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Variability Studies in Soybean Genotypes under Different Water Regimes

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Soybean (*Glycine max* L.) is economically one of the most important oilseed crop worldwide which have high protein and oil content. Its productivity is frequently affected due to drought occurrence in India. Variability for root shoot traits under early seedling stage under drought stress may be important selection criteria for development of drought tolerant genotypes. The present investigation was carried out at Net house of Experimental Farm, Mandsaur University, Mandsaur. Sixty genotypes, procured from ICAR-IISR, were used to know the extent of genetic variability under different water regimes [normal, 100 ml (100%), S_1, 50 ml (50%), S_2, 25 ml (25%) and S_3,0 ml (0%)] for root-soot traits and relative leaf water content under early seedling stage. Significant genetic variability was recorded for all the traits among genotypes studied under normal and water stress conditions respectively which showed the presence of ample variability in studied material.

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High Phenotypic Coefficient of Variation than their corresponding Genotypic Coefficient of Variation for the entire trait under different water regimes denoted influence of environment on these traits. The large genetic variation found in these genotypes may be used to develop varieties with better drought tolerance behavior and used as drought donor lines in drought breeding programs. We measured high heritability for selected characters under non water stress condition (75.05% to 100%) and water stress conditions S_1 (81.40% to 100%), S_2 (85.69% to 100%) and S_3 (92.60% to 99.26%) respectively. Additive gene action interacted to control characters under different water regimes because high broad sense heritability along with high genetic advance as percentage of mean were recorded for most of traits. It is indicating that simple phenotypic selection would be effective for these traits under water stress condition.

Keywords: Heritability; soybean; variability; water regimes; water stress.

1. INTRODUCTION

Soybean (*Glycine max* L. Merrill) is the world's most important oilseed crop (Narayanan and Fallen, 2019; Mishra and Patidar, 2023; Bairagi et al., 2023). Soybean oil is secondly most widely consumed oil and rich source of protein in world (Sunaryo et al., 2016). In International market soya oil trading is next only to palm oil (Bhuva et al. 2020). It contributes to 25 % of the global edible oil, about two-thirds of the world's protein concentrate for livestock feeding. The soybean is not only known for its high total protein (5-52%) content but the quality of soy protein which is higher than that of other grain legume plant proteins (25-46%) and like animal protein (Hughes et al. 2011; Vollmann 2016).Soybean is known as the "Golden Bean" because of its health and nutritional benefits such as low Glycaemic index, low saturated fat, and cholesterol-free and is widely used as oilseed (Kumawat et al., 2023). It is primarily produced by the United States, Brazil, Argentina, China, and India (Thu et al., 2014). Soybean is also a very important *kharif* season crop of India. Kharif season is rainy season which start after onset of monsoon in India and considered from June- July to October-November. The top three soybean growing states in India are Madhya Pradesh (52 Lakh hectares; 55.40 Lakh ton), Maharashtra (45 Lakh hectares; 50.17 Lakh ton) and Rajasthan (11.13 Lakh hectares; 10.53 Lakh ton). Madhya Pradesh state is leading state in both area and production point of view in all over India (118.32 Lakh hectares; 125.82 Lakh ton) and emerged as India's Soy State (SOPA 2023; Kumawat et al., 2023; Mishra and Patidar, 2023). Madhya Pradesh has 45% share in soybean production in the country. Soybean meal is a valuable ingredient in formulated feeds for poultry and fish.

Drought stress causes a decrease of 50% of the total yield soybean production (Sunaryo et al., 2016). Water deficit affects physiological and agronomic traits of soybean plants, thus negatively influencing plant growth and development, resulting in grain yield reduction (Stolf-Moreira et al., 2010; Giordani et al., 2019, Nair et al. 2023; Kumawat et al., 2023). Scientific forecasts draw a future with dark scenarios of water restrictions around the world (Dai, 2013; Mishra and Patidar, 2023).

Information on the magnitude of variability and extent, to which desirable characters are heritable, is important for planning breeding programme and ascertaining the scope of its improvement (Sileshi, 2019). The success of phenotypic selection depends upon the range of genetic diversity available in the population, whereas estimate of heritability and genetic advance are useful in inferring the genetic factors. Root traits affect the amount of water and nutrient absorption, and are important parameters for maintaining crop yields indirectly under water stress conditions (Fenta et al., 2014; Mishra et al., 2016; Mishra et al., 2017; Vijay et al., 2018; Aski et al., 2022). Despite the importance of root traits in drought tolerance, few breeding programs take these traits into account when developing drought-tolerant soybean varieties. Information regarding the soybean genetic variability of the root traits is limited, and the exploitation of this variability can assist soybean breeding programs in the development of varieties with desired root traits for drought tolerance.

Keeping in view the above fact the aim of present study was to observe genetic variability and heritability among sixty genotypes of soybean in terms of root traits under seedling stage for the purpose of selection of parental genotypes for further crosses in order to develop progenies with drought tolerant types with increased early vigor of roots and stems.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted at Net house facility situated at Campus-I, Faculty of Agriculture Sciences, Mandsaur University, Mandsaur (M.P.). Net house and laboratory experiments were conducted to achieve the objective of present experiment.Seedlings were raised in 480 polybags during *September*-October 2022.

2.2 List of Genotypes and Experimental Design

Total sixty lines collected from ICAR- Indian Institute of Soybean Research, Indore were sown on dated 02/09/2023 in four different water regimes (nonstress-100 ml, 50 ml, 25 ml and 0 ml) using completely randomized block design with two replications for each set of experiment. The bags were filled with standard soil having mixture of 1% sand, 1% FYM and 1% clay loamy soil. Every polybag was measure by using electronic weighing balance having capacity of 20 Kg. Each bag was filled with 8 Kg soil. The soil was also treated with readymade 1/4th MS Media for obtaining healthy plants. The list of genotypes is presented in Table 1.

2.3 Water Stress Imposition

Regular irrigation was continued till two leaf stage of plants under both normal and water stress conditions (Fig. 5). After two leaf stage of plants (after 7 days), drought was imposed by applying water in proportion of 100% means 100 ml in non-water stress (control), 50% means 50 ml (stress S_1), 25% means 25 ml (stress S_2) and 0% (stress S_3) conditions till 30 days after sowing. After seed sowing at 15-20 days, the extra plants were rouged out except one to two healthy seedlings so that there will not any competition for nutrient and for healthy growth of plant for observation. The whole plant from bags were picked up by making vertical cut on bags, washed with tape water and data were observed for root length (cm), shoot length (cm), root fresh weight (gm), shoot fresh weight (gm), root dry weight (gm), shoot dry weight (gm), root shoot ratio by length, root shoot ratio by weight and relative leaf water content (%) respectively.

