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ANALYSIS OF TRAIT DISTRIBUTION, SKEWNESS, AND KURTOSIS IN F_2, SOYBEAN (*GLYCINE MAX* L.) SEGREGATING POPULATION UNDER DROUGHT AND IRRIGATED CONDITIONS

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ABSTRACT

The present study was conducted to evaluate genetic variability, frequency distribution patterns, skewness, kurtosis, and normality behaviour of morpho-physiological and yield-related traits in an F_2 segregating population of soybean (*Glycine max* L.) under contrasting moisture regimes. An F_2 population derived from a cross between drought-tolerant genotype EC 602288 and drought-sensitive variety KDS 1173 was assessed at MPKV, Rahuri during Summer-2024 using a randomized block design with three replications. Substantial variability was observed for important drought-responsive and yield-contributing traits, particularly yield per plant (YPP), number of pods per plant (NPP), canopy temperature depression (CTD), plant height (PH), relative leaf water content (RLWC), and normalized difference vegetation index (NDVI) under both drought stress and irrigated conditions. Higher coefficients of variation recorded under drought stress reflected greater environmental influence on trait expression. Frequency distribution analysis exhibited predominantly positive skewness and leptokurtic tendencies for most traits under drought, indicating the occurrence of transgressive segregants. In contrast, distributions under irrigated conditions were largely near-normal and symmetrical, suggesting polygenic control with additive gene action and more stabilized trait expression in the absence of moisture stress. The Kolmogorov–Smirnov normality test further confirmed significant deviations from normality in several traits across both environments. The results emphasize the significance of evaluating distribution patterns and normality in traits to inform effective early-generation selection strategies for improving yield and drought tolerance in soybean breeding.

Key words: Soybean, Frequency distribution, Skewness and kurtosis, Kolmogorov–Smirnov test, Drought stress, Yield traits

Introduction

Soybean (*Glycine max* L. Merrill) is a legume of global agronomic and economic importance, valued for its high protein and oil content, making it a vital source for food, livestock feed, and diverse industrial applications (Bhartiya *et al*., 2024). In India, soybean is mainly cultivated under rainfed conditions, particularly across central and western agro-climatic zones. However, its yield potential is frequently limited by abiotic stresses, with drought being one of the most critical constraints, especially during sensitive reproductive stages (Rasheed *et al*., 2022).

Drought stress during key reproductive phases, such as flowering and pod filling, causes the most significant yield losses by reducing seed number, seed weight, and harvest index, while also impairing seed quality (Manavalan *et al*., 2009; Igiehon *et al*., 2021). It is estimated that soybean experiences average annual yield losses of around 40% due to drought (Specht *et al*., 1999), with reductions reaching up to 80% under severe and prolonged water deficit conditions (Guimarães-Dias *et al*., 2012; Du *et al*., 2020). With climate change increasing the frequency and severity of drought episodes, the development of drought-tolerant soybean varieties has become a critical priority to ensure stable productivity and food security.

Drought tolerance is a multifaceted quantitative trait regulated by numerous genes and influenced by a range of morphological and physiological responses (Park *et al.*, 2025). Traits such as relative leaf water content (RLWC), canopy temperature depression (CTD), normalized difference vegetation index (NDVI), specific leaf weight (SLW), root-to-shoot ratio (R/S), and harvest index (HI) have been identified as useful indicators of drought adaptation in soybean (Guendouz *et al.*, 2012). A comprehensive understanding of the genetic basis and inheritance of these traits is essential for designing effective selection strategies.

Developing high-yielding and drought-tolerant soybean varieties through conventional breeding remains a cost-effective and sustainable approach to addressing water scarcity, particularly in rainfed and terminal drought-prone regions. The efficiency of any crop improvement strategy is primarily determined by the level of genetic variability within the breeding material and the proportion of that variability governed by heritable factors (Priyanka *et al.*, 2019; Bello *et al.*, 2012). The F_2, generation, derived from hybridization between genetically contrasting parental genotypes, is a critical stage for selection as it allows for segregation and recombination of traits. It serves as a foundational resource to investigate inheritance patterns and estimate the number of genes influencing trait expression (Mahendra, 2010; Christiana, 1996).

