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GENETIC POTENTIAL AND TRAIT ANALYSIS OF GARLIC (*ALLIUM SATIVUM* L.) LANDRACES FROM THE LOWER WESTERN HIMALAYAS

JASDEEP KAUR, BS DOGRA, NIKHIL THAKUR* AND RISHABH KUMAR

Department of Vegetable Science, College of Horticulture and Forestry, Neri Hamirpur, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan-177001, Himachal Pradesh, India

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Abstract

Thirty-eight garlic genotypes were evaluated for their genetic variability attributes during *Rabi,* 2021-2022. Estimation of phenotypic and genotypic coefficient variation was high for stemphylium blight incidence and clove count per bulb. High heritability along with high genetic advance was observed in plant height, bulb breadth, bulb weight, number of cloves per bulb, bulb, clove length and yield per plot. Bulb yield per plot was positively and significantly associated with plant height, number of leaves per plant, bulb length and bulb breadth. Bulb weight exhibited positive and direct effect on bulb yield followed by total soluble solids, drying percentage and bulb breadth. Cluster analysis grouped the genotypes into distinct clusters, highlighting substantial genetic diversity. Principal component analysis revealed significant variability, with the first five components explaining 75.47% of the total variation. Therefore, selection based on these traits could be effective for higher bulb yield in garlic genotypes.

Introduction

Garlic (*Allium sativum* L.), belonging to the family Alliaceae, is the second most consumed bulb crop worldwide and a valuable spice in India. Its global annual production reaches 28,494,130 tons across 1,546,741 hectares. India ranks as the second-largest garlic producer after China, with an annual production of 2,910 thousand metric tonnes and a productivity rate of 8.12 tonnes per hectare (FAO 2024). Garlic cultivation spans various Indian regions, showing notable variability in quantitative and qualitative traits. As a sterile diploid species, clonally propagated for centuries, garlic has developed distinct genotypes adapted to diverse agroclimatic conditions, leading to significant phenotypic diversity (Benke *et al.* 2018). Local genotypes, particularly landraces and farmers' varieties are valued for their bioactive compounds and antioxidant properties (Tesfaye *et al.* 2021). These landraces contribute to agricultural biodiversity, offering genetic diversity, local adaptation, and nutritional benefits (Thakur *et al.* 2025). The growing demand for natural, eco-friendly products has reignited interest in landraces as sources of high-quality value-added foods. Understanding genetic variability and trait associations aids in effective breeding, with D^2 statistics identifying diverse parental lines. The aim of this study was to evaluate garlic genotypes for low-hill conditions in Himachal Pradesh.

Materials and Methods

The experiment was conducted at the Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur, under Dr. YSP University of Horticulture and Forestry, Solan, Himachal Pradesh. Thirty-eight garlic accessions, including 37 local genotypes (LGCOHF) and one check variety (Kandaghat Selection) (Fig. 1), were collected locally from different districts of the Himachal Pradesh. The experiments were carried out in RCBD with three replicates during 2021-2022 rabi, using 1 m × 1 m plots with 50 plants at 20 cm ×10 cm spacing. Thirteen

*Author for correspondence: <nikhilthakuruhf96@gmail.com>

traits, including plant height, bulb yield, clove weight, and drying percentage were recorded. Data were analyzed using SPSS (v20) to perform variability, correlation, path analysis and principal component analysis (PCA) were conducted using PAST (v4.11).