2.4 Statistical Analysis

The replicated values were subjected to statistical analysis of variance (ANOVA) as prescribed by Panse and Sukhatme (1978) for individual characters for each environment.

Components of variance, coefficient of variation, broad sense heritability, and genetic advance were evaluated separately for each trait both in water stress and non-stress conditions.

Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) were calculated in range of low (if it is less than 10 percent), moderate (10-20 percent) and high (If more than 20 percent) as classified by Shivasubramanian and Menon (1973).

Table 1. Name of 60 genotypes of *Glycin max* L. used for study

S.No	Name of genotypes	S.No	Name of genotypes	S.No	Name of genotypes	S.No	Name of genotypes
1	GW-34	16	GW-234	31	NRC-37(CHECK)	46	RSC-1107(CHECK)
2	GW-371(K-21C)	17	GW-196	32	GW-178	47	GW-212
3	GW-63(K-21)	18	GW-382	33	GW-87	48	NRC-138
4	GW-237(K-25)	19	GW-134	34	GW-45	49	GW-214
5	GW-155	20	AMS-2014-1(CHECK)	35	GW-89	50	NRC-142
6	GW-159	21	AGS-218	36	JS-2069	51	NRC-127
7	GW-99	22	GW-108	37	GW-207	52	JS-9560
8	GW-164	23	GW-132	38	GW-188	53	GW-203
9	GW-312	24	PK-472(CHECK)	39	GW-185	54	JS-20-116
10	GW-143	25	GW-100	40	GW-52	55	JS-2034
11	GW-152(K-21-C)	26	GW-10	41	GW-286	56	GW-253
12	GW-15 (CHECK)	27	IC-073710	42	GW-223	57	GW-225
13	GW-51(K-21)	28	GW-17	43	GW-251	58	TGX-9336E
14	GW-21	29	GW-13	44	GW-291	59	SQL-110
15	GW-161	30	GW-28	45	GW-221	60	AGS-25

The range (low-< 30%, medium-30%-60%, high> 60%) of heritability and genetic advance (GA) as percentage of mean range (low-< 10%, medium-10%-20%, and high> 20%) was calculated as suggested by Johnson et al., (1955). The data were analyzed by using OPSTAT software.

3. RESULTS AND DISCUSSION

The increasing population, abiotic factors are threatening the global food security (Saha and Choyal, 2022). The sudden change in environmental factors further reduces the water availability and causes drought stress in major agro-systems especially rain fed ecosystem worldwide. It affects severely the crop production and productivity including soybean which varies with the crop stage of the crop as well as with the local environmental conditions (Okunlola et al., 2017). Water stress affects the seed germination, vegetative and reproductive growth and maturity stage of a crop especially seedling and germination stage by reducing seedling length and seedling biomass, seedling water content, biochemical and molecular attributes depending upon the frequency and duration of drought stress (Anjum et al., 2017). The use of morpho-physiological traits in relation to drought tolerance has been suggested by many researchers (Painwadee et al. 2009) because the inheritance of these characters is simpler than pod yield. Genetic variability is essential to know response to selection pressure. It has also been reported that the magnitude of genetic variability present in base population of any crop species is important in crop improvement and must be exploited by plant breeder for yield improvement (Akram et al., 2011; Mehra et al., 2020). The information related to heritability of characters is important for plant breeders to formulate appropriate breeding strategies to achieve breeding objectives.

Results of genetic variability under non-water stress and water stress conditions have been presented in following heads:

3.1 Genetic Variability under Non-Water Stress (Normal Water) Condition

Many researchers have reported variability in root traits among soybean cultivars. This variability was observed during early growth (Manavalan et al., 2009; Fenta et al., 2014; Thu et al., 2014; Fried et al., 2018; Falk et al., 2020; Dayoub et al., 2021; Syiem *et. al.*, 2022), at flowering stage (Zhao et al., 2004; Mwamlima et al., 2019) or at maturity (Ao et al., 2010).

3.2 Analysis of Variance Non Stress

The results from ANOVA (Table2**)** in non-stress condition (100 ml water) indicated that high amount of variability was present among the genotypes for all the traits investigated because significant difference were observed among sixty genotypes. Similar results under non-water stress condition were reported by Meena et al. (2014) in chickpea for plant height and relative leaf water content, Prince et al.(2015), Falk et al. (2020), Yan et al. (2020), Mishra et al. (2021), Dayoub et al. (2021), Syiem et al. (2022) in soybean; Kumar et al.(2023) for root length, shoot length and shoot dry weight in wheat; for RWC, Bayoumi et al. (2008) in wheat and Kumar et al. (2021) in chickpea; Shankar et al., (2019) for plant height, root length, root shoot ratio by length and RWC in groundnut, Priya et al. (2021) and Reddy et al. (2023) for root length in lentil, green gram and black gram respectively. Presence of sufficient amount of variability in the studied germplasm provides ample scope for selection of superior and desired genotypes.

3.3 Genetic Variability Parameters under Non Water Stress Condition

The estimates of variability parameters for all the traits are shown in Table 3 and Fig. 1 for non-water stress condition. PCV values for all traits had generally greater, but closer values to their corresponding GCV values which indicated presence of lower environmental influence on the expression of these traits. Similar results were also reported by Kumar et al. (2023) in wheat.

The root length was ranged 5.05 cm to 18.20 cm with grand mean of 10.42 cm. The estimated values of PCV and GCV recorded were 24.48 and 21.21 per cent, respectively. High heritability (bs) 75.05 per cent coupled with medium genetic advance over percentage of mean37.85per cent were noticed for this trait. Similarly, high (More than 20%) PCV and GCV, (>60%) high heritability and high genetic advance (>30%) was recorded by Gobu et al. (2017) in eggplant, Kumar et al. (2023) in wheat; Shankar et al., 2019 in groundnut and Hoque et al. (2021) in rice and Syiem et al. (2022) in soybean under normal water condition. High heritability for this trait was also reported by Reddy et al. (2023) in green gram (89%) and black gram (89%).

