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Genetic Variability and Stability Analysis in Chilli (*Capsicum annuum* L.) Landraces of North-Western Himalayas †

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Abstract: The present investigation was carried out during summer seasons of 2020 and 2021 and winter season of 2020–2021 at the Experimental Farm of Regional Horticultural Research and Training Station of Dr YS Parmar University of Horticulture and Forestry Dhaulakuan, Sirmour (HP). The experimental material comprising of variable 19 chilli landraces, which are confined to the kitchen gardens, were collected from different villages of north-western Himalayas and compared with the prevalent cultivar DKC-8. These lines are better pre-adapted to weather extremes and assumed to carry different characteristics which could be better utilized in future breeding programmes, as per the revelations made through stability analysis. Green fruit yield was greatly influenced by the seasonal effects during the winter season. Magnitude of Phenotypic coefficient of variation was found higher than genotypic coefficient of variation which indicated that expression of the characters was greatly influenced by the environment. Valuable selection could be done using green fruit yield in summer seasons. Therefore, variability in the landraces is not only due to the genotype but environment also plays an important role in influencing variation. High heritability and genetic advance were recorded for number of green fruits plant^{-1} and green fruit yield plant^{-1} in summer and winter seasons. It is also inferred that both the seasons, summer and winter, could be utilized in evaluating landraces, which will certainly hasten the process of conventional breeding programme. The computation of correlation coefficients further revealed that the average fruit weight, fruit girth, fruit length and number of fruits plant^{1} had positively and significantly contributed characters towards green fruit yield plant^{-1}. Although days to 50% flowering also played a significant role in contributing to the fruit yield but the direction was negative. Path analysis for fruit yield indicated that correlations between average fruit weight, number of fruits and days to maturity were due to the direct effects of these characters which confirmed true relationship between them. Thus, direct selection for these characteristics would be effective in yield improvement. On the basis of stability analysis, deviation from linear regression (S^2di) was non-significant for all landraces in the characteristics *viz.* 50% flowering, days to maturity, number of fruits and fruit yield indicating less contribution of linear regression toward GxE interaction. Genotypes CS1, CS3 and CS10 had values of regression coefficients approaching unity. Genotypes CS7 and CS9 had values greater than unity whereas, genotypes CS2 and CS14 had values of regressions less than unity for maturity characteristics. Genotypes CS6, CS10 and CS19 had values of regressions approaching unity, genotype CS16 had values greater than unity whereas three other genotypes had values of regression coefficients less than unity for yield contributing characteristics. Genotypes possessing more than unity values were stable in favourable environments, approaching unity were stable under all kind of environments and those possessing values below unity were stable under unfavourable environments.

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1. Introduction

Chilli (*Capsicum annuum* L.) belongs to Solanaceae family. It is believed to be originated in the Latin American regions of New Mexico and Guatemala as a wild crop. The natives domesticated this crop around 5000 BC. Chilli is high in essential nutrients and bioactive compounds with antimicrobial, antioxidant, antiviral, anti-inflammatory and anticancer properties. It is a good source of vitamin C and also other vitamins i.e., A, B_1, B_2, B_3, B_6, K and minerals like iron, calcium, magnesium, potassium and thiamine (Chakrabarty et al., 2017). The genus *Capsicum* consists of approximately 35 species (Garcia et al., 2016), of which five species namely *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens* and *C. pubescens* are of commercial importance and are cultivated in different parts of the world. Chilli is considered to be a facultative cross-pollinating species and natural out-crossing up to the extent of 90 per cent does occur. Due to the long history of cultivation, out crossing nature of crop, selection and popularity of this crop sufficient genetic variability has been generated. Rich variability in morphological traits in hot pepper occurs throughout India, particularly in the south peninsular region, north eastern foot hills of Himalayas and Gangetic plains.

Native genotypes offer pre-natal advantage of adaptability. Further significance of these genotypes can be ascertained by applying bio-metrical approaches. The amount of heterogeneity present in the germplasm can be detected by using genotypic and phenotypic coefficients of variance characteristics. Heritability and genetic advance aid in assessing the role of environments in character expression and the level of improvement that can be achieved after selection. As a result, new genotypes must be characterised in order to assess variability and determine promising genotypes for future breeding programmes (Sreelathakumary and Rajmony, 2004). Chilli, being sensitive to environmental fluctuations, exhibits a large range of variations in yield. Phenotypically stable genotypes are of great importance because environmental conditions vary from season to season. Stability of a genotype is its ability to live in several different environments, so that the phenotype does not undergo much change in *per-se* performance in each environment. Determining the existence and degree of genotype x environment interaction, as well as identifying phenotypically stable genotypes with low genotype x environment interaction is important. This requires the screening of promising genotypes in a set of environmental conditions. Stable genotypes are particularly of great importance in chilli growing areas of Himachal Pradesh, where the crop is grown in varied environmental conditions. Multi environmental testing of genotypes provides an opportunity to plant breeders to identify the adaptability of a genotype to a particular environment and also the stability of the genotypes over different environments.

Stable genotypes are particularly of great importance in chilli growing areas of Himachal Pradesh, where the crop is grown in varied environmental conditions. Multi environmental testing of genotypes provides an opportunity to plant breeders to identify the adaptability of a genotype to a particular environment and also the stability of the genotypes over different environments. Although a number of varieties have been recommended for cultivation, yet the information on stability is lacking across agro-climate zones of Himachal Pradesh. Hence, the present investigation was carried out to identify high yielding stable genotypes among the various pre-adapted landraces. Therefore, the aim of current study is to put chilli landraces under evaluation for exploring their genotypic worth through stability analysis.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted at Regional Horticultural Research and Training Station of Dr YS Parmar University of Horticulture and Forestry Dhaulakuan, Sirmour (HP), India during summer and winter season of 2020 and summer season of 2021. The experimental area is located at 30°4′ North latitude and 77°5′ East longitude at an elevation of 468 m above mean sea level under low lying hills of agro climatic Zone-1 of Himachal Pradesh where summer is very hot in May-June, humid with higher temperature in July-September and winter is cool with the inception of fog during December-January while frost is experienced occasionally. The soil structure of the experimental site is gravelly loam to gravelly clay loam with a pH range of 6.85–7.04.

2.2. Experimental Material

The experimental material comprising of variable 19 chilli landraces, which are confined to the kitchen gardens, was collected from different villages of north-western Himalayas and compared with the prevalent cultivar DKC-8. The landraces along with their sources of collection have been presented in Table 1.

Table 1. List of chilli landraces along with their sources of collection.