Trait frequency distribution in segregating generations provides critical insights into the genetic control and underlying gene action. The use of histograms and statistical descriptors such as skewness and kurtosis enables breeders to interpret whether traits are under additive, dominant, or epistatic control (Patricia *et al.*, 1988; Fisher *et al.*, 1932; Robson, 1956). The direction of skewness provides insight into gene action, where positive skewness points to complementary gene effects and negative skewness implies duplicate gene involvement (Pooni *et al.*, 1977). Similarly, kurtosis reflects the peakedness of the distribution: a mesokurtic curve (kurtosis $H \approx 0$) denotes normal distribution, leptokurtic (positive) implies the control of a few major genes, and platykurtic (negative) suggests polygenic inheritance influenced by environmental factors (Kapur, 1980; Pooni *et al.*, 1977). Insight into trait distribution patterns plays a pivotal role in optimizing selection strategies. Traits with approximately normal distribution and high heritability are well-suited for selection in early segregating generations, whereas traits exhibiting skewness or deviation from normality often indicate complex genetic control, warranting selection in later generations (Lwin *et al.*, 2022).

The present investigation was undertaken to evaluate the extent of genetic variability and trait distribution behaviour for key drought-adaptive and yield-related traits in an F_2, population developed from a cross between drought-tolerant EC 602288 and drought-susceptible KDS 1173. The study conducted under contrasting moisture regimes during the summer 2024 season, aimed to estimate the distribution patterns, skewness, and kurtosis of critical traits to identify promising segregants for improving drought tolerance in soybean.

Materials and Methods

The present investigation was conducted at the Post Graduate Institute Research Farm, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, District Ahmednagar, Maharashtra, India, across four consecutive crop seasons: *Kharif* 2022, Summer 2022, *Kharif* 2023, and Summer 2023. The experiment aimed to evaluate the genetic variability and distribution behaviour of drought adaptive and yield-related traits in soybean under contrasting moisture regimes.

The breeding program was initiated during the *Kharif* 2022 season with the hybridization of two contrasting parental genotypes: drought-tolerant EC 602288 and drought-susceptible KDS 1173. The resulting F_1 seeds were grown in Summer 2023, and the parental cross was also repeated during the same season to ensure adequate F_1 seed production. Both F_1 and F_2, populations were raised in *Kharif* 2023. Subsequently, the F_2, segregating population was evaluated during Summer 2024 under two contrasting moisture regimes drought stress and irrigated control on uniformly managed fields with similar soil fertility and topography.

The experiment followed a Randomized Block Design (RBD) with three replications to ensure statistical precision. Drought stress was imposed by withholding irrigation from the R_2, stage (flower initiation) onward, while control plots received irrigation as per standard agronomic recommendations. Physiological observations were recorded between 11:00 AM and 3:00 PM on clear, cloud-free days to minimize diurnal variability.

A total of 120 individual F_2, plants were evaluated under each moisture condition. Observations were recorded for 16 morpho-physiological and yield traits, including: Days to 50% flowering (DFF), Days to physiological maturity (DPM), Plant height (PH), Number of clusters per plant (NCP), Number of pods per cluster (NPC), Number of pods per plant (NPP), Number of primary branches per plant (NPBP), Hundred seed weight (HSW), Harvest index (HI), Relative leaf water content (RLWC), Canopy temperature depression

Table 1: Descriptive statistics for morphophysiological and yield traits under drought conditions.