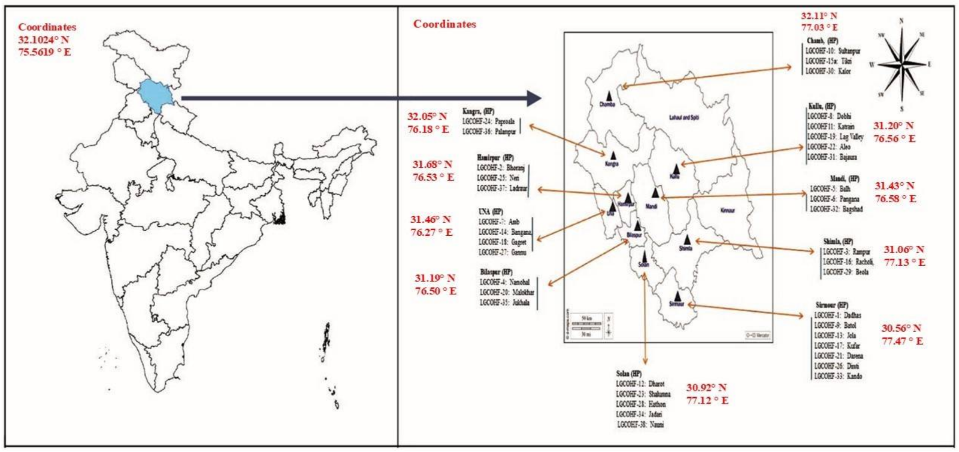

Fig. 1. Codes of the accession, collection sites and prefectures of the local genotypes of garlic.

Results and Discussion

The analysis of variance showed significant differences among the genotypes for all horticultural traits. Variability among 38 garlic genotypes for phenotypic coefficient variation (PCV), genotypic coefficient variation (GCV), heritability (h^2), and genetic advance as a percent of the mean is summarized in Table 1. PCV exceeded GCV for all the traits, indicating minimal environmental influence and scope for improvement. PCV and GCV ranged from 4.38 to 48.33% and 5.55 to 42.33%, respectively. High PCV and GCV for stemphylium blight incidence and clove count per bulb suggest strong genetic enhancement potential, consistent with Meena *et al.* (2020). Traits like plant height, bulb breadth, and clove count showed high heritability and genetic advance, indicating additive gene effects (Sharma *et al.* 2016). Moderate heritability was observed for bulb length that corroborated with Jabbes *et al.* (2012) and Ijaz *et al.* (2015).

The correlation analysis revealed higher genotypic correlation coefficients than phenotypic ones, indicating inherent associations between traits (Fig. 2). Bulb yield per plot showed positive and significant genotypic and phenotypic correlations with plant height, number of leaves per plant, bulb length, bulb breadth, bulb weight, clove weight, clove length, and days to maturity, highlighting these as key traits for selection to improve yield. These findings align with Chotaliya and Kulkarni (2017) and Thakur *et al.* (2022) who reported similar positive correlations with yield-contributing traits.

Path coefficient analysis quantified the direct and indirect effects of traits on bulb yield (Table 2). Bulb weight, total soluble solids, drying percentage, and bulb breadth showed the highest positive direct effects, making them key contributors. Negative direct effects were observed for days to maturity, number of cloves per bulb, clove length, clove weight, plant height, neck thickness, number of leaves, and bulb length. Clove weight had the strongest positive indirect effect, while the number of cloves per bulb had the highest negative indirect effect. These findings align with Bhatt *et al.* (2017) and Shibana and Menon (2019).

Table 1. Estimation of range, coefficients of variation, heritability and genetic gain of garlic.

Character	Range	Mean range ± SE(d)	Coefficients of variability (%)		Heritability (%)	Genetic gain (%)
			Genotypic	Phenotypic		
Plant height (cm)	54.09-76.48	63.15±0.51	10.62	10.67	99.16	21.79
Number of leaves per plant	6.30-8.25	7.35±0.38	5.55	8.43	43.43	7.54
Bulb length (cm)	2.78-4.60	3.68±0.24	15.83	16.88	77.17	26.83
Bulb breadth (cm)	3.34-6.34	4.57±0.15	16.18	16.66	94.38	32.38
Neck thickness (cm)	0.51-1.32	0.86±0.06	21.92	23.24	88.97	42.60
Bulb weight (gm)	18.31-39.63	30.47±1.05	18.75	19.21	95.21	37.68
Number of cloves per bulb	8.54-29.82	14.63±0.67	32.62	33.46	97.22	67.01
Clove weight (gm)	1.39-4.27	2.68±0.24	26.34	28.61	84.79	50.97
Clove length (cm)	1.12-3.36	2.77±0.12	16.79	17.60	91.00	32.99
Total Soluble Solids (B)	18.19-33.30	25.94±0.12	12.32	12.34	97.80	25.36
Drying percentage (%)	36.53-44.47	39.75±0.58	4.38	4.73	85.81	8.36
Days to maturity	195.44-23.73	217.25±0.56	4.68	4.69	89.63	9.62
Disease intensity	7.35-40.62	23.72±0.51	42.33	48.42	95.64	13.38
Bulb yield per plot (kg)	0.92-1.98	1.534±0.06	19.18	19.85	93.34	38.17