Table 2. Analysis of variance (mean sum of squares) for nine characters in soybean under non-stress (normal water) condition

Source of variation	DF	Root length (cm)	Shoot length (cm)	Root fresh weight (g)	Shoot fresh weight (g)	RWC %	Root dry weight (g)	Shoot dry weight (g)	Root shoot ratio by length	Root shoot ratio by weight
Replication	1	0.09	0.00	0.000	0.047	0.74	0.000	0.001	0.001	0.007
Treatment	59	16.28**	394.02**	0.017**	0.269**	835.44**	0.0002**	0.008**	0.034**	0.046**
Error	59	1.62	2.86	0.000	0.014	1.78	0.000	0.000	0.001	0.001
Total	119	8.88	196.77	0.009	0.141	415.10	0.000	0.004	0.017	0.023

*** Significant at 1% (P= 0.01) level of significance*
** Significant at 5% (P=0.05) level of significance*

A wide significant range of variation (12.20 cm to 79.45 cm with an overall mean of 46.94 cm) was found among all the germplasm accessions for shoot length. The recorded PCV and GCV for this character were 24.59 and 24.32 per cent, respectively. Similar results of high PCV and GCV were reported by Bayoumi et al. (2008) in wheat. This character revealed high h^2 (97.85 per cent) along with high GA(49.57per cent). Similar result of high heritability for this trait was also reported by Riaz et al. (2013) in cotton; Meena et al., (2014) in chickpea. Similarly, high (10-30%) PCV and GCV, (>60%) high heritability and high genetic advance (>30%) was recorded by Gobu et al. (2017) in eggplant, Shankar et al., 2019 in groundnut, Hoque et al. (2021) in rice and Syiem et al. (2022) in soybean under normal water condition.

The root fresh weight was ranged 0.042 gm to 0.389 gm with total mean of 0.199 gm. The phenotypic coefficient of variation (38.53) and genotypic coefficient of variation (36.95), heritability (91.93 per cent) and genetic advance over percentage of mean (72.98per cent) respectively were found for this trait. Result of high GCV, PCV, heritability and high GA as percentage of mean was also noticed by Syiem et al. (2022) in soybean for root fresh weight under non-water stress condition. Similar result of high heritability for this trait was also recorded by Riaz et al. (2013) in cotton.

A wide range of variation (0.041 to 1.592 gm with an overall mean of 0.807 gm) was found among all the germplasm accessions for shoot fresh weight. The PCV (39.00), GCV (36.15), heritability (h^2) (85.95%) and genetic advance over mean of(69.05%)were recorded respectively for shoot fresh weight. Similar findings for soybean for shoot fresh weight under seedling stage were also reported by Syiem et al. (2022) in soybean in normal water. Similar result of high heritability for this trait was also found by Riaz et al. (2013) in cotton.

The physiological character, relative leaf water content (RWC) varied from 18.765 to 93.150% with an overall mean of 62.851%. The PCV (26.61), GCV (26.52), heritability (h^2) (99.36%) and genetic advance over mean of percentage(54.46%)were observed respectively for this parameter. Similar results on heritability for this trait was also obtained by Bayoumi et al. (2008) in wheat, Garg et al. (2017) in rice and Kumar et al. (2021) in chickpea.

The root dry weight ranged from 0.009 to 0.079 with an overall mean of 0.025 gm. Recorded values of PCV and GCV were 39.41 and 39.41 per cent respectively. The values of high heritability (100.00%) together with high genetic advance as per cent mean (81.19) were recorded for this trait. Similar finding on heritability for this trait was also found by Riaz et al. (2013) in cotton; Lalitha et al. (2015) in chickpea.

The grand mean of shoot dry weight was 0.130 with a range of 0.0250 to 0.300. High phenotypic (40.10%) and genotypic coefficient of variability (39.72%) along with heritability (98.13%) and genetic advance as per cent mean (81.05) were recorded for this trait. Similar PCV PCV and GCV (>30%), heritability (>60%) and genetic advance (>30%) was recorded by Kumar et al. (2023) in wheat and by Lalitha et al. (2015) in chickpea

Character, root shot ratio by length ranged from 0.101 to 1.023 with a grand mean value of 0.246. The PCV and GCV observed were 44.60 and 42.45 per cent, respectively. Heritability (bs) 90.59 per cent coupled with high genetic advance over percentage of mean83.23per cent were noticed for this trait. This is according to finding as reported by Gobu et al. (2017) in eggplant, Shankar et al. (2019) in groundnut and Hoque et al. (2021) in rice for this trait under normal water condition.