Trait	Mean	SD	Min	Max	Range	CV (%)	Skewness	Kurtosis	Kurtosis Type	K–S Sig.
pH	36.15	10.14	18.52	61.30	42.78	28.05	0.36	-0.82	Platykurtic	0.345
NPBP	2.38	1.20	0.00	7.00	7.00	50.22	0.42	0.87	Leptokurtic	0.001**
NCPP	12.98	4.93	4.00	31.00	27.00	38.00	0.65	0.54	Leptokurtic	0.198
NPPC	2.45	0.76	1.00	5.00	4.00	30.82	1.17	1.30	Leptokurtic	0.000**
NPPP	38.53	10.59	20.00	67.00	47.00	27.49	0.68	-0.15	Mesokurtic	0.081
100S	7.60	1.36	4.50	13.30	8.80	17.93	0.56	1.71	Leptokurtic	0.933
YPP	5.63	2.33	2.44	13.77	11.33	41.44	1.77	3.45	Leptokurtic	0.001**
HI	27.30	6.62	12.80	44.20	31.40	24.24	0.13	-0.25	Mesokurtic	0.998
DF	43.06	1.40	42.00	48.00	6.00	3.25	2.27	4.86	Leptokurtic	0.000**
DPM	102.89	1.92	100.00	106.00	6.00	1.87	0.18	-1.14	Platykurtic	0.013**
NDV	0.71	0.15	0.44	0.96	0.52	21.60	-0.14	-1.12	Platykurtic	0.372
NDVI	0.41	0.14	0.18	0.67	0.49	33.89	0.14	-1.17	Platykurtic	0.217
RLWC	46.11	9.43	23.27	59.84	36.57	20.46	-0.74	-0.47	Mesokurtic	0.016*
SLW	0.0035	0.00085	0.0011	0.0059	0.0048	24.00	-0.26	0.61	Leptokurtic	0.559
RSR	0.28	0.08	0.04	0.42	0.38	28.00	-0.62	0.54	Leptokurtic	0.646
CTD	2.96	2.20	-2.20	8.70	10.90	74.32	0.20	-0.23	Mesokurtic	0.828

Note: *, ** Significant at 5% and 1% level of significance, respectively. NDVI at R_2: Normalized difference vegetation index at full bloom stage, NDVI at R_5: Normalized difference vegetation index at Beginning seed filling stage

PH: Plant Height (cm); NPBP: No. of primary branches per plant; NCPP: No. of clusters per plant; NPPC: No. of pods per cluster; NPPP: No. of pods per plant; 100S: 100 seed wt. (g); YPP: Yield per plant (g); HI: Harvest index (%); DF: Days to 50% flowering; DPM: Days to physiological maturity; NDV: NDVI at full bloom stage; NDVI: NDVI at Beginning seed filling stage; RLWC: Relative leaf water content (%); SLW: Specific leaf weight (g/cm^2); RSR: Root to shoot ratio; CTD: Canopy temperature depression (^{o}C)

(CTD), Specific leaf weight (SLW), Normalized difference vegetation index at flower initiation stage (R_2) (NDVI-R_2), NDVI at grain filling stage (R_5) (NDVI-R_5), Root-to-shoot ratio (R/S) and Yield per plant (YPP).

Statistical Analysis

Descriptive statistics including mean, standard deviation, range, and coefficient of variation (CV) were computed for all traits using SPSS v22. Frequency distribution patterns were visualized through histograms to assess the normality of trait variation. Skewness and kurtosis statistics were estimated according to Snedecor and Cochran (1989) for understanding the nature of distribution of the F_2 population for yield contributing traits and drought adaptive traits to identify a superior segregant in the F_2 generation of cross under study. Skewness and kurtosis mean values as well as correlation analysis were computed using the 'SPSS' software programme. The test of normality of the F_2 populations was carried out by using the Kolmogorov–Smirnov (K–S) test.

Results and Discussion

Mean Performance, Range, and Coefficient of Variation (CV%)

The F_2, population of soybean cross KDS 1173 × EC 602288 displayed significant variation across 16 morpho-physiological and yield-related traits under drought and irrigated environments. The influence of water availability was clearly evident in the trait expressions. The descriptive statistics for both environments are presented in Table 1 and Table 2.

Plant height (PH) was markedly reduced under drought (mean: 36.15 cm; range: 18.52–61.30 cm) compared to irrigation (mean: 48.97 cm; range: 34.10–65.10 cm), with higher variability (CV: 28.05%) under drought. Similar suppression in height due to drought has been reported in soybean and green gram (Mariyammal *et al.*, 2019; Manju Devi *et al.*, 2025). Yield per plant (YPP) decreased significantly from 11.34 g (irrigated) to 5.63 g (drought), with a range of 2.44-13.77 g under stress. High CVs under both conditions (41.44% and 45.77%) reflect strong phenotypic variation and scope for selection. Other key yield attributes such as number of pods per plant (NPP) and hundred seed weight (HSW) also declined under drought, consistent with findings by Hussainbi *et al.*, (2023), Bassuony *et al.*, (2022) and Sumathi *et al.*, (2018).