Genotype	Source	Genotype	Source
CS1	Kando (Shillai) Sirmour (HP)	CS11	Ghasan (Shillai), Sirmour (HP)
CS2	Kuffar (Shillai) Sirmour (HP)	CS12	Bali (Shillai) Sirmour (HP)
CS3	Dimti (Shillai) Sirmour (HP)	CS13	Bhatnol (Shillai) Sirmour (HP)
CS4	Bandli (Shillai) Sirmour (HP)	CS14	Chakri (Shillai) Sirmour (HP)
CS5	Forrar (Shillai) Sirmour (HP)	CS15	Nera (Shillai), Sirmaur (HP)
CS6	Dadhas (Shillai) Sirmour (HP)	CS16	Pandhog (Shillai) Sirmaur (HP)
CS7	Dudhog (Shillai) Sirmour (HP)	CS17	Gitaddi (Shillai) Sirmaur (HP)
CS8	Aeraana (Shillai) Sirmour (HP)	CS18	Gawali (Shillai) Sirmaur (HP)
CS9	Choila (Shillai) Sirmour (HP)	CS19	Kandiyari (Shillai) Sirmour (HP)
CS10	Patan (Shillai) Sirmour (HP)	DKC-8	Department of Vegetable Science (UHF NAUNI)

CS, Collection from Sirmour.

2.3. Designs and Layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The details of experiment are mentioned below:-

- Number of landraces: 20 (including check, DKC-8)
- Design: Randomized Complete Block Design (RCBD)
- Replication(s): 3
- Spacing: 45 cm × 45 cm
- Plots Size: 2.25 m × 0.9 m (10 plants/plot)
- Source of germplasm: Indigenous Landraces of block Shillai, Sirmour

- Date of Sowing: (1) 21 January 2020
    - (2) 21 September 2020
    - (3) 21 January 2021

2.4. Nursery Raising and Field Operations

The chilli seeds were collected from different villages of Block Shillai, District Sirmour, Himachal Pradesh. The seeds of all genotypes after treating with Captan @ 2 g/kg of seed were sown in rows in well prepared nursery beds on 21 January (summer 2020) and 21 September (winter 2020) and 21 January (summer 2021). Inter-cultural operations in respect of watering, hoeing and weeding were carried out till the seedlings became ready for transplanting. The experimental field was brought to a fine tilth by ploughing followed by harrowing. FYM was incorporated and the land was leveled properly. The seedlings were transplanted on 15 March (summer 2020) and 15 November (winter 2020) and 15 March (summer 2021) and immediately after transplanting, the field was irrigated lightly. The standard cultural practices were applied as per the recommended package of practices for vegetable crops, to produce a healthy crop of chilli (Anonymous, 2020).

2.5. Observations Recorded

The observations on various horticultural characteristics under study related to plant growth, flowering, fruiting and yield were recorded. The observations pertaining to green fruit traits were recorded on five selected plants in each genotype in each replication and their means were worked out for statistical analysis. All the genotypes were evaluated for the following characteristics:

2.5.1. Days from Transplanting to 50 Percent Flowering

It was recorded as the number of days taken from the date of transplanting to the date when the first flower emerged (full bloom stage) in 50 per cent of the plants.

2.5.2. Days from Transplanting to Green Maturity

The days were counted from the date of transplanting to mature green stage.

2.5.3. Fruit Length (cm)

The polar distance of ten randomly selected green fruits at second harvest was measured by cutting a longitudinal section of the fruits from the stem end to the blossom end.

2.5.4. Fruit Girth (cm)

The green fruits used for recording the fruit length were also used for measuring the fruit girth with the help of digital vernier caliper.

2.5.5. Number of Green Fruits plant^{-1}

The green fruits harvested from each selected plants were counted at every harvest and finally summed up to work out the average number of fruits plant^{-1}.

2.5.6. Average Green Fruit Weight (g)

The total weight of harvested green fruits from five tagged plants was divided by the total number of fruits to get the average weight of single fruit in each genotype.

2.5.7. Green Fruit Yield plant^{-1} (g)

Weight of fresh marketable green fruits harvested from five selected plants at mature green stage was divided by five to work out the yield of green fruits plant^{-1}.

2.6. Statistical Analysis

The data recorded was analyzed using MS-Excel and OPSTAT. The mean values of each genotype in each replication for all the traits under study were subjected to statistical analysis as per Randomized Complete Block Design. The data collected on different characteristics was processed for the Analysis of Variance as suggested by Panse and Sukhatme (1967). The table for analysis of variance (ANOVA) was set as explained by Gomez and Gomez (1983), parameters of variability was estimated as per formula given by Burton and Devane (1953), correlation analysis were estimated as per Al-Jibouri et al. (1958) and Path coefficients analysis as per the formula suggested by Dewey and Lu (1959). For variability studies, Bartlett's chi-square test was employed to test the homogeneity of variances. The chi-square values for summer 2020 and summer 2021 data were non-significant, the data being homogeneous were pooled for these two seasons. However, when chi-square was implied on three seasons under test, the data were found heterogeneous. For stability analysis, the mean values recorded for different characteristics in respect of 20 genotypes in 3 seasons were used for analysis of variance for phenotypic stability. The methods of stability analysis used in this investigation were suggested by Eberhart and Russell (1966).

3. Results and Discussions

3.1. Variability Studies

In the present investigation, Bartlett's chi-square test has been used for testing the homogeneity of variances. Since chi-square was non-significant for summer 2020 and summer 2021 data, the data were homogeneous; therefore pooled for these two seasons. However, when chi-square was employed for the three seasons under test, the data recorded were heterogeneous; hence the inferences for winter season have been drawn separately.

3.1.1. Phenotypic and Genotypic Coefficients of Variation

For all the characteristics under study, phenotypic coefficients of variation (PCV) were greater than genotypic coefficients of variation (GCV). It indicated that the genotypic worth of any cultivar was certainly influenced by environment. During summer seasons (Table 2, Figures 1 and 2), high PCV and GCV were recorded for green fruit yield plant^{-1} (31.84%, 31.28%). Moderate amounts of PCV and GCV were observed for average green fruit weight (28.73%, 28.56%) and number of green fruits plant^{-1} (22.30%, 22.23%). In contrast, maximum PCV and GCV were observed for the green fruit yield plant^{-1} (36.23%, 36.06%) and moderate amounts of PCV and GCV were observed for average green fruit weight (29.73%, 29.54%) and number of green fruits plant^{-1} (25.08%, 25.00%) during winter season. Besides, low PCV and GCV were reported for days to 50 per cent flowering (7.61% and 7.77%) as well as days to green maturity (4.63% and 4.72%). Low PCV and GCV indicated that genotypes possessed comparatively low genetic variation for these characteristics. Hence, these characteristics cannot be used for selection programmes.