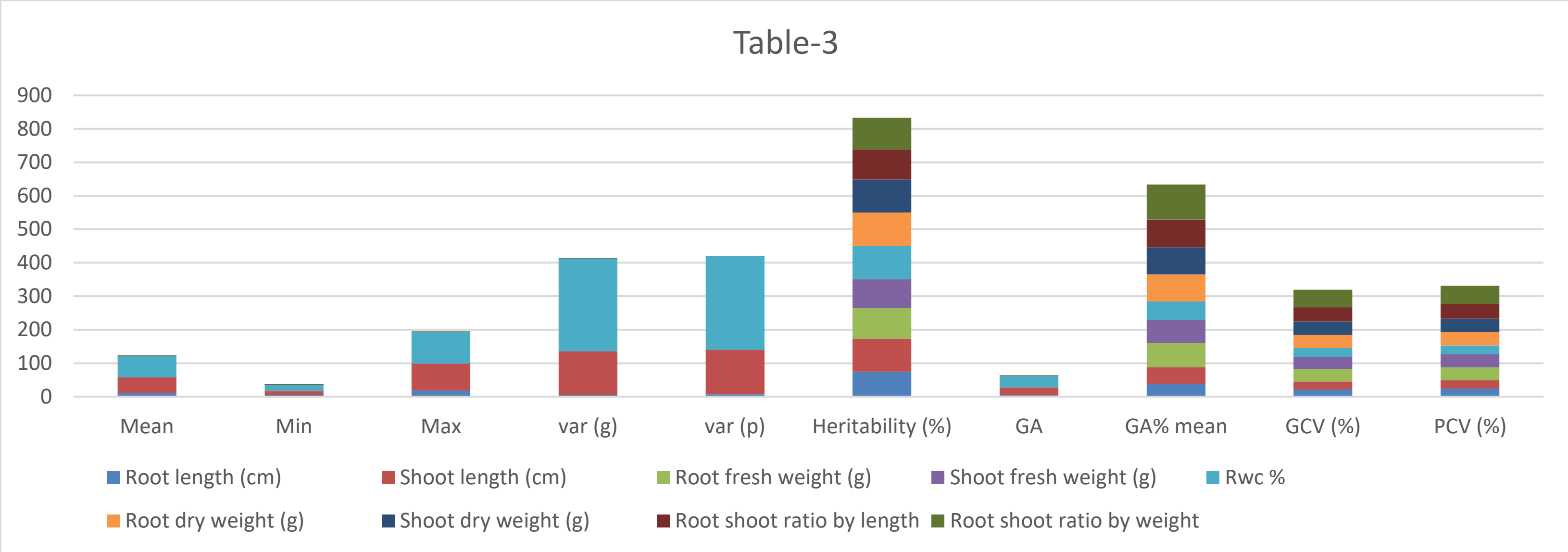

Fig. 1. Determination of mean, range and genetic variability parameters for nine traits in soybean under non-stress (normal water) condition

A perusable mean value of different genotypes of trait root shoot ratio by weight revealed that overall mean value of it was 0.234. High PCV (53.60) and high GCV (52.20) were recorded for this parameter. The high heritability (94.85%) coupled with high genetic advance (104.73%) were noticed for it.

3.4 Genetic Variability under Drought Conditions

Genetic variability for drought tolerance has been reported by many researchers in different crops like (Thu et al., 2014; Falk et al., 2020; Yan et al., 2020; Mishra et al., 2021; Dayoub et al., 2021; Bui et al., 2022 in soybean), (Raina et al., 2019; Amarapali 2022 in green gram), (Widuri et al., 2018; Langat et al., 2020 in common beans), (Ali et al., 2010 in chickpea) (Upadhyay, 2005; Songsri et al. 2009 and Painwadee et al., 2009; Thakur et al., 2013; Vaidya et al., 2015; Shankar et al., 2016 in peanut or groundnut), (Kumari et al., 2019; Aneja et al., 2021 in mustard), (Praveen et al., 2021 in sunflower) (Rajarajan et al. 2018 in sorghum), (Dutta and Borua, 2017 in rice), (Li et al., 2015 in maize), (Narayanan et al., 2014; Fernandes et al., 2020 in wheat) (Handi and Katageri, 2016 in cotton).

3.5 Analysis of Variance

Mean sum of squares of accessions in water stress condition S_1(50% water imposition), S_2 (25% water imposition) and S_3 (0% water imposition) indicated significant difference among all the genotypes for all the nine traits showed good deal of variability in the material used (Tables 4, 6 and 8). Similarly significant differences for trait RWC was reported by Bayoumi et al. (2008) in wheat, Kanvi et al. (2020) in green gram and Ajayi (2022) in cow pea; Shankar et al., (2019) for plant height, root length, root shoot ratio by length, root fresh weigh, shoot fresh weight, root dry weight, shoot dry weight and RWC in groundnut; Langat et al. (2019) for plant height in common beans (*Phaseolus vulgaris* L.); Priya et al. (2021) for root length in lentil and Wattoo et al. (2018) for relative leaf water content, root length, shoot length, root fresh weight, shoot fresh weight, root dry weight and shoot dry weight in maize.

Table 3. Determination of mean, range and genetic variability parameters for nine traits in soybean under non-stress (normal water) condition

Genotypes	Mean	Min	Max	var (g)	var (p)	Heritability (%)	GA	GA% mean	GCV (%)	PCV (%)
Root length (cm)	10.424	5.050	18.200	4.89	6.51	75.05	3.95	37.85	21.21	24.48
Shoot length (cm)	46.943	12.200	79.450	130.39	133.24	97.85	23.27	49.57	24.32	24.59
Root fresh weight (g)	0.199	0.042	0.389	0.005	0.006	91.93	0.15	72.98	36.95	38.53
Shoot fresh weight (g)	0.807	0.041	1.592	0.085	0.099	85.95	0.56	69.05	36.15	39.00
RWC %	62.851	18.765	93.150	277.89	279.67	99.36	34.23	54.46	26.52	26.61
Root dry weight (g)	0.025	0.009	0.079	0.0001	0.0001	100.00	0.020	81.19	39.41	39.41
Shoot dry weight (g)	0.130	0.025	0.300	0.0027	0.0027	98.13	0.105	81.05	39.72	40.10
Root shoot ratio by length	0.246	0.101	1.023	0.0109	0.0121	90.59	0.205	83.23	42.45	44.60
Root shoot ratio by weight	0.234	0.043	0.756	0.0150	0.0158	94.85	0.245	104.73	52.20	53.60

*** Significant at 1% (P= 0.01) level of significance*
** Significant at 5% (P=0.05) level of significance*

Table 4. Analysis of variance (mean sum of squares) for nine characters in soybean under S_1 (50% water) stress condition

Source of variation	DF	Root length (cm)	Shoot length (cm)	Root fresh weight (g)	Shoot fresh weight (g)	RWC %	Root dry weight (g)	Shoot dry weight (g)	Root shoot ratio by length	Root shoot ratio by weight
Replication	1	0.20	0.71	0.001	0.002	7.87	0.000	0.001	0.000	0.000
Treatment	59	10.40**	279.82**	0.046**	0.196**	719.33**	0.0001**	0.005**	0.015**	0.047**

Source of variation	DF	Root length (cm)	Shoot length (cm)	Root fresh weight (g)	Shoot fresh weight (g)	RWC %	Root dry weight (g)	Shoot dry weight (g)	Root shoot ratio by length	Root shoot ratio by weight
Error	59	0.74	4.11	0.001	0.013	8.36	0.000	0.000	0.001	0.001
Total	119	5.52	140.78	0.023	0.104	360.85	0.000	0.003	0.008	0.024

*** Significant at 1% (P= 0.01) level of significance*
** Significant at 5% (P=0.05) level of significance*

3.6 Genetic Variability Parameters under Water Stress Conditions

The estimates of variability parameters of all genotypes for root shoot characters under water stress have been presented in Tables 5, 7 and 9 and Figs. 2,3 and 4.