Physiological traits like canopy temperature depression (CTD) and relative leaf water content (RLWC) were severely affected under drought, with CTD dropping from 7.36°C (irrigation) to 2.96°C and RLWC declining from 69.57% to 46.11%, confirming stress-induced impairment in water balance and transpiration cooling. CVs were highest for CTD (74.32%) and NPBP (56.35%) under irrigation, indicating considerable genotypic divergence and environmental responsiveness.

Skewness and Kurtosis Analysis

Most traits under drought exhibited positive skewness, such as YPP (1.77), NPC (1.17), and NCP (0.65), indicating a preponderance of lower-performing individuals with potential transgressive segregants (Falconer & Mackay, 1996; Kanavi *et al*., 2020). This trend aligns with findings by Manju Devi *et al*., (2025), where yield traits showed positive skewness, implying directional selection potential.

Negative skewness under drought was seen for RLWC (-0.74) and CTD (-0.23), reflecting prevalence of individuals with superior stress resilience. Kurtosis analysis revealed leptokurtic distribution for YPP (3.45) and DFF (4.86) under drought, suggesting trait control by a few major genes (Kapur, 1980; Robson, 1956). In contrast, traits such as PH and SLW showed platykurtic distributions under both conditions, implying polygenic inheritance and environmental influence (Table 1 & 2).