Since, GCV was in close proximity to PCV, hence, it can be deduced that the despite their prevalence, environmental effects had a meager effect on the expression of the characters. Therefore, variability in the characters is caused not only due to the genotype since the environment certainly plays an important role in creating variation among the landraces when tested under different sets of environments. High PCV and GCV green fruit yield per plant were reported by Pandit and Adhikari (2014) and Patel et al. (2015); average green fruit weight were reported by Patel et al. (2015), Nahak et al. (2018).

Table 2. Estimation of phenotypic and genotypic coefficients of variation, heritability and genetic advance for various traits in chilli.

Characters	Range		PCV		GCV		Heritability (%)		Genetic Advance	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Days from transplanting to 50% flowering	41.00–61.50	75.00–97.67	12.53	7.77	11.93	7.61	90.63	95.84	12.32	12.80
Days from transplanting to green maturity	66.00–90.50	102.00–121.67	10.36	4.72	9.91	4.63	91.57	96.17	15.41	10.33
Fruit length (cm)	4.89–12.67	4.87–12.18	22.55	22.36	21.40	20.79	90.04	86.45	3.03	2.83
Fruit girth (cm)	0.74–1.54	0.73–1.54	17.86	18.38	17.49	17.98	95.92	95.69	0.32	0.32
Number of green fruits plant^{-1}	38.93–97.42	31.14–90.92	22.30	25.08	22.23	25.00	99.37	99.42	32.78	33.31
Average green fruit weight (g)	1.85–4.93	1.79–4.79	28.73	29.73	28.56	29.54	98.85	98.77	1.72	1.75
Green fruit yield plant^{-1} (g)	119.93–352.48	98.47–317.30	31.84	36.23	31.28	36.06	96.48	99.03	131.98	137.14

PCV, Phenotypic coefficient of variability; GCV, Genotypic coefficient of variability.

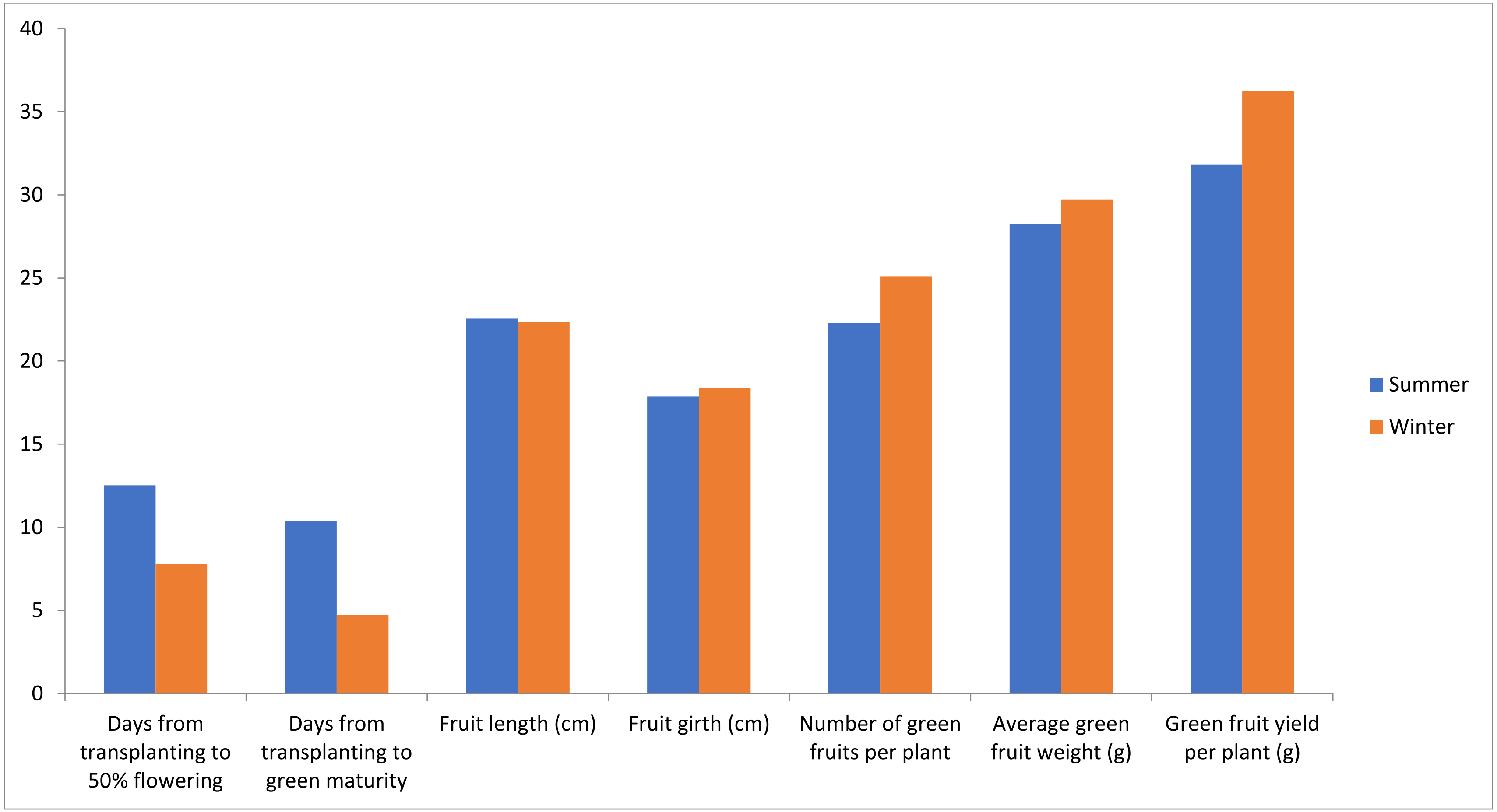

Figure 1. Phenotypic coefficient of variability for summer and winter cropping seasons in chilli landraces.