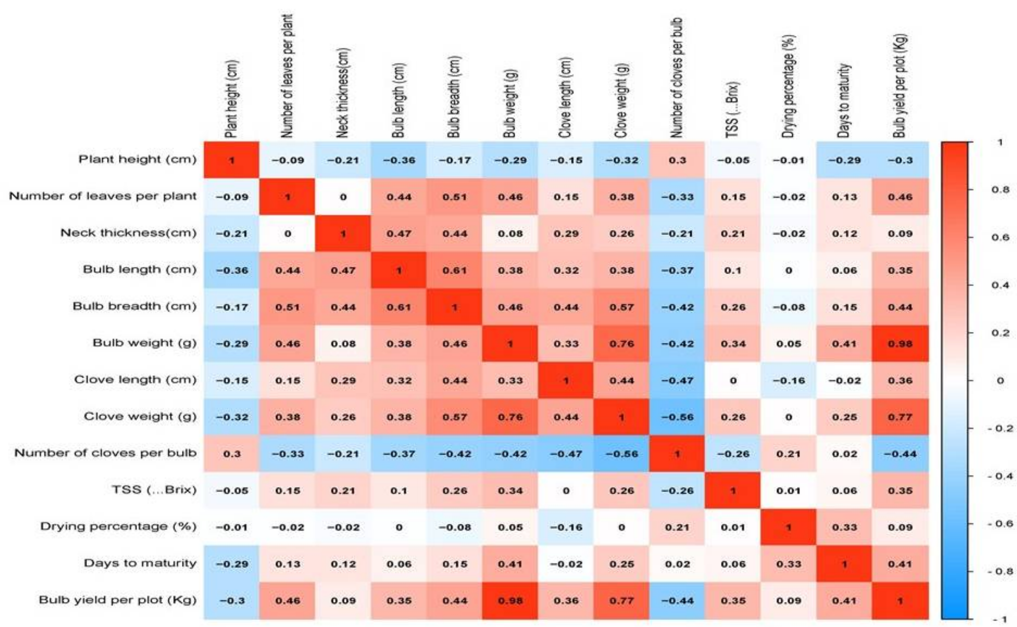

Fig. 2. Estimation of phenotypic (P) and genotypic (G) correlation coefficients for different traits.

This study revealed significant diversity among garlic genotypes, as evidenced by the dendrogram which classified the 38 cultivars into two main clusters- one with seven genotypes and the other with 31, each further divided into sub-clusters (Fig. 3). The dendrogram highlights the phenotypic diversity among genotypes, with multivariate analysis confirming variability across all 38 genotypes and significant phenotypic polymorphism. This indicates the presence of diverse morphotypes, offering opportunities to combine favorable traits in specific genotypes. These findings align with similar studies in onion by Singh *et. al.* (2014) and Sharma *et al.* (2018), indicating that the variation observed in the garlic genotypes studied is mainly due to foliage traits and bulb/clove morphological characteristics.

Table 2. Path coefficient analysis of different traits on bulb yield per plot.