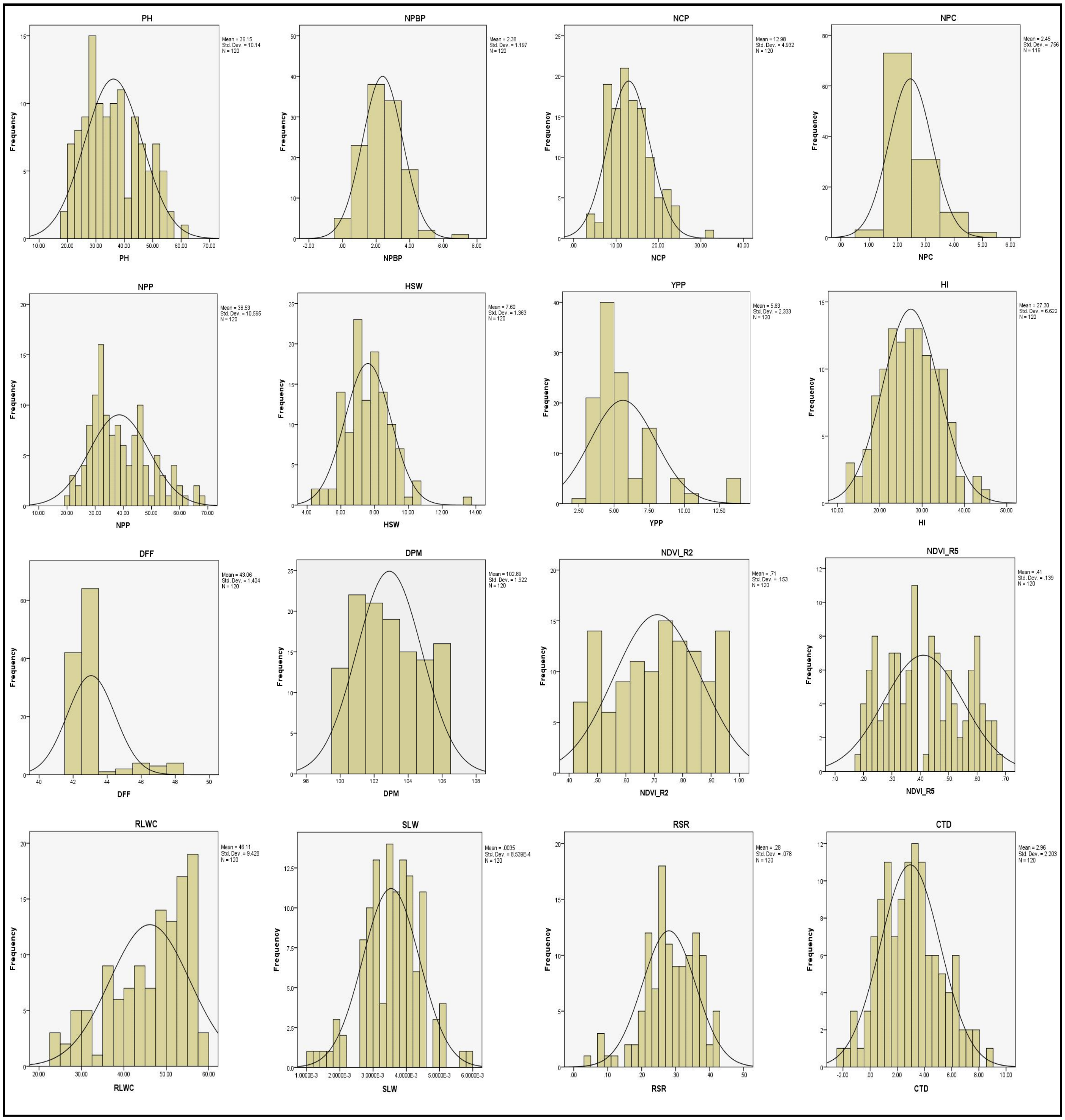

Fig. 1: Histogram Depicting Frequency Distribution of Key Traits in F_2 Soybean Population (KDS 1173 × EC 602288) under Drought Conditions.

Table 2: Descriptive statistics for morphophysiological and yield traits under irrigated conditions.

Trait	Mean	SD	Min	Max	Range	CV (%)	Skewness	Kurtosis	Kurtosis Type	K–S Sig.
pH	48.97	5.59	34.10	65.10	31.00	11.41	0.10	-0.13	Mesokurtic	0.447
NPBP	3.23	1.82	0.00	7.00	7.00	56.35	0.46	-0.73	Platykurtic	0.000**
NCPP	23.81	9.59	10.00	54.00	44.00	40.29	0.90	0.54	Leptokurtic	0.176
NPPC	3.15	0.68	1.00	5.00	4.00	21.64	-0.03	0.49	Leptokurtic	0.000**
NPPP	72.75	9.56	50.00	99.00	49.00	13.14	-0.71	0.59	Leptokurtic	0.002**
100S	11.09	2.11	7.59	14.93	7.34	19.04	0.26	-1.10	Platykurtic	0.242
YPP	11.34	5.19	2.37	28.70	26.33	45.77	0.81	0.83	Leptokurtic	0.427
HI	37.13	5.01	28.42	48.57	20.15	13.49	-0.08	-1.20	Platykurtic	0.245
DF	52.15	4.34	45.00	60.00	15.00	8.32	0.20	-1.12	Platykurtic	0.059
DPM	109.78	5.69	101.00	120.00	19.00	5.18	0.19	-1.15	Platykurtic	0.144
NDV	0.70	0.15	0.44	0.95	0.51	22.00	-0.03	-1.31	Platykurtic	0.095
NDVI	0.72	0.16	0.44	0.95	0.51	22.02	-0.20	-1.27	Platykurtic	0.078
RLWC	69.57	9.20	52.85	85.52	32.67	13.23	-0.14	-1.14	Platykurtic	0.534
SLW	0.0057	0.00089	0.0042	0.0072	0.0030	15.57	-0.19	-1.13	Platykurtic	0.175
RSR	0.18	0.045	0.10	0.26	0.16	25.46	-0.01	-1.15	Platykurtic	0.145
CTD	7.36	2.26	0.50	12.00	11.50	30.71	-0.54	0.82	Leptokurtic	0.288

Note: *, ** Significant at 5% and 1% level of significance, respectively. NDVI at R_2: Normalized difference vegetation index at full bloom stage, NDVI at R_5: Normalized difference vegetation index at Beginning seed filling stage