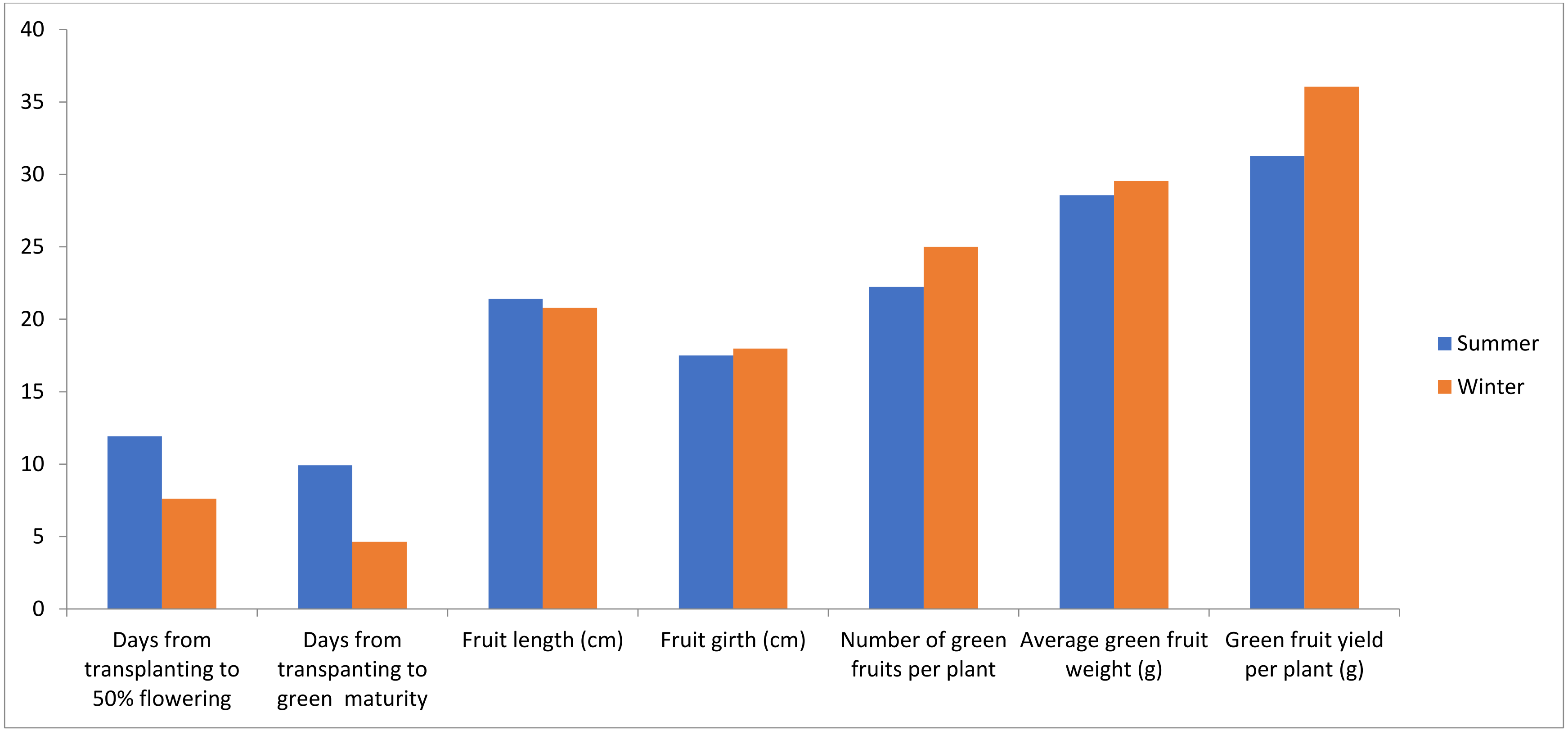

Figure 2. Genotypic coefficient of variability for summer and winter seasons in chilli landraces.

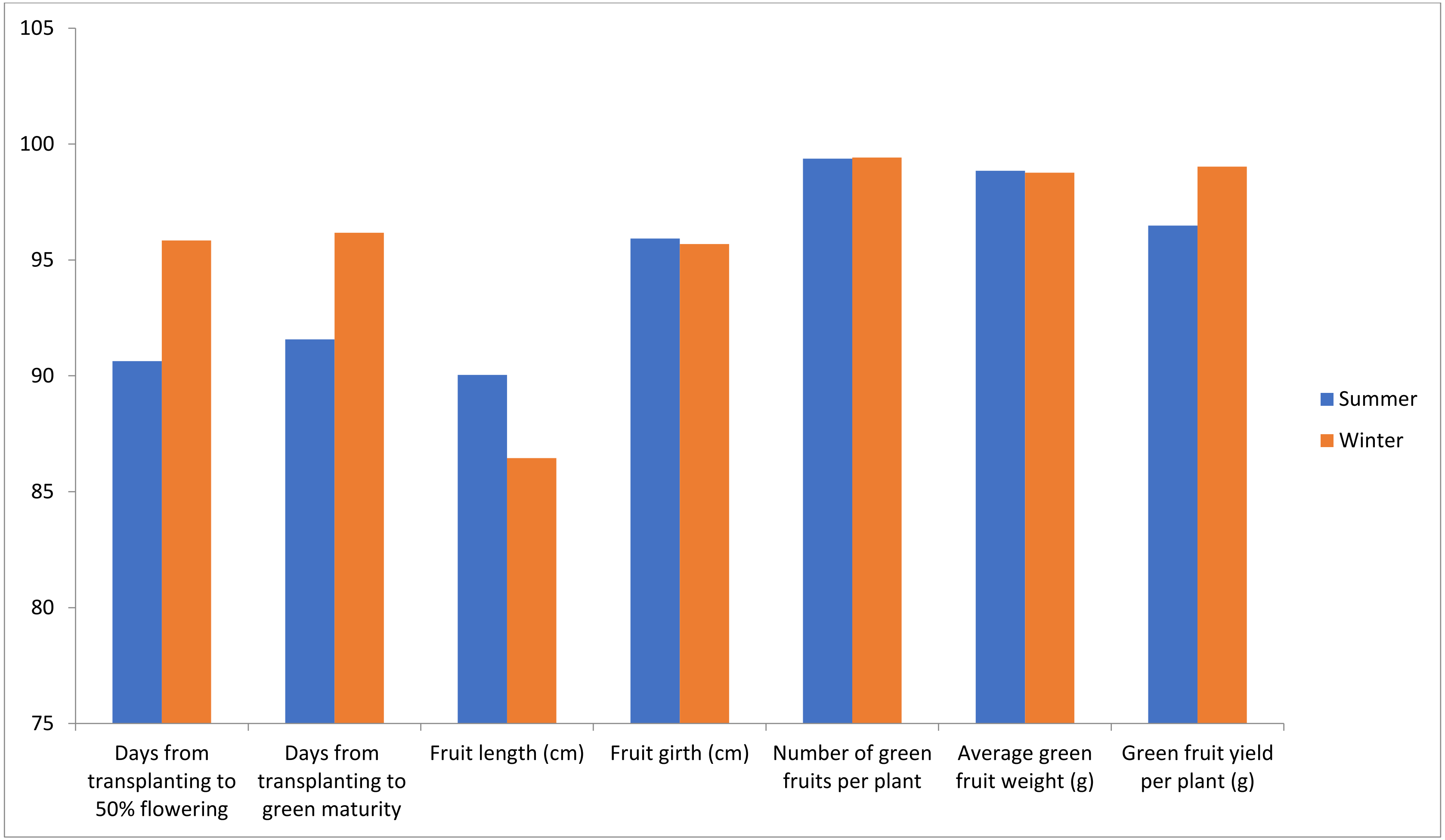

Figure 3. Heritability for summer and winter cropping seasons in chilli landraces.