Among abiotic factors, the scarcity of water great impact on root distribution system and root length. A dry soil surface with high water stress often forces roots to increase their growth deep into the soil profile where water is more available (Adiku et al., 1996, Amarapali, 2022). The deep and dense root system show better drought tolerance by extracting water from deeper soil layers (Parameshwarappa et al., 2012)**.** The root length showed significant good amount of genetic variation under stress conditions among the genotypes used for investigation. Under stress S_1 (50% water), the range of mean was 4.55 cm to 16.10 cm with overall mean of 9.59 cm. In stress condition S_2 (25% water) the range of root length variability was observed from 3.75 cm to 16.45 cm with the grand mean of 9.55 cm. Under stress condition S_3 (0% water) highest root length was calculated by genotype NRC138 (20.50 cm) whereas lowest was recorded by GW312 (3.40 cm) with the overall mean of 0.41 cm. It indicates that germplasm lines are genetically variable. Similar increasing range of variation under water stress in comparison to normal condition was also noticed by Dayoub et al. (2021) in soybean; Raina et al. (2019) in mung bean. PCV and GCV recorded were (20.75% and 18.72%) under stress S_1 (50% water); (22.96 and 21.25 per cent) under stress condition S_2 (25% water) and (22.96 and 21.25 per cent) under stress condition S_2 (25% water) respectively. Similar high variability was reported by Manickvelu et al. (2006), Dutta and Borua (2017), Sallleh et al. (2021) in rice; Rajkumar and Fakrudin (2018) in sorghum, Shankar et al., (2019) in groundnut, Bayoumi et al. (2008) in wheat, Mishra and Sharma, (2015) in muskmelon, Wattoo et al. (2019) in maize. High heritability along with high genetic advance as percentage of mean was observed (81.40% and 34.80%) under stress S_1 (50% water); (85.69%

Table 5. Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under S_1 (50% water) stress condition

Genotypes	Mean	Min	Max	var (g)	var (p)	Heritability (%)	GA	GA% mean	GCV (%)	PCV (%)
Root length (cm)	9.587	4.550	16.100	3.22	3.96	81.40	3.34	34.80	18.72	20.75
Shoot length (cm)	47.468	15.050	74.000	91.90	96.01	95.72	19.32	40.70	20.20	20.64
Root fresh weight (g)	0.198	0.044	0.995	0.015	0.016	95.15	0.25	123.88	61.65	63.20
Shoot fresh weight (g)	0.769	0.072	1.727	0.061	0.074	82.81	0.46	60.32	32.18	35.36
Rwc %	63.320	20.555	93.265	236.99	245.35	96.59	31.17	49.22	24.31	24.74
Root dry weight (g)	0.021	0.006	0.044	0.0001	0.0001	76.92	0.014	64.72	35.82	40.84
Shoot dry weight (g)	0.123	0.041	0.298	0.0018	0.0018	100.00	0.087	70.55	34.25	34.25
Root shoot ratio by length	0.217	0.101	0.641	0.0049	0.0055	90.08	0.137	63.20	32.32	34.06
Root shoot ratio by weight	0.205	0.032	0.942	0.0153	0.0166	92.63	0.246	119.97	60.51	62.87

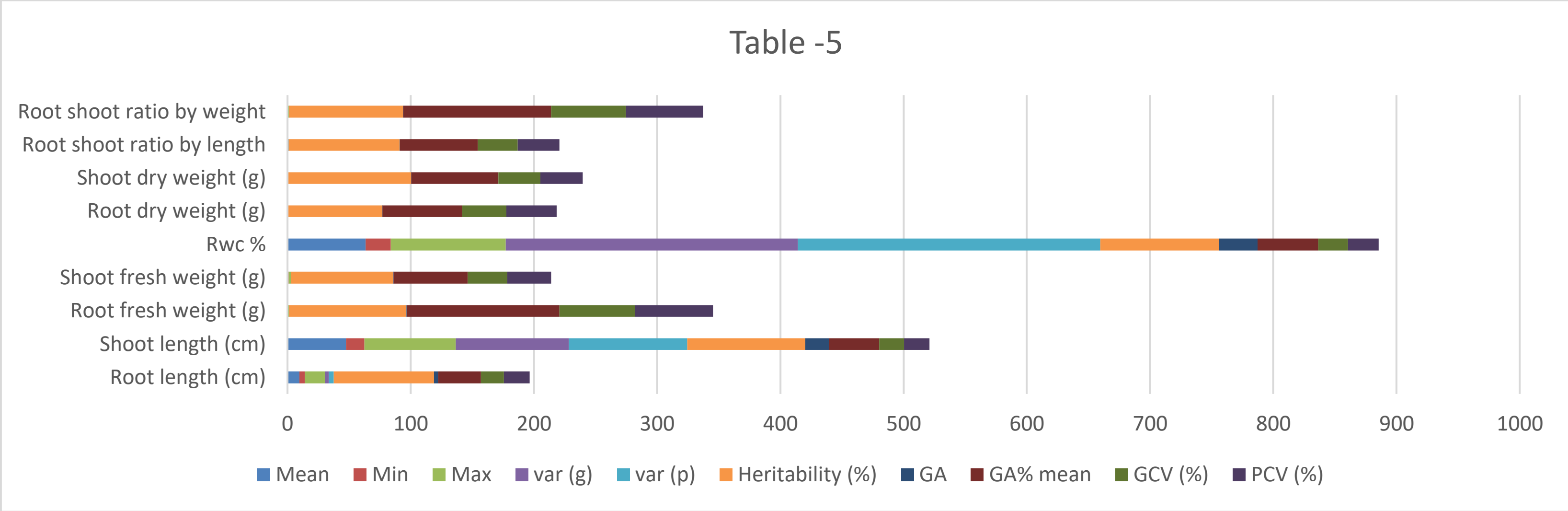

Fig. 2. Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under S_1 (50% water) stress condition

and 40.52%) in stress condition S_2 (25% water) and (92.60% and 56.52%) in stress condition S_3 (0% water) respectively. High heritability coupled with high genetic advance represent that character root length is governed by additive gene action. It is indicating that simple selectionwould be effective for this trait under stress condition. Similar result of high heritability and high genetic advance for this trait was also observed by Irum et al., (2011) and Riaz et al. (2013) in cotton, Dutta and Borua (2017) in rice, Gobu et al.(2017) in eggplant, Rajkumar and Fakrudin (2018) in sorghum, Shankar et al.(2019) in groundnut, Mishra and Sharma, (2015) in muskmelon, Gedam et al. (2021) in onion and Kumar et al. (2023) in wheat under stress condition. Bayoumi et al. (2008) in wheat, Wattoo et al. (2019) in maize and Pavitra et al. (2022) in rice for high heritability.