PH: Plant Height (cm); NPBP: No. of primary branches per plant; NCPP: No. of clusters per plant; NPPC: No. of pods per cluster; NPPP: No. of pods per plant; 100S: 100 seed wt. (g); YPP: Yield per plant (g); HI: Harvest index (%); DF: Days to 50% flowering; DPM: Days to physiological maturity; NDV: NDVI at full bloom stage; NDVI: NDVI at Beginning seed filling stage; RLWC: Relative leaf water content (%); SLW: Specific leaf weight (g/cm^2); RSR: Root to shoot ratio; CTD: Canopy temperature depression (^{o}C)

Frequency Distribution Patterns and Trait Behaviour

The distribution patterns of key morpho-physiological and yield-related traits in the F_2, population under drought and irrigated conditions are depicted in Fig. 1 and Fig. 2, respectively. These histograms visually corroborate the statistical interpretations derived from skewness and kurtosis analyses.

Under drought stress (Fig. 1), traits such as number of primary branches per plant (NPBP), number of pods per plant (NPP), and yield per plant (YPP) exhibited positively skewed and leptokurtic distributions. This indicates that a majority of individuals possessed lower values for these traits, while a few transgressive segregants exhibited higher performance. The frequency curve for YPP, in particular, demonstrates this trend, aligning with its high skewness (1.77) and kurtosis (3.45) values. Similar peaked distributions for traits like NPC and HSW suggest the involvement of major genes or directional gene action, offering scope for selection of superior drought-resilient genotypes. These findings are in agreement with those reported in other legume crops under stress conditions (Manju Devi *et al.*, 2025; Mariyammal *et al.*, 2019).

In contrast, under irrigated conditions (Fig. 2), the frequency distributions for traits such as plant height (PH), NDVI (R_2, and R_5) , and specific leaf weight (SLW) appeared more symmetrical and mesokurtic to platykurtic, suggesting polygenic control and environmental buffering. Traits like relative leaf water content (RLWC) and root-to-shoot ratio (R/S) demonstrated near-normal, bell-shaped distributions, consistent with the outcomes of the Kolmogorov–Smirnov test and implying their suitability for early-generation selection.

These visual trends affirm the numerical interpretations of trait variability, reinforcing the influence of environmental stress on segregation patterns. The observed differences in trait distribution across moisture regimes highlight the importance of considering skewness, kurtosis, and frequency patterns when designing breeding strategies aimed at enhancing drought adaptation and yield performance in soybean.

Kolmogorov–Smirnov (K–S) Test for Normality

The K–S test confirmed significant deviations from normality in several traits under drought, including YPP, NPBP, DFF, and NPC (Table 1). This non-normal distribution suggests complex gene action, possibly involving epistasis and gene × environment interaction (Tanksley, 1993; Mahendra, 2010). In contrast, traits like PH, CTD, NDVI, and RSR showed normal distribution under irrigation, supporting their use in early selection due to stable inheritance (Table 2).

Conclusion

The present study demonstrated considerable phenotypic variability and distributional divergence among morpho-physiological and yield traits in the F_2, population of soybean (KDS 1173 × EC 602288) under contrasting moisture regimes. Drought stress significantly affected trait expression, notably reducing plant height (PH), yield per plant, relative leaf water content, and canopy temperature depression. High coefficients of variation under drought for traits like CTD (74.32%), NPBP (50.22%), and YPP (41.44%) indicated substantial genetic variability and selection scope.

Frequency distribution analysis revealed predominantly positive skewness and leptokurtic tendencies under drought conditions, particularly for yield per plant (skewness = 1.77; kurtosis = 3.45), indicating transgressive segregants and potential major gene effects. In contrast, irrigated environments showed more mesokurtic to platykurtic distributions, reflecting polygenic inheritance and stabilized expression. The Kolmogorov–Smirnov test confirmed significant non-normality in several traits under drought, suggesting non-additive gene