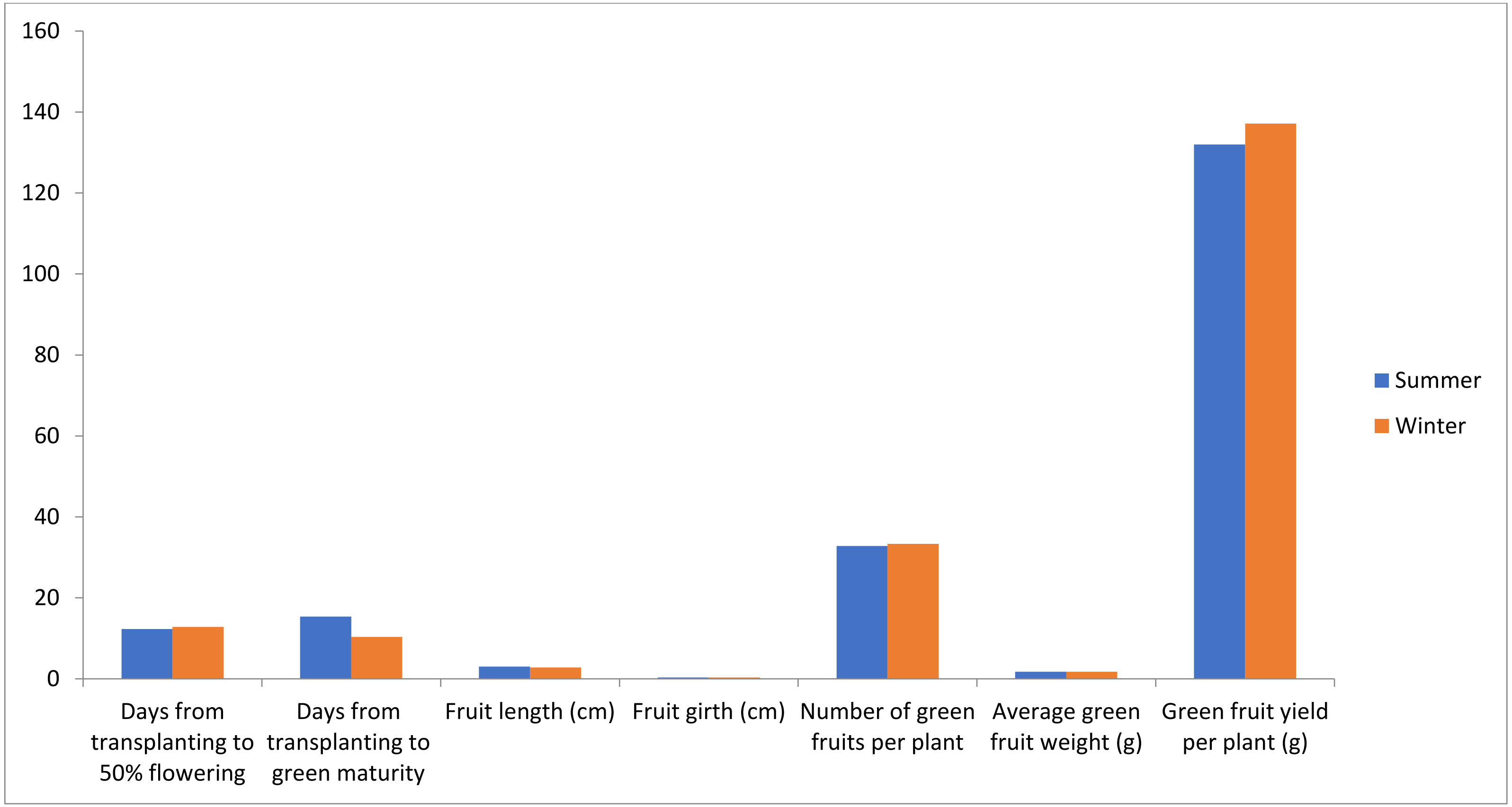

Figure 4. Genetic advance for summer and winter seasons in chilli landraces.

3.1.2. Heritability and Genetic Advance

During summer seasons (Table 2), the heritability range for the different characteristics varied from 90.04 to 99.37%. The values were greater for number of fruits plant^{-1} (99.37%), average green fruit weight (98.85%), green fruit yield plant^{-1} (96.48%), fruit girth (95.92%), days to green maturity (93.05%), days to 50 per cent flowering (90.63%) and fruit length (90.04%). On the contrary, during winter season, the heritability range for the different characteristics varied from 86.45 to 99.54%. High heritability was recorded for number of green fruits plant^{-1} (99.42%), green fruit yield plant^{-1} (99.03%), average green fruit weight (98.77%), days to green maturity (96.17%), days to 50 per cent flowering (95.84%), fruit girth (95.69%). High value of heritability was recorded during summer and winter seasons for all the characteristics which indicated their simple inheritance pattern irrespective of the genes governing them. Selection of plants based on highly heritable quantitative traits is easy and reliable. Thus, greater improvement could be expected for these characters. It is also inferred that both the seasons, summers as well as winters, can be utilized for evaluating landraces, which would certainly hasten the process of conventional breeding programme.

High heritability and genetic advance were recorded for average green fruit weight (99.84, 118.52), number of fruits plant^{-1} (93.43%, 76.85%) and fruit yield plant^{-1} (87.21%, 57.90%) by Nahak et al. (2018) and number of fruits plant^{-1} (97.45%, 127.36%) and fruit yield plant^{-1} (94.14%, 174.09%) by Jyothi et al. (2011).

As per Table 2, high values of genetic advance were recorded for green fruit yield plant^{-1} (131.98%, 137.16%), number of fruits plant^{-1} (32.78%, 33.31%) in summer and winter seasons respectively, The results were in close agreement with those of Gupta et al. (2015), Jyothi et al. (2011), Pandit and Adhikary (2014) and Janaki et al. (2015) who also reported high genetic advance for green fruit yield plant^{-1} and number of fruits plant^{-1}.