A wide variation was found among the germplasm accessions for shoot length. This character varied from 15.05 cm to 74.00 cm with an overall mean of 47.47 cm in S_1 ; 17.90 cm to 73.25 cm with the overall mean of 46.74 cm in S_2 and 14.10 to 90.50 cm with a grand mean of 49.36 cm in stress conditions in S_3. The PCV and GCV were 20.64 and 20.20 per cent; 20.36 and 19.95 per cent; 24.06 and 23.55 per cent respectively in stress conditions S_1 (50% water), S_2 (25% water) and S_3 (0% water). Similarly, high (More than 20%) PCV and GCV, was recorded by Mishra et al., (2015) in muskmelon, Bayoumi et al. (2008), Ashfaq et al. (2022) and Kumar et al. (2023) in wheat. The estimates of h^2 (95.72%, 96.01% and 95.81 per cent) together with an expected GA over mean of (40.70%, 40.28% and 47.48 per cent) were recorded for this character in stress conditions S_1 (50% water), S_2 (25% water) and S_3 (0% water) respectively. Similar data on heritability for this trait was also obtained by Meena et al. (2014) in chickpea, Mishra and Sharma, (2015) in muskmelon, Gobu et al. (2017) in eggplant, Shankar et al. (2019) in groundnut, Wattoo et al. (2019) in maize, Gedam et al. (2021) in onion; for high h^2 and high GA as percentage of mean by Riaz et al. (2013) in cotton and by Kumar et al. (2023) in wheat for this trait.

Table 6. Analysis of variance (mean sum of squares) for nine characters in Soybean under S_2 (25% water) stress condition

Source of variation	DF	Root length (cm)	Shoot length (cm)	Root fresh weight (g)	Shoot fresh weight (g)	RWC %	Root dry weight (g)	Shoot dry weight (g)	Root shoot ratio by length	Root shoot ratio by weight
Replication	1	0.01	2.22	0.001	0.003	0.10	0.000	0.001	0.000	0.007
Treatment	59	13.03**	264.65**	0.030**	0.283**	657.89**	0.001**	0.008**	0.015**	0.118**
Error	59	0.69	3.61	0.001	0.014	1.86	0.000	0.000	0.000	0.001
Total	119	6.80	133.03	0.015	0.147	327.11	0.000	0.004	0.008	0.059

*** Significant at 1% (P= 0.01) level of significance*
** Significant at 5% (P=0.05) level of significance*

Table 7. Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under stress S_2 (25% watering) condition

Genotypes	Mean	Min	Max	var (g)	var (p)	Heritability (%)	GA	GA% mean	GCV (%)	PCV (%)
Root length (cm)	9.546	3.750	16.450	4.12	4.80	85.69	3.87	40.52	21.25	22.96
Shoot length (cm)	46.749	17.900	73.250	87.01	90.63	96.01	18.83	40.28	19.95	20.36
Root fresh weight (g)	0.191	0.011	0.885	0.010	0.010	94.36	0.20	103.04	51.49	53.01
Shoot fresh weight (g)	0.757	0.104	1.739	0.090	0.104	86.22	0.57	75.66	39.55	42.60
Rwc %	64.274	26.435	92.115	218.68	220.54	99.16	30.33	47.19	23.01	23.11
Root dry weight (g)	0.025	0.006	0.084	0.0002	0.0002	100.00	0.026	107.55	52.21	52.21
Shoot dry weight (g)	0.123	0.032	0.319	0.0027	0.0027	100.00	0.107	87.33	42.39	42.39
Root shoot ratio by length	0.218	0.095	0.471	0.0048	0.0052	91.21	0.136	62.29	31.66	33.15
Root shoot ratio by weight	0.259	0.030	1.635	0.0389	0.0398	97.74	0.402	154.97	76.09	76.96

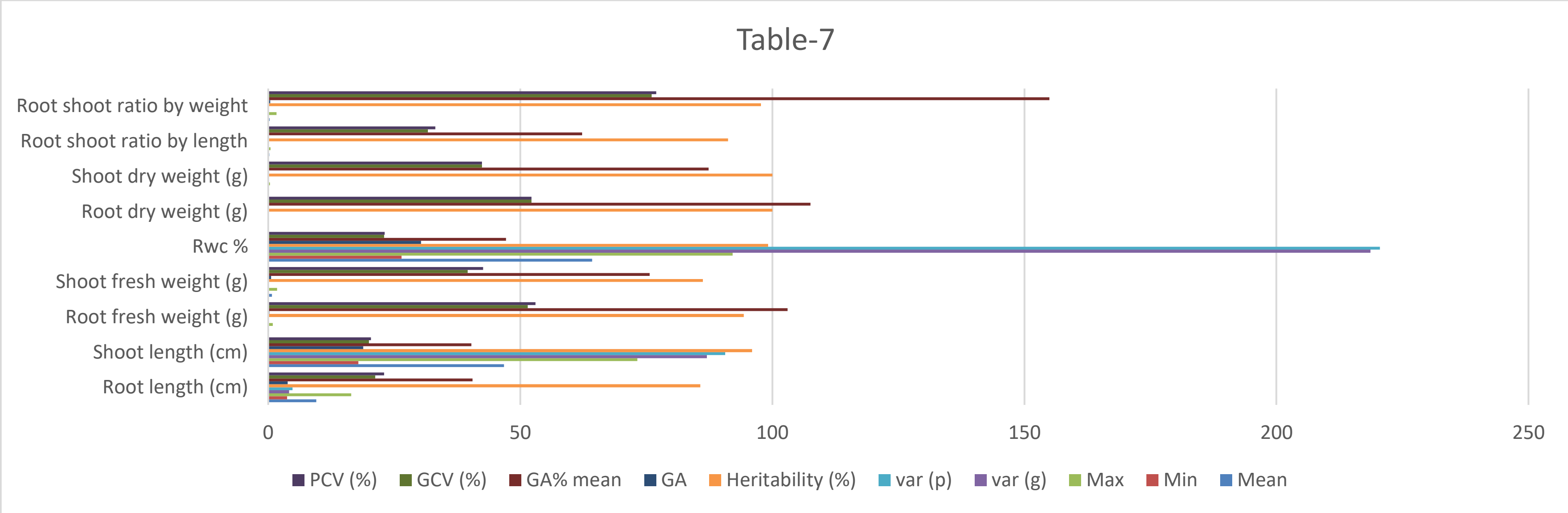

Fig. 3. Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under stress S_2 (25% watering) condition