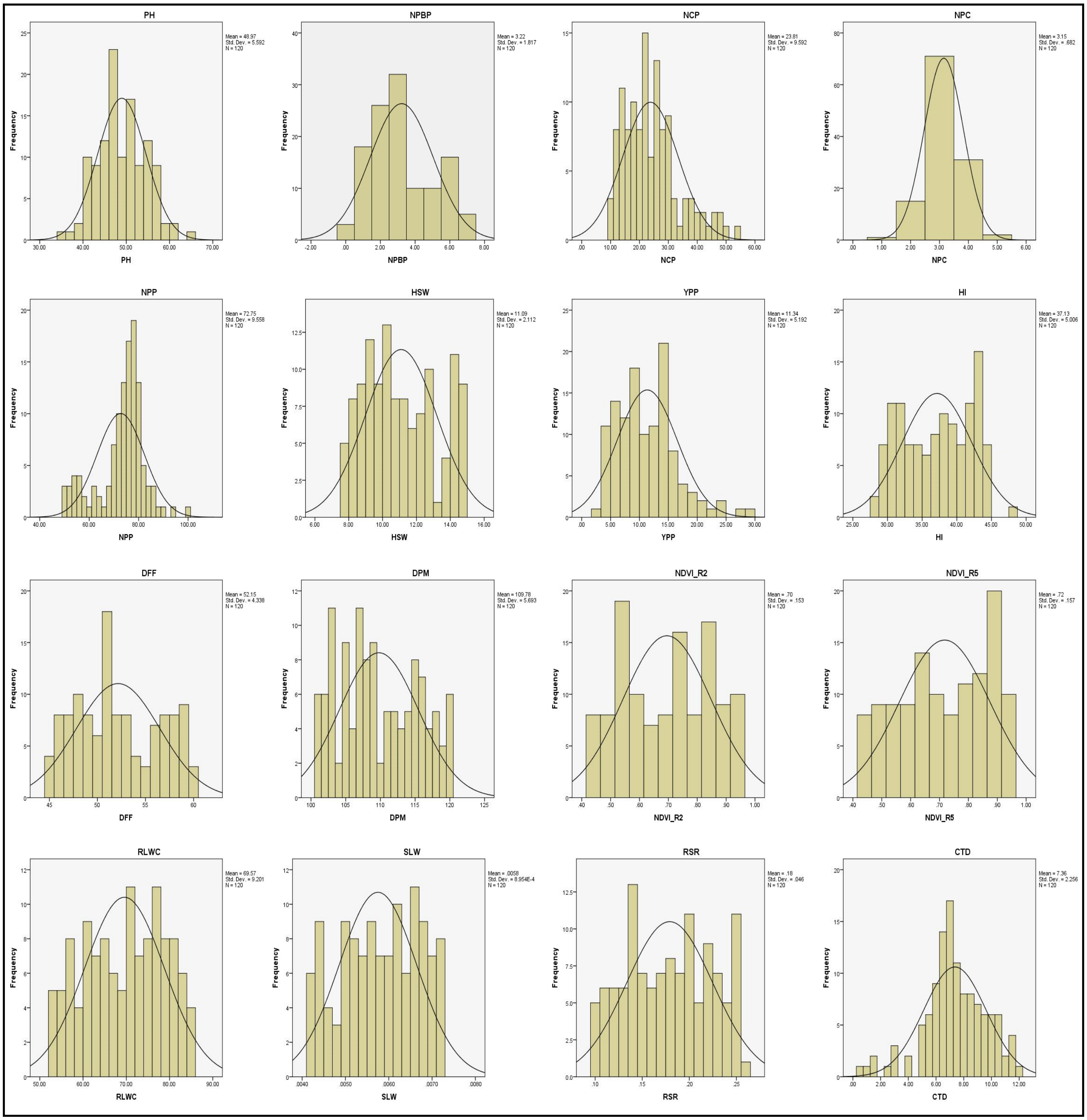

Fig. 2: Histogram Depicting Frequency Distribution of Key Traits in F_2 Soybean Population (KDS 1173 × EC 602288) under irrigated Conditions.

action and the impact of environmental stress.

Traits such as YPP, CTD, RLWC, and R/S ratio emerged as key indicators for drought adaptation. The integration of skewness, kurtosis, and normality assessments offers valuable insight for designing efficient selection strategies, particularly in early generations. These findings support the use of phenotypic distribution behaviour as a strategic tool in soybean improvement for drought resilience.

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Conflict of Interest: The authors declare no conflict of interest.

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