	PH	NLPP	BL	BW	NT	BWT	NCPB	CW	CL	TSS	DP	DTM	BYPP
PH	**-0.021**	0.001	0.001	-0.002	0.001	-0.306	-0.011	0.007	0.004	0.004	0.000	0.012	-0.327
NLPP	0.002	**-0.004**	-0.002	0.007	0.000	0.554	0.013	-0.010	-0.004	-0.001	-0.001	-0.005	0.571
BL	0.008	-0.002	**-0.003**	0.007	-0.001	0.374	0.014	-0.009	-0.008	-0.002	0.000	-0.005	0.396
BW	0.004	-0.003	-0.002	**0.011**	-0.001	0.463	0.014	-0.013	-0.011	-0.003	-0.001	-0.008	0.475
NT	0.005	0.010	-0.002	0.005	**-0.013**	0.114	0.007	-0.006	-0.008	0.006	0.000	-0.008	0.13
BWT	0.006	-0.002	-0.001	0.005	0.000	**0.993**	0.015	-0.018	-0.010	0.003	0.001	-0.017	1.000
NCPW	-0.007	0.002	0.001	-0.005	0.001	-0.444	**-0.034**	0.013	0.012	0.005	0.003	0.001	-0.467
CW	0.007	-0.002	-0.001	0.007	-0.001	0.796	0.020	**-0.022**	-0.012	0.003	0.000	-0.013	0.809
CL	0.003	-0.001	-0.001	0.005	-0.001	0.407	0.017	-0.011	**-0.025**	0.000	-0.003	0.001	0.421
TSS	-0.002	0.000	0.000	-0.001	0.000	0.081	-0.004	-0.001	0.000	**0.039**	0.002	-0.008	0.107
DP	0.000	0.000	0.000	-0.001	0.000	0.071	-0.007	-0.001	0.004	0.005	**0.016**	-0.010	0.08
DTM	0.007	-0.001	0.000	0.002	-0.001	0.449	0.001	-0.008	0.001	0.008	0.004	**-0.038**	0.442

Residual effect: 0.00456

PH: Plant height, NLPP: Number of leaves per plant, BL: Bulb length, BB: Bulb breadth, NT: Neck thickness, BWT: Bulb weight, NCPB: Number of cloves per bulb, CW: Clove weight, CL: Clove length, TSS: Total soluble solids, DP: Drying percentage, DTM: Days to maturity and BYPP: Bulb yield.

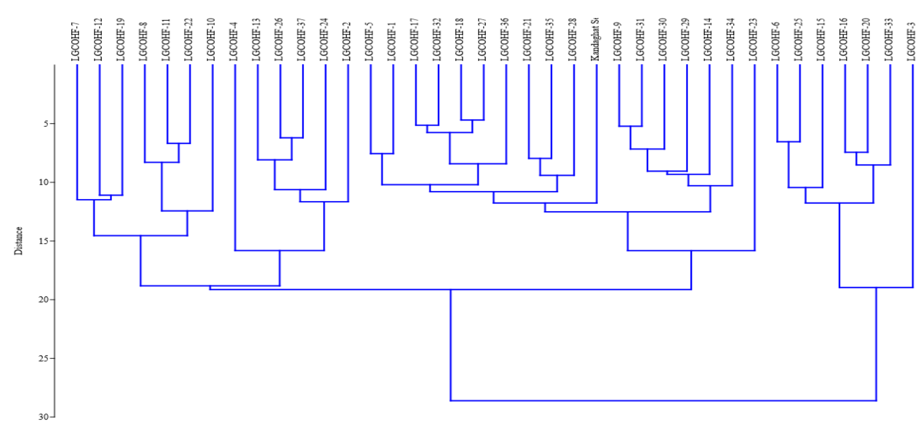

Fig. 3. Dendrogram visualization of 38 garlic genotypes based on different characters.

Principal component analysis (PCA) identified five significant components, accounting for 75.47% of the total variation (Table 3). PC1, contributing 36.95% of the variance, was predominantly influenced by clove weight and bulb yield per plot. PC2 (13.01%), PC3 (9.94%), PC4 (7.98%), and PC5 (7.60%) were associated with days to maturity, neck thickness, plant

Table 3. Principal component analysis of different garlic genotypes based on different qualitative and quantitative characters.