3.2. Correlation studies

The data (Tables 3 and 4) implies that green fruit yield plant^{-1} was positively and significantly correlated with fruit length, fruit girth, number of green fruits plant^{-1} and average fruit weight. However, significant negative correlation of green fruit yield was found with days to 50 per cent flowering at both genotypic and phenotypic levels. Bundela et al. (2017) and Pedada and Rawat (2020) have also reported positive and significant correlation of green fruit yield with fruit length and fruit girth; Vikram et al. (2014) also reported positive and significant correlation with fruit length, average fruit weight and fruit breadth and Patel et al. (2015) reported negative and significant correlation of green fruit yield with days to 50 per cent flowering. These coefficients revealed that average green fruit weight, fruit girth, fruit length and number of green fruits plant^{-1} were positively and significantly contributing characteristics towards green fruit yield per plant. Although days to 50% flowering also played a significant role in contributing to fruit yield, yet its direction was negative. It indicated that the early maturing genotypes (as observed in CS9 and CS7) could prove better yielders, as the earlier flowering enhanced fruiting duration.

Table 3. Genotypic and Phenotypic coefficients of correlation among different traits in green chilli conducted over summer seasons.

Characters		DFTTFPF	DFTTGM	FL	FG	NOF	AFW
DFTTGM	**G**	0.843 *					
	P	0.792 *					
FL	**G**	−0.280 *	−0.067				
	P	−0.282 *	−0.085				
FG	**G**	−0.231	−0.068	0.938 *			
	P	−0.214	−0.082	0.882 *			

NOF	**G**	−0.479 *	−0.426 *	−0.279 *	−0.257 *		
	P	−0.454 *	−0.404 *	−0.265 *	−0.252		
AFW	**G**	−0.138	0.115	0.605 *	0.612 *	−0.233	
	P	0.131	0.116	0.573 *	0.594 *	−0.234	
GFYPP	**G**	−0.511 *	−0.236	0.386 *	0.381 *	0.507 *	0.704 *
	P	−0.472 *	−0.210	0.358 *	0.369 *	0.495 *	0.705 *

DFTTFPF, Days from transplanting to 50% flowering; DFTTGM, Days from transplanting to green maturity; FL, Fruit length; FG, Fruit girth; NOF, Number of fruits Plant^{-1}; AFW, Average fruit weight; GFYPP, Green fruit yield plant^{-1}; Single star, Significant at 5 per cent level; G, Genotypic level; P, Phenotypic level.

Table 4. Genotypic and Phenotypic coefficients of correlation among different traits in green chilli in winter season.

Characters		DFTTFPF	DFTTGM	FL	FG	NOF	AFW
DFTTGM	**G**	0.672 *					
	P	0.638 *					
FL	**G**	−0.055	−0.053				
	P	−0.035	−0.041				
FG	**G**	−0.026	0.048	0.933 *			
	P	−0.030	0.055	0.853 *			
NOF	**G**	−0.582 *	−0.493 *	−0.238	−0.217		
	P	−0.566 *	−0.485 *	−0.222	−0.213		
AFW	**G**	0.147	0.213	0.586 *	0.595 *	−0.154	
	P	0.146	0.206	0.541 *	0.582 *	−0.153	
GFYPP	**G**	−0.344 *	−0.217	0.340 *	0.340 *	0.602 *	0.685 *
	P	−0.332 *	−0.215	0.314 *	0.333	0.601 *	0.686 *

DFTTFPF, Days from transplanting to 50% flowering; DFTTGM, Days from transplanting to green maturity; FL, Fruit length; FG, Fruit girth; NOF, Number of fruits Plant^{-1}; AFW, Average fruit weight; GFYPP, Green fruit yield plant^{-1}; Single star, Significant at 5 per cent level; G, Genotypic level; P, Phenotypic level.

3.3. Path Coefficient Analysis

The analysis of path coefficients (Tables 5 and 6) showed that average green fruit weight had the highest positive direct effects on green fruit yield plant^{-1} followed by number of fruits plant^{-1}, fruit length and days to green maturity. whereas, the highest negative direct effects on green fruit yield plant^{-1} were observed through fruit girth followed by days to 50 per cent flowering. The highest positive indirect effects at genotypic level were observed on average fruit weight via fruit girth and fruit length followed by fruit length via fruit girth, fruit length via average fruit weight, whereas, maximum negative indirect effects were observed on number of fruits per plant via days to 50 per cent flowering. The findings are in consonance with the inferences drawn by Bijalwan and Mishra (2014), Pujar et al. (2014), Hasanuzzaman and Golam (2011), Patel et al. (2015), Vidya et al. (2018) and Krishnamurthy et al. (2016). The residual effect at genotypic level was observed to be 0.02073. Path analysis for green fruit yield linked the correlations between average fruit weight, number of fruits and days to green maturity to the direct effects of these characters confirming true relationship between them. Thus, the direct selection for these characteristics would be effective in yield improvement.

Table 5. Estimates of direct and indirect effects of different traits on yield of green chilli in summer seasons.

Characters	DFTTFPF	DFTTGM	FL	FG	NOF	AFW	Genotypic Correlation (r_g) with GFYPP
DFTTFPF	**−0.038**	0.003	−0.064	0.039	−0.338	−0.114	−0.51 *
DFTTGM	−0.032	**0.004**	−0.015	0.011	−0.299	0.095	−0.23
FL	0.010	−0.0003	**0.229**	−0.158	−0.196	0.500	0.38 *
FG	0.009	−0.0003	0.215	**−0.169**	−0.181	0.507	0.38 *
NOF	0.018	−0.002	−0.064	0.043	**0.704**	−0.193	0.50 *
AFW	0.005	0.0005	0.139	−0.103	−0.164	**0.828**	0.70 *

Residual effect = 0.02073; r_g = Genotypic correlation coefficient; Diagonal bold values are direct effects DFTTFPF, Days from transplanting to 50% flowering; DFTTGM, Days from transplanting to green maturity; FL, Fruit length; FG, Fruit girth; NOF, Number of fruits Plant^{-1}; AFW, Average fruit weight; GFYPP, Green fruit yield plant^{-1}.

Table 6. Estimates of direct and indirect effects of different traits on yield of green chilli in winter season.

Characters	DFTTFPF	DFTTGM	FL	FG	NOF	AFW	Genotypic Correlation (r_g) with GFYPP
DFTTFPF	**−0.047**	0.014	−0.010	0.004	−0.418	0.114	−0.34 *
DFTTGM	−0.032	**0.021**	−0.010	−0.007	−0.354	0.164	−0.21
FL	0.003	−0.001	**0.188**	−0.131	−0.171	0.452	0.34 *
FG	0.001	0.001	0.175	**−0.140**	−0.156	0.459	0.34 *
NOF	0.027	−0.010	−0.044	0.030	**0.718**	−0.119	0.60 *
AFW	−0.007	0.005	0.110	−0.083	−0.111	**0.771**	0.68 *

Residual effect = 0.02073; r_g = Genotypic correlation coefficient; Diagonal bold values are direct effects DFTTFPF, Days from transplanting to 50% flowering; DFTTGM, Days from transplanting to green maturity; FL, Fruit length; FG, Fruit girth; NOF, Number of fruits Plant^{-1}; AFW, Average fruit weight; GFYPP, Green fruit yield plant^{-1}.

3.4. Stability Analysis

A genotype does not exhibit the same phenotypic features under diverse environments. GxE interactions are important for plant breeders in producing stable hybrids (Eberhart and Russell, 1966). Plant breeders are primarily concerned with improving productivity by multiplying the crop performance variations. Stability becomes quintessential in this situation.

3.4.1. Analysis of Variance for Phenotypic Stability

The pooled data over environments were analysed to estimate the interaction effects between genotypes × environment. The mean sum of squares for phenotypic stability for various characteristics has been shown in Table 7. The mean sum of squares due to genotypes, environments and genotypes × environment interaction was significant for all the characteristics. Environment (linear) mean sum of squares were significant for all the characteristics when tested against pooled deviation. Genotypes × environment (linear) interactions were also significant for all characteristics except plant height and green fruit yield per plant. The significance of mean sum of squares due to genotypes, environments, genotypes × environment interactions and Environment (linear) has also been reported by Zewdiel and Poulos (1996), Datta and Dey (2009) and Raghavendra et al. (2017).

Table 7. Pooled analysis of variance for stability of characters across seasons.

Source of Variation	df	DFTTFPF	DFTTGM	FL (cm)	FG (cm)	NOF	AFW (g)	GFYPP (g)
Genotypes	**19**	112.20 *	117.74 *	7.26 *	0.08 *	769.82 *	2.15 *	13009.36 *
Environment	**2**	6171.32 *	6664.14 *	0.13 *	0.001 *	321.21 *	0.02 *	3532.90 *
Genotype × Environment	**38**	4.61 *	17.75 *	0.02 *	0.0001 *	2.39 *	0.004 *	85.80 *
Environment (Linear)	**1**	12342.63 *	117.74 *	0.26 *	0.002 *	642.42 *	0.044 *	7065.81 *
Environment × Genotype (Linear)	**19**	8.67 *	6664.14 *	0.02 *	0.0001	4.38 *	0.007 *	93.19
Pooled deviation	**20**	0.53	17.75	0.01	0.000	0.38	0.001	74.49

* Significant at 5 per cent level of significance; df, degree of freedom; DFTTFPF, Days from transplanting to 50% flowering; DFTTGM, Days from transplanting to green maturity; FL, Fruit length; FG, Fruit girth; NOF, Number of fruits Plant^{-1}; AFW, Average fruit weight; GFYPP, Green fruit yield plant^{-1}.

3.4.2. Maturity Characteristics

Maturity characteristics *viz.* 50% flowering and days taken to green maturity were studied for stability analysis and the data presented in Table 8 showed that deviation from linear regression (S^2di) was non-significant for all the genotypes indicating less contribution of linear regression toward G × E interaction. Genotypes CS7, CS9, CS13, CS15, CS10, CS1, CS3 and CS6 had mean values less than population mean. Among various genotypes CS1, CS3, and CS10 had values of regression nearing unity (bi = 1) which indicated that these genotypes are stable in performance across all environments. Genotypes CS7 and CS9 were responded to favourable environments because values of regression coefficients greater than unity (bi > 1) whereas genotypes CS2 (flowering) and CS14 (maturity) were responded to unfavourable environments as evident from values of regression coefficients which were less than unity. Raghavendra et al. (2017) also reported that one hybrid had values of regressions greater than unity and two hybrids had values nearing unity, whereas another had values less than unity.

Table 8. Stability parameters for days from transplanting to 50% flowering and days from transplanting to green maturity.

Genotypes	Days from Transplanting to 50% Flowering			Days from Transplanting to Green Maturity		
	Mean	**S^2d_i**	**b_i**	**Mean**	**S^2d_i**	**b_i**
CS1	60.44	−0.90	0.95	85.78	−0.32	1.04
CS2	64.56	−0.81	0.80	84.56	−0.49	1.13
CS3	56.33	0.17	0.95	82.67	−1.38	1.01
CS4	65.67	−0.90	0.97	90.44	−1.51	1.20
CS5	70.89	−0.78	0.98	96.11	−1.36	0.74
CS6	62.56	−0.80	1.02	88.89	−0.80	1.16
CS7	52.89	−0.56	1.17	80.00	−1.22	1.33
CS8	73.56	−0.58	1.19	100.89	0.02	0.99
CS9	53.11	−0.90	1.19	83.11	0.22	1.28
CS10	60.89	−0.25	1.02	83.22	−1.53	1.03
CS11	70.22	−0.79	1.14	94.56	−1.50	0.70
CS12	65.89	−0.80	1.02	94.56	−1.38	1.10
CS13	55.11	−0.56	1.05	83.56	−1.17	1.43
CS14	64.33	−0.29	0.81	84.78	−1.45	0.82
CS15	55.22	−0.90	1.02	82.44	0.23	1.18
CS16	63.33	0.15	0.82	92.00	−1.46	0.59

CS17	70.33	−0.23	1.09	99.33	−0.94	0.90
CS18	64.33	2.27	0.95	91.78	3.20	0.79
CS19	65.78	0.25	0.95	93.56	−1.53	0.81
DKC−8	67.89	−0.59	0.98	95.22	−1.45	0.80
Mean	**63.17**			**89.37**		

bi, regression coefficient; S^2d_i, squared deviation from linearity of regression.

3.4.3. Yield Characteristics

3.4.3.1. Fruit Length (cm), Fruit Girth (cm) and Average Fruit Weight

The perusal of data (Table 9) indicated that deviation from linear regression was significant for all the genotypes. Among various genotypes CS5, CS8, CS9, CS10, CS12, CS15, CS16, CS18 had mean values greater than population mean for characteristics *viz.* fruit length, fruit girth and average fruit weight and exhibited values of regression greater or less than one. However their performance was unpredictable over environments because the deviation from linear regression was significant indicating that these parameters were influenced more by genetic components than by environmental components.

Table 9. Stability parameters for fruit length (cm) and fruit girth (cm).

Genotypes	Fruit Length (cm)			Fruit Girth (cm)			Average Green Fruit Weight (g)		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
CS1	6.48	−0.61	−0.12 *	0.85	1.26	−0.003 *	1.86	2.13	−0.004 *
CS2	6.46	2.66	−0.13 *	0.84	0.53	−0.001 *	1.97	1.42	−0.003 *
CS3	6.80	1.58	−0.13 *	0.87	0.23	−0.005 *	2.21	0.51	−0.003 *
CS4	7.92	2.99	−0.12 *	0.94	−0.08	−0.008 *	2.46	3.43	−0.002 *
CS5	7.35	2.30	−0.12 *	0.94	2.16	−0.001 *	3.34	4.64	−0.004 *
CS6	5.77	3.18	−0.11 *	0.81	−0.17	−0.004 *	2.53	−1.79	−0.003 *
CS7	7.43	−0.10	−0.03 *	0.84	0.53	−0.008 *	1.83	0.79	−0.002 *
CS8	7.53	1.07	−0.13 *	0.98	1.58	−0.002 *	4.32	−0.379	0.001 *
CS9	12.51	3.49	−0.13 *	1.54	0.83	−0.003 *	4.88	2.58	−0.003 *
CS10	7.54	0.68	−0.13 *	0.90	2.32	−0.002 *	3.55	1.50	−0.003 *
CS11	7.27	1.70	−0.13 *	0.90	0.36	−0.005 *	2.77	−1.37	−0.004 *
CS12	5.29	0.12	−0.13 *	0.81	1.34	−0.005 *	3.11	2.54	−0.003 *
CS13	4.88	0.12	−0.13 *	0.74	0.73	−0.009 *	2.88	2.573	−0.001 *
CS14	6.21	0.19	−0.13 *	0.85	1.64	−0.007 *	2.11	0.77	−0.001 *
CS15	8.16	−0.09	−0.13 *	0.86	−0.72	0.002 *	4.32	−2.69	−0.004 *
CS16	7.79	0.15	−0.13 *	0.87	−1.19	−0.008 *	3.26	0.1	−0.003 *
CS17	8.41	0.08	−0.13 *	0.93	4.56	−0.005 *	2.60	1.65	−0.002 *
CS18	6.58	0.06	−0.13 *	0.83	1.26	−0.008 *	3.24	0.67	0.003 *
CS19	7.15	0.20	−0.13 *	0.88	2.53	−0.003 *	2.65	0.46	−0.001 *
DKC−8	6.44	0.22	−0.13 *	0.82	0.29	−0.009 *	2.66	0.46	−0.003 *
Mean	**7.20**			**0.90**			**2.93**		

bi, regression coefficient; S^2d_i, squared deviation from linearity of regression.

3.4.3.2. Number of Green Fruits plant^{-1} and Green Fruit Yield plant^{-1}

The data in Table 10 shows that deviation from linear regression (S^2di) was non-significant for all the genotypes indicating less contribution of linear regression toward G x E interaction. Genotypes CS10, CS15, CS6 and CS19 had mean values greater than the population mean for characteristics *viz.* number of green fruits, and green fruit yield per plant. Among various genotypes, CS6, CS10, and CS19 had values of regression coefficients near unity (bi = 1) which indicated that these genotypes were stable in performance across all environments. Genotype CS16 responded to favourable environments because values of regression coefficients were greater than unity (bi > 1) whereas CS7 and CS10 were responsive to unfavourable environments as evident from values of regression coefficients which were less than one. Raghavendra et al. (2017) also reported that one hybrid had values of regressions greater than unity, two hybrids had values near unity, whereas another hybrid had values less than unity.

Table 10. Stability analysis for Number of green fruits plant^{-1} and green fruit yield plant^{-1}(g).

Genotypes	Number of Green Fruits plant^{-1}			Green Fruit Yield plant^{-1} (g)		
	Mean	**S^2d_i**	**b_i**	**Mean**	**S^2d_i**	**b_i**
CS1	61.30	−0.49	0.79	114.29	−42.94	0.7
CS2	65.47	−0.42	1.08	129.07	−38.96	0.84
CS3	83.91	−0.27	1.77	185.45	−56.01	1.31
CS4	52.93	−0.64	0.61	130.51	−28.94	0.84
CS5	36.33	−0.63	1.13	121.60	−36.10	1.50
CS6	95.25	−0.66	0.95	240.713	−46.40	0.96
CS7	72.52	−0.22	0.86	132.93	−58.20	0.65
CS8	43.38	−0.52	0.74	187.65	−47.85	0.98
CS9	69.77	0.16	0.76	340.75	−55.37	1.53
CS10	74.34	−0.20	0.9 6	264.28	−56.24	0.95
CS11	64.27	0.40	0.81	178.142	−52.90	0.46
CS12	53.70	−0.58	1.88	167.40	−36.99	2.05
CS13	89.38	0.72	0.68	257.27	−32.03	1.07
CS14	80.90	−0.66	0.99	171.02	−53.76	0.84
CS15	69.73	−0.63	0.82	301.27	−58.18	0.62
CS16	75.05	−0.63	1.63	244.88	−58.13	1.63
CS17	50.75	−0.37	1.25	144.46	454.49	1.97
CS18	89.53	0.87	0.81	285.42	446.41	0.51
CS19	80.92	−0.58	0.95	216.28	−6.19	1.01
DKC−8	80.27	−0.16	0.97	204.04	188.52	0.26
Mean	**69.48**			**200.87**		

bi, regression coefficient; S^2d_i, squared deviation from linearity of regression.

4. Conclusions

Green fruit yield in winter season was greatly influenced by the seasonal effects. The magnitude of PCV was found higher than that of GCV which indicated that the expression of the characters was greatly influenced by the environment. Valuable selection could be done using green fruit yield in summer seasons. Therefore, variability in the landraces is not solely due to genotype but environment also plays an important role in influencing variation. High heritability and genetic advance were recorded for number of green fruits per plant and green fruit yield per plant in summer and winter seasons. It is also inferred that both the seasons, summer and winter, could be utilized for evaluating landraces, which will certainly hasten the process of conventional breeding programme. The computation of correlation coefficients further revealed that characters such as average fruit weight, fruit girth, fruit length and number of fruits plant^{-1} made positive and significant contribution towards fruit yield per plant. Although days to 50% flowering also played a significant role in contributing to fruit yield, yet the direction was negative. Path analysis for fruit yield indicated that correlations between average fruit weight, number of fruits and days to maturity were due to the direct effects of these characters which confirmed true relationship between them. Thus, direct selection for these characteristics would be effective in yield improvement. On the basis of stability analysis, mean sum of squares due to genotypes, environments, Environment (linear) and genotypes × environment interaction were found significant for all the characteristics. Genotypes CS1, CS3 and CS10 were stable in performance across all environments for 50 per cent flowering and green maturity. Genotypes CS6, CS10 and CS19 were stable in performance across all environments for the number of green fruits and green fruit yield. These lines are better pre-adapted to weather extremes and assumed to carry different characteristics which could be better utilized in future breeding programmes, as per the revelations made through stability analysis.

CS9

CS15

CS18

CS10

Figure 5. Some promising genotypes of chilli.

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