × White Pale, PM × IPC-126, IPC-122 × White Pale, IPC-122 × IPC-126, IPC-122 × PM, B and C scales in White Pale × PM and PM ×IPC-122 crosses and scales B and D in IPC-126 × White Pale cross. The χ^2 values were also significant in all the crosses indicating the inadequacy of additive-dominance model (Table 2) and further revealing the presence of interallelic gene interactions which are presented in Table 3. The positive dominance [*h*], additive × dominance [*j*] and dominance × dominance [*l*] type of gene interaction was significantly governing the lycopene content in White Pale × IPC-126 White Pale × IPC-122, White Pale × PM, IPC-126 ×

IPC-122 and IPC-126 × PM cross combinations. The dominance [h], dominance × dominance [l] were expressed with positive directions whereas the additive × additive [*i*] and additive × dominance [*j*] genetic effects had negative directions in IPC-126 × White Pale, PM × White Pale and IPC-122 × White Pale crosses. Positive heterosis was observed in the effects of positive value of [*h*] and [*l*] effects as reported by JINKS and JONES (1958). The dominance [*h*] and dominance × dominance [*l*] gene interaction were positively controlling lycopene content but the additive × dominance [*j*] gene interactions negatively influenced this trait in PM × IPC-126 and IPC-126 × IPC-122 crosses. The additive × dominance [*j*] and dominance × dominance [*l*] gene interactions were controlling this trait in PM × IPC-122 and IPC-122 × PM. The positive similar sign effects of [*h*] and [*l*] and complimentary epistatic gene interaction were noticed in all cross combinations except in PM × IPC-122 and IPC-122 × PM. In this crosses, duplicate type of epistasis was observed due to dissimilar sign effects of [*h*] and [*l*]. The positive association of [*h*] and [*l*] effects tends to increase heterosis for lycopene content in all crosses as supported in tomato (LI *et al*., 2006). Therefore, heterosis exploitation can be successfully followed in all crosses whereas biparental mating of PM × IPC-122 and IPC-122 × PM cross combinations followed by recombinant segregants selection through mass and recurrent selection was more useful for selection of lycopene rich genotypes as elaborated by HOLLAND (2007; 2011). Further, the role of additive (*d*+*i*) and non-additive (*h*+*l*) gene interactions in the inheritance of lycopene content has reported by LI *et al*. (2006) in tomato.

Total anthocyanin content

The simple scale estimates of A, B, C and D were found highly significant in White Pale IPC-126 cross whereas significant A, B and D scales were observed in IPC-126 × White Pale, IPC-126 × White Pale, IPC-126 × IPC-122, IPC-126 × PM, PM × IPC-126, IPC-122 × IPC-126 crosses (Table 2). The joint scaling test in three parameter model were inadequate to explain gene interaction thereby digenic parameter model well fitted for epistatic gene interaction (Table 3).

Table 3. Estimation of type of gene interaction and its effects of the best fit model on generation means for nutritional traits in three different crosses of tropical carrot (Daucus carota L.) evaluated at Indian Agricultural Research Institute during winter season of 2011-15

Biochemical Traits	Cross	Gene interactions and effects						Type of epistasis
		m ± SE	d ± SE	h ± SE	i ± SE	j ± SE	l ± SE	
Moisture content (%)	White Pale × IPC-126	85.30**±0.28	-0.44±0.62	5.07**±1.70	5.88**±1.67	-2.10±1.25	0.50*±2.79	C
	White Pale × IPC-122	85.34**±0.24	-0.51±0.51	4.47**±1.43	5.77**±1.41	-2.26*±1.04	-0.78*±2.32	D
	White Pale × PM	85.35**±0.23	-0.48±0.48	4.34**±1.35	5.81**±1.34	-2.17*±0.97	-1.41*±2.18	D
	IPC-126 × White Pale	85.39**±0.22	-0.57±0.47	6.42**±1.39	5.65**±1.30	-1.13±0.97	-7.13**±2.30	D
	IPC-126 × IPC-122	87.32**±0.11	-1.13**±0.25	2.25**±0.73	0.75±0.68	-2.13**±0.59	-1.59**±1.24	D
	IPC-126 × PM	87.16**±0.15	2.04±0.19	0.73**±0.85	0.82±0.73	2.21**±0.64	-2.29**±1.31	D
	PM × White Pale	87.17**±0.19	2.05±0.20	0.79**±1.08	0.91±0.88	2.21*±0.89	-2.28**±1.71	D
	PM × IPC-126	87.13**±0.14	1.99±0.18	0.88**±0.80	0.78±0.68	2.37*±0.53	-1.92**±1.25	D
	PM × IPC-122	87.17**±0.15	2.02±0.18	0.48**±0.85	0.65±0.73	2.09*±0.66	-2.05**±1.30	D