Table 8. Analysis of variance (mean sum of squares) for nine characters in Soybean under S_3 (0% water) stress condition

Source of variation	DF	Root length (cm)	Shoot length (cm)	Root fresh weight (g)	Shoot fresh weight (g)	RWC %	Root dry weight (g)	Shoot dry weight (g)	Root shoot ratio by length	Root shoot ratio by weight
Replication	1	0.03	4.73	0.000	0.004	5.40	0.000	0.002	0.000	0.007
Treatment	59	27.15**	411.19**	0.026**	0.497**	756.20**	0.001**	0.013**	0.028**	0.065**
Error	59	0.70	5.91	0.000	0.012	1.87	0.000	0.000	0.000	0.001
Total	119	13.81	206.84	0.013	0.252	375.90	0.000	0.007	0.014	0.033

*** Significant at 1% (P= 0.01) level of significance*
** Significant at 5% (P=0.05) level of significance*

Root biomass and root length that aid in greater soil moisture extraction were identified as important root traits during terminal drought (Kashiwagi et al., 2006; Varshney et al., 2011). High PCV, GCV, heritability and genetic advance as percentage of mean was observed for root fresh weight under stress condition S_1, S_2 and S_3 respectively. In stress conditions S_1 (50% water) the range of genetic variability for the trait root fresh weight was found from 0.04 gm to 0.10 gm with the overall mean (0.20 gm), in stress condition S_2 (25% water) the grand mean of root fresh weight was 0.19 gm whereas highest root fresh weight was depicted by genotype GW312 (0.885 gm) and lowest by genotype GW212 (0.011 gm), in stress condition S_3 (0% water) the overall mean of it was 0.19 gm while highest root fresh weight was produced by genotype GW312 (0.79 gm) and lowest by GW212 (0.01 gm). The observed values of PCV, GCV, heritability and GA over percentage of mean were (63.20, 61.65 per cent, 95.15% and 123.28%); (53.01 and 51.49 per cent, 94.36% and 103.04%); (50.34, 49.06 per cent, 94.99% and 98.50%) under stress conditions S_1, S_2 and S_3 respectively. The observed values of PCV, GCV, heritability and GA over percentage of mean were according to findings of by Riaz et al. (2013) in cotton and Rajkumar and Fakrudin (2018) in sorghum; by Wattoo et al. (2019) in maize and by Shankar et al. (2019) in groundnut.

A wide variation was observed among the germplasm accessions for shoot fresh weight. The character shoot fresh weight varied from (0.072 to 1.73 gm; 0.10 to 1.74 gm; 0.13 to 2.35 gm) with an overall mean of (0.77 gm; 0.76 gm; 0.85 gm) under S_1, S_2 and S_3 respectively. The PCV, GCV, h^2 together with an expected GA over mean under S_1, S_2 and S_3 were (35.36%, 32.18%, 82.81% and 60.08%); (42.60%, 39.55%, 86.22% and 75.66 %); (48.82%, 47. %, 86.22 % and 75.66 %) respectively. Similar result of high PCV and GCV and heritability for this trait was also recorded by Wattoo et al. (2019) in maize; for high heritability by Irum et al. (2011), Riaz et al. (2013), Handi and Katageri (2016) in cotton; for high heritability and high genetic advance by Shankar et al. (2019) in groundnut.

RWC is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit. In case of absorption of water by the plant by roots from soil, water potential is useful in dealing with water transport in the soil-plant-atmosphere continuum but does not account for osmotic adjustment (OA). Osmotic adjustment (OA) mechanism is responsible for conserving cellular hydration under drought stress and RWC expresses the effect of osmotic adjustment (OA) in this respect. Therefore, RWC analysis is an appropriate estimate of plant water status in terms of cellular hydration under the possible effect of both leaf water potential and OA. The method is simple and measure of water deficit in the leaf. RWC value generally range between 98% in turgid and transpiring leaves to about 40% in severely desiccated and dying leaves. In most crop species the typical RWC at about wilting is around 60% to 70%, with exceptions. A wide range of variation in S_1, S_2 and S_3 stress (20.55 to 93.26%; 26.43 to 92.11%; 20.06% to 95.84%) was found among all the genotypes for relative leaf water content and the overall mean of physiological character was 63.32%, 64.27% and 63.18%. The PCV (24.74%, 23.11% and 25.19%), GCV (24.31, 23.01 and 25.10%), heritability (h^2) (96.59%, 99.16% and 99.26%) and genetic advance over mean of percentage (49.22%, 47.19% and 51.51%) were observed respectively for this parameter under all the three water stress conditions (50%, 25% and 0%). Similar results were also reported by Manickvelu et al. (2006) in rice. High heritability for this parameter was also reported by Meena et al. (2014) in chickpea, Garg et al. (2017) in rice, Wattoo et al. (2019) in maize, Shankar et al. (2019) in groundnut and Gedam et al. (2021) in onion.

Data of variability for root dry weight under drought has been presented in Tables 5, 7 and 9. While studying of the genotypes for drought tolerance, dry weight of a plant at age is universally considered as more stable character than other morphological parameters (Dutta and Bera, 2008; Vijay et al. 2018). The PCV and GCV obtained for root dry weight were (40.84 and 35.82 per cent; 52.21% and 52.21%; 65.23% and 62.99%) respectively. The values of heritability (76.92%, 100.00% and 93.24%) along with high genetic advance as per cent mean (64.72%, 107.55% and 125.29%) were observed for this trait under water stress conditions S_1, S_2 and S_3 respectively. High PCV, GCV, heritability and genetic advance were also reported for this trait by Riaz et al. (2013) in cotton and Rajkumar and Frakudin (2018) in sorghum; for high PCV, GCV and heritability by Wattoo et al. (2018) in maize. The findings on heritability for this trait was according to Irum et al. (2011), Handi and Katageri (2016) in cotton; Lalitha et al. (2015) in chickpea and Gurumurthy et al. (2019) in black gram.