	PC1	PC2	PC3	PC4	PC5
Eigen Value (Root)	4.80	1.69	1.29	1.04	1.00
% Var. Exp.	36.95	13.01	9.94	7.98	7.60
Cum. Var. Exp.	36.95	49.96	59.89	67.87	75.47
Plant height (cm)	-0.44	-0.08	-0.40	0.51	0.12
Number of leaves per plant	0.58	0.03	-0.23	0.34	0.53
Neck thickness (cm)	0.39	-0.38	0.65	0.18	-0.28
Bulb length (cm)	0.65	-0.30	0.38	0.16	0.30
Bulb breadth (cm)	0.75	-0.27	0.14	0.29	0.19
Bulb weight (g)	0.84	0.36	-0.25	-0.06	-0.03
Clove length (cm)	0.54	-0.41	-0.04	-0.34	0.43
Clove weight (g)	0.85	0.07	-0.14	-0.13	-0.08
Number of cloves per bulb	-0.66	0.32	0.22	0.19	0.16
TSS (ºBrix)	0.38	0.09	-0.15	0.54	-0.66
Drying percentage (%)	-0.02	0.62	0.40	0.20	0.12
Days to maturity	0.34	0.66	0.36	-0.13	0.01
Bulb yield per plot (Kg)	0.85	0.37	-0.24	-0.07	-0.05

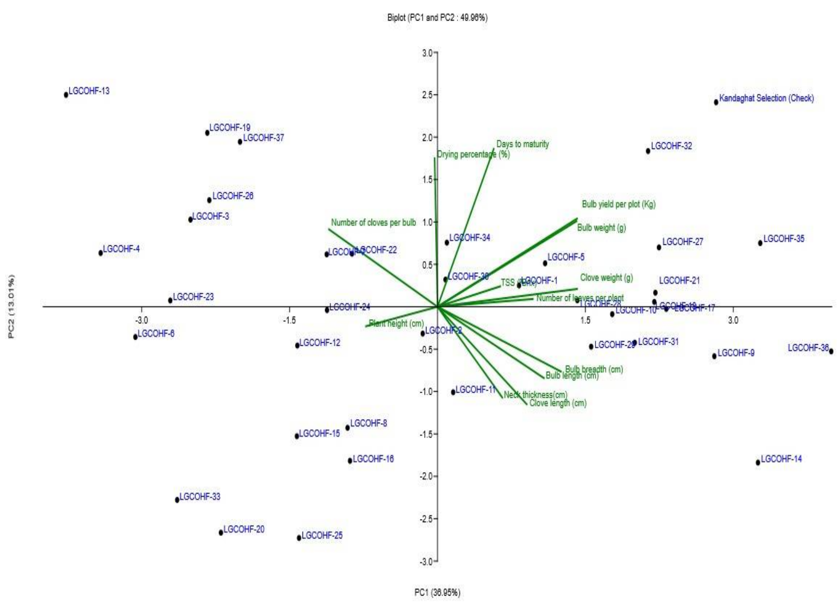

Fig. 4. PCA biplot of 38 garlic genotypes for different horticultural traits in garlic.

height, and number of leaves per plant, aligning with Mishra *et al.* (2018) and Meena *et al.* (2020). The PC1-PC2 biplot (Fig. 4) highlighted agro-morphological trait variability and genotype diversity among accessions (Fig. 1). Traits like clove weight and number of cloves per bulb, governed by additive genes, exhibited strong selection potential, consistent with Shibana and Menon (2019). High heritability and genetic advance for bulb weight, breadth, clove weight, and plant height reinforce their importance in breeding. High-performing genotypes, including

LGCOHF-35, LGCOHF-32 and Kandaghat selection, provide a robust foundation for developing superior cultivars to enhance garlic yield and quality, thereby contributing significantly to the genetic improvement and sustainability of garlic production under diverse agro-climatic conditions.

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