	IPC-122 × White Pale	85.38**±0.21	-0.41±0.39	3.90**±1.18	5.93**±1.15	-1.91*±0.80	-3.2**7±1.86	D
	IPC-122 × IPC-126	87.34**±0.11	0.08±0.26	-0.32**±0.75	-1.81**±0.70	0.21±0.62	3.39**±1.30	D
	IPC-122 × PM	87.17**±0.14	2.04±0.19	0.53**±0.81	0.74±0.71	2.08**±0.57	-2.53*±1.26	D
Total Solids (%)	White Pale × IPC-126	14.70**±0.28	0.44±0.62	-5.07**±1.70	-5.88**±1.67	2.10±1.25	-0.50**±2.79	C
	White Pale × IPC-122	14.65**±0.24	0.51±0.51	-4.47**±1.43	-5.77**±1.41	2.26*±1.04	0.78*±2.32	D
	White Pale × PM	14.64**±0.23	0.48±0.48	-4.34**±1.35	-5.81**±1.34	2.17*±0.97	1.41*±2.18	D
	IPC-126 × White Pale	14.60**±0.22	0.57±0.47	-6.42±1.39	-5.65±1.30	1.13±0.97	7.13**±2.30	D
	IPC-126 × IPC-122	12.67**±0.11	1.13**±0.25	-2.25**±0.73	-0.75±0.68	2.13**±0.59	1.59**±1.24	D
	IPC-126 × PM	12.83**±0.15	-2.04±0.19	-0.73**±0.85	-0.82±0.73	-2.21**±0.64	2.29*8±1.31	D
	PM × White Pale	12.82**±0.19	-2.05±0.20	-0.79**±1.08	-0.91±0.88	-2.21**±0.89	2.28**±1.71	D
	PM × IPC-126	12.86**±0.14	-1.99±0.18	-0.88**±0.80	-0.78±0.68	-2.37*±0.53	1.92**±1.25	D
	PM × IPC-122	12.82**±0.15	-2.02±0.18	-0.48**±0.85	-0.65±0.73	-2.09*±0.66	2.05**±1.30	D
	IPC-122 × White Pale	14.61±0.21	0.41±0.39	-3.90**±1.18	-5.93±1.15	1.91*±0.80	3.27**±1.86	D
	IPC-122 × IPC-126	12.65**±0.11	-0.08±0.26	0.32**±0.75	1.81**±0.70	-0.21±0.62	-3.39**±1.30	D
	IPC-122 × PM	12.82**±0.14	-2.04±0.19	-0.53**±0.81	-0.74**±0.71	-2.08±0.57	2.53**±1.26	D
TSS (°Brix)	White Pale × IPC-126	8.35**±0.13	-1.63**±0.49	0.00*±1.19	-0.96±1.13	0.89±1.04	-0.34*±2.17	D
	White Pale × IPC-122	7.80**±0.21	-1.46**±0.53	-0.79*±1.49	-0.09±1.35	0.98±1.17	-3.66**±2.60	C
	White Pale × PM	7.13**±0.28	-1.44**±0.45	3.09*±1.52	3.11*±1.45	0.33±0.95	-7.40**±2.32	D
	IPC-126 × White Pale	8.76**±0.14	-0.46±0.43	-1.18*±1.17	-1.15±1.04	-5.08**±0.93	-3.57**±2.13	C
	IPC-126 × IPC-122	7.97**±0.29	0.39±0.53	3.83*±1.64	4.34**±1.59	0.53±1.18	-4.52**±2.58	D
	IPC-126 × PM	7.94**±0.20	0.08±0.64	1.72*±1.59	2.31±1.52	-0.76±1.32	-1.87**±2.86	D
	PM × White Pale	7.84**±0.22	-0.64±0.45	3.04**±1.32	2.10±1.26	-4.51**±0.95	-6.30**±2.15	D
	PM × IPC-126	8.26**±0.17	0.24±0.58	-2.39**±1.50	0.77±1.36	1.42±1.19	-5.26**±2.76	C
	PM × IPC-122	8.20**±0.19	-0.49±0.52	-1.22*±1.46	0.11±1.30	-0.30±1.14	-0.51*±2.60	C
	IPC-122 × White Pale	8.79**±0.31	-0.16±0.58	-1.61**±1.86	-0.72±1.72	-4.24**±1.27	-6.77*±3.02	C
	IPC-122 × IPC-126	8.26**±0.24	-0.50±0.68	-3.76**±1.96	-0.23±1.68	-0.75±1.44	-2.59**±3.54	C
	IPC-122 × PM	7.98**±0.17	0.10±0.56	2.78**±1.63	5.09**±1.33	-0.46±1.21	-11.55**±3.03	D
TCC (mg100g FW)	White Pale × IPC-126	6.41**±0.34	-0.76±0.80	6.06**±2.10	0.57±2.10	-1.41**±1.60	-7.17*±3.48	D
	White Pale × IPC-122	10.55**±0.64	0.18±1.62	7.16**±4.16	-0.46±4.16	12.95**±3.25	3.91**±7.00	C
	White Pale × PM	9.69**±0.50	0.20±1.28	15.45**±3.27	0.23±3.27	7.11**±2.57	9.37**±5.53	C
	IPC-126 × White Pale	7.36**±0.50	-1.47±1.06	7.05*±2.93	1.45±2.93	-4.89*±2.13	-12.48**±4.72	D
	IPC-126 × IPC-122	11.76**±0.59	0.27±1.39	10.01**±3.66	-0.86±3.66	11.19**±2.78	10.26*±6.04	C
	IPC-126 × PM	10.16±0.56	0.15±1.44	7.46*±3.66	0.78±3.66	5.05±2.88	-6.79**±6.20	D
	PM × White Pale	9.98**±0.49	0.06±1.25	15.07**±3.18	-0.13±3.18	-6.56**±2.49	8.88*±5.37	C
	PM × IPC-126	10.17**±0.59	0.12±1.31	4.99*±3.54	-1.76±3.54	-4.50±2.63	-1.55*±5.78	D
	PM × IPC-122	14.16**±0.47	0.13±1.13	8.89**±2.96	0.00±2.96	6.15**±2.27	4.46**±4.93	C
	IPC-122 × White Pale	10.42**±0.64	-0.15±1.73	8.06**±4.33	0.24±4.33	-12.9**±3.47	3.40**±7.41	C
	IPC-122 × IPC-126	11.67±0.63	0.41±1.57	12.77**±4.05	-0.64±4.05	-9.80**±3.15	15.28**±6.79	C
	IPC-122 × PM	13.97**±0.47	0.19±1.13	8.57**±3.01	-0.40±2.97	-5.50*±2.28	6.22**±5.03	C