The results of shoot dry weight indicated that out of 60 genotypes, 30 genotypes showed high values in comparison to the grand mean (0.12gm). High phenotypic and genotypic coefficient of variability along with high heritability and genetic advance as per cent mean recorded were (34.25%, 42.39% and 46.87%), (34.25%, 42.39% and 46.52%), (100.00%, 100.00 % and 98.50 %) and (70.55%, 87.33% and 95.10%) respectively. Similar findings of high PCV, GCV, high h^2 along with high genetic advance as percentage of mean was reported by Kumar et al. (2023) in wheat. Similar result of high heritability and high GA as percentage of mean for this trait was also found by Irum et al. (2011), Riaz et al. (2013), Handi and Katageri (2016) in cotton, Lalitha et al. (2015) in chickpea, Langat et al. (2019) in common beans (*Phaseolus vulgaris* L.), Gurumurthy et al. (2019) in black gram, Shankar et al. (2019) in groundnut. High PCV and GCV for this trait were also reported by Doumbia et al. (2022) in cowpea.

Perusal data of root shot ratio by length indicated the range of genetic variability (0.10-0.64), (0.10 to 0.47) and (0.01-0.91) with grand mean of (0.22, 0.22 and 0.23). The PCV and GCV observed were (34.06, 33.15, 43.88) and (32.32, 31.6642.44) per cent, respectively while high heritability (bs) of (90.08 per cent, 91.21 per cent, 96.14 per cent) coupled with high genetic advance over percentage of mean (63.20 per cent, 62.29 per cent, 85.71 per cent) were noticed under water stress conditions S_1, S_2 and S_3 respectively. Similarly high PCV and GCV, heritability and genetic advance of root shot ratio by length were recorded by Mishra and Sharma, (2015) in muskmelon, Gobu et al. (2017) in eggplant, Rajkumar and Frakudin (2018) in sorghum and Shankar et al. (2019) in groundnut.

Table 9. Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under stress S_3 (0% watering) condition

Genotypes	Mean	Min	Max	var (g)	var (p)	Heritability (%)	GA	GA% mean	GCV (%)	PCV (%)
Root length (cm)	10.41	3.40	20.50	8.82	9.52	92.60	5.89	56.52	28.51	29.63
Shoot length (cm)	49.36	14.10	90.50	135.09	141.01	95.81	23.44	47.48	23.55	24.06
Root fresh weight (g)	0.186	0.013	0.789	0.008	0.009	94.99	0.18	98.50	49.06	50.34
Shoot fresh weight (g)	0.854	0.125	2.348	0.162	0.174	93.05	0.80	93.57	47.09	48.82
Rwc %	63.18	20.06	95.84	251.45	253.31	99.26	32.54	51.51	25.10	25.19
Root dry weight (g)	0.026	0.004	0.135	0.0003	0.0003	93.24	0.033	125.29	62.99	65.23
Shoot dry weight (g)	0.144	0.031	0.378	0.0045	0.0045	98.50	0.137	95.10	46.52	46.87
Root shoot ratio by length	0.227	0.093	0.911	0.0093	0.0097	96.14	0.195	85.71	42.44	43.28
Root shoot ratio by weight	0.229	0.023	0.750	0.0214	0.0225	95.17	0.294	128.62	64.00	65.60

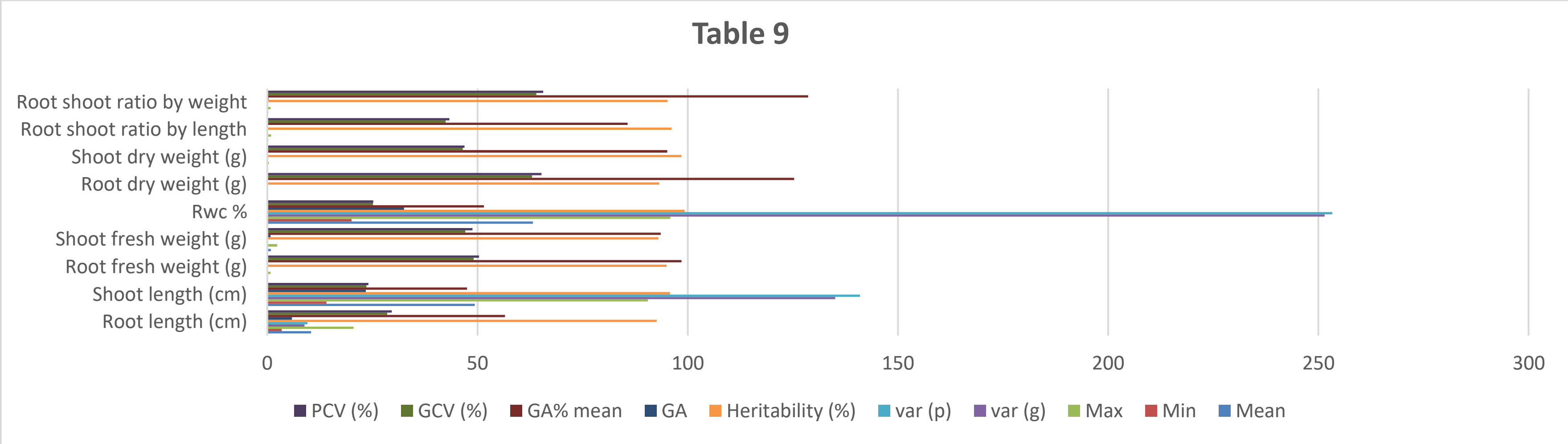

Fig. 4.Estimation of mean, range and genetic variability parameters for nine quantitative characters in Soybean under stress S_3 (0% watering) condition

Fig. 5. Experimental View at Net house

The character root shoot ratio by weight expressed ranged from 0.03 to 0.94, 0.03 to 1.64 and 0.02 to 0.75 under all the three water stress conditions (S_1, S_2 and S_3). The grand mean of root shoot ratio in weight was 1.39, 0.26 and 0.23. The estimates of PCV (62.87%, 76.96 % and 65.60%), GCV (60.51%, 76.96% and 64.00%), h^2 (92.63%, 97.74% and 95.17%) and G.A. (119.97%, 154.97% and128.62%) respectively were recorded for this trait under all the three water regimes (S_1, S_2 and S_3) created for drought. Similar results of high GCV, heritability and high GA as percentage of mean was reported by Handi and Katageri (2016) in cotton.

High heritability along with high