β-CC (mg/100g FW)	White Pale × IPC-126	4.94**±0.26	-0.59±0.61	4.65**±1.62	0.44±1.62	0.36**±1.23	-5.48*±2.69	D
	White Pale × IPC-122	8.13**±0.50	0.14±1.25	5.52**±3.21	-0.35±3.21	9.99**±2.50	3.02**±5.40	C
	White Pale × PM	7.48**±0.39	0.15±0.99	11.92**±2.52	0.17±2.52	5.48**±1.98	7.22**±4.26	C
	IPC-126 × White Pale	5.68**±0.38	-1.13±0.82	5.42*±2.26	1.12±2.26	-3.82*±1.64	-9.58**±3.64	D
	IPC-126 × IPC-122	9.07±0.45	0.21±1.07	7.69**±2.82	-0.66±2.82	8.59±2.14	7.96*±4.66	C
	IPC-126 × PM	7.84**±0.43	0.11±1.11	5.73*±2.82	0.60±2.82	3.85±2.22	-5.19**±4.78	D
	PM × White Pale	7.70**±0.37	0.05±0.96	11.63**±2.45	-0.10±2.45	-5.06**±1.92	6.85*±4.14	C
	PM × IPC-126	7.84**±0.45	0.09±1.01	3.83*±2.73	-1.36±2.73	-3.43±2.03	-1.15*±4.45	D
	PM × IPC-122	10.92**±0.36	0.10±0.87	6.86**±2.28	0.00±2.28	4.74**±1.75	3.44**±3.80	C
	IPC-122 × White Pale	8.03**±0.50	-0.12±1.33	6.22**±3.34	0.19±3.34	-9.95**±2.67	2.62**±5.71	C
	IPC-122 × IPC-126	9.00**±0.49	0.32±1.21	9.83**±3.12	-0.49±3.12	-7.51**±2.43	11.83**±5.24	C
	IPC-122 × PM	10.78**±0.36	0.15±0.87	6.61**±2.32	-0.31±2.29	-4.24*±1.75	4.80**±3.88	C
LC (mg/100g FW)	White Pale × IPC-126	0.94**±0.02	0.09±0.03	0.25**±0.15	-0.11±0.14	1.06**±0.08	0.21**±0.22	C
	White Pale × IPC-122	4.47**±0.30	0.04±0.67	8.43**±1.82	0.73±1.81	10.64**±1.35	18.10**±2.96	C
	White Pale × PM	1.62**±0.10	-0.09±0.25	1.88**±0.66	-0.60±0.66	0.77**±0.50	2.48**±1.09	C
	IPC-126 × White Pale	0.89**±0.03	-0.14±0.18	2.14**±0.40	-1.57**±0.40	-1.15**±0.37	2.98**±0.77	C
	IPC-126 × IPC-122	4.60**±0.26	0.52±0.63	7.39**±1.67	-0.71±1.67	10.67**±1.28	23.12**±2.77	C
	IPC-126 × PM	1.55**±0.11	0.41±0.20	1.90*±0.62	-1.01±0.62	0.91**±0.40	6.19**±0.93	C
	PM × White Pale	1.47**±0.10	0.03±0.12	1.34**±0.50	-1.60**±0.50	-0.90**±0.25	5.95**±0.67	C
	PM × IPC-126	1.63**±0.12	-0.06±0.28	2.60**±0.76	-0.53±0.76	-0.23**±0.57	5.34**±1.25	C
	PM × IPC-122	3.41**±0.22	-0.12±0.55	-0.11*±1.44	0.18±1.43	9.28**±1.11	9.48**±2.41	D
	IPC-122 × White Pale	5.60**±0.30	-0.50±0.59	8.19**±1.70	-1.16±1.70	-11.55**±1.18	15.36**±2.66	C
	IPC-122 × IPC-126	4.54**±0.27	0.00±0.65	8.15**±1.72	-0.05±1.72	-9.62**±1.32	22.24**±2.86	C
	IPC-122 × PM	4.74**±0.34	-0.92±0.71	-0.65*±1.97	0.51±1.97	11.38**±1.43	4.37**±3.17	D
TAC (mg/100g FW)	White Pale × IPC-126	41.61**±1.87	-0.58±6.23	26.35±14.55	-62.59**±14.55	85.34**±12.46	309.73**±26.03	C
	IPC-126 × White Pale	19.285**±2.27	-1.27±5.68	93.42**±14.71	2.62±14.56	-89.05**±11.38	272.33**±24.86	C
	IPC-126 × IPC-122	19.75**±2.22	1.42±6.55	117.86**±15.9	10.90±15.83	-83.66**±13.10	286.22**±27.86	C
	IPC-126 × PM	19.00**±9.55	-0.49±-0.09	108.20**±8.35	0.37±0.03	-87.50**±-8.70	312.02**±14.22	C
	PM× IPC-126	36.25**±3.74	-8.41±10.61	121.20**±26.0	9.69±25.98	69.67**±21.23	231.76**±45.07	C
	IPC-122 × IPC-126	39.25**±4.25	-0.89±10.24	105.52**±26.6	-4.27±26.64	84.71**±20.50	244.26**±44.50	C

= Mean, [*d*] = additive effects, [*h*] = dominance effects, [*i*] = additive × additive effects, [*j*] = additive × dominance effects, [*l*] = dominance × dominance effects.

** = significant (P≤0.01) and * = significant (P≤0.05) TCC-total carotenoids content; *β*-CC- *β*-carotene content LC-Lycopene content; TAC- Total anthocyanin content;

TCC-total carotenoids content; *β*-CC- *β*-carotene content; LC- Lycopene content; TAC- Total anthocyanin content;

The positive effects of dominance [*h*], dominance × dominance [*l*] gene and negative effects of additive × dominance [*j*] were responsible for total anthocyanin content in IPC-126 × White Pale, IPC-126 × IPC-122 and IPC-126 × PM crosses. The magnitude of dominance × dominance [*l*] was mainly governing this trait than dominance [*h*], additive × dominance [*j*] gene interaction in PM × IPC-126 and IPC-122 × IPC-126 cross combinations. The positive effects of additive × dominance and dominance × dominance [*l*] gene interaction were highly significant than the negative effects of additive × additive [*i*] gene interaction in White Pale × IPC-126 cross. Complimentary type of epistatic gene interactions were expressed in all cross combinations due to similar signs of [*h*] and [*l*] gene effects. These results are in line with those obtained in eggplant (SRIKANTH SABOLU *et al.*, 2014; JHA, 2013; THANGAVEL *et al*., 2011), carrot (TRAKA-MAVRONA, 1996) and tomato (CAUSSE *et al*., 2007; RODRIGUEZ *et al*., 2004). Therefore, hybrid exploitation through heterosis breeding would be successfully utilized for enrichment of anthocyanin content in all these cross combinations (HALLAUER and MIRANDA, 1988; HOLLAND, 2007; 2011).

CONCLUSION

The genetic analysis of twelve crosses showed that the additive [*d*+*i*] and non-additive [*h*+*l*] effects governed the nutritional traits which differed in different crosses. The complimentary type of epistatic gene interaction was operative in the moisture content and total solids (White Pale IPC-126 cross), total soluble solids (White Pale × IPC-122, PM × IPC-126, PM × IPC-122, IPC-122 × White Pale, IPC-122 × IPC-126 and IPC-122 × PM), total carotenoids and *β*-carotene (White Pal × IPC-122, White Pale × PM, IPC-126 × IPC-122, PM × White Pale, PM × IPC-122, IPC-122 × White Pale, IPC-122 × IPC-126 and IPC-122 × PM crosses), lycopene (in all crosses except PM IPC-122) and total anthocyanin content (White Pale × IPC-126, IPC-126 × White Pale, IPC-126 × IPC-122, IPC-126 × PM, PM × IPC-126 and IPC-122 × IPC-126 crosses) due to association of favourable alleles between parents in these crosses. The dissimilar effects of dominance [*h*] and dominance × dominance [*l*] type of gene interaction was conditioning effects in the moisture and total solids (all crosses except White Pale × IPC-126), total soluble solids (White Pale × IPC-126, White Pale × PM, IPC-126 × IPC-122, IPC-126 × PM and PM × White Pale), total carotenoids and β-carotene and lycopene (PM × IPC-122 and IPC-122 × PM crosses) content. These epistatic gene interactions and effects can be fixed in the earlier [*h*+*l*] and advanced [*d*+*i*] generation through heterosis and recurrent selection breeding strategy, receptively for nutritional traits in respective crosses. The genetic information of non-allelic gene interaction would be useful to understand and frame for enhancement of nutritional traits in tropical carrot.

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GENETIČKA ANALIZA NUTRITIVNIH SVOJSTAVA TROPSKE ŠARGAREPE (*Daucus carota* L.)

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Izvod

Šargarepa ima široku paletu boja, posebno ljubičastu, narandžastu, crvenu i žutu u zavisnosti od sadržaja antocijana, β-karotena, likopena i luteina. Zbog povećane svesti o zdravstvenoj bezbednosti hrane, povećava se potrošnja šargarepe od strane potrošača, zahvaljujući ogromnoj bioraspoloživosti vitamina, fitonutrijenata i bioaktivnih sastojaka iz šargarepe. I pored oplemenjivanja za sorte šargarepe bogate multinutritijentima, postoji potreba za proučavanjem i razumevanjem genetičkog mehanizma nutritivnih osobina, vlage, ukupnih čvrstih materija, ukupnih rastvorljivih čvrstih materija, ukupnih karotenoida, sadržaja β-karotena, likopena i ukupnog antocijana. Imajući ovo u vidu, ovo istraživanje je osmišljeno da prouči šest genetskih parametara u šest generacija od dvanaest kombinacija ukrštanja. Šest digenskih parametarskih modela jasno je pokazalo da aditivna [d], dominantna [h], aditivna × aditivna [i], aditivna × dominantna [j] i dominantna × dominantna [l] interakcija regulišu nutritivne osobine u ispitivanim ukrštanjima. Pozitivni znak dominantnosti [h] i dominantnost × dominantnost [l] rezultirao je epistatičkim interakcijama koje kontrolišu sadržaj vlage i ukupne čvrste materije, ukupno rastvorljivih čvrstih materija, ukupnih karotenoida i β-karotena, likopena (u svim ukrštanjima osim PM × IPC-122). i ukupnog sadržaja antocijana. Zbog veće frekvencije alela podeljenih [a + i] između roditelja, očigledno je da proces selekcije treba da bude odložen dok se ne postigne homozigotnost novih generacija koja se može dobiti intermatingom roditelja, a zatim cikličnom rekurentnom selekcijom i masovnom selekcijom za nutritivna svojstva sa uzastopnim kombinacijama ukrštanja. Ovaj epistatski parametar genetičke analize mogao bi se efikasno koristiti u oplemenjivanju za poboljšanje nutritivnih osobina šargarepe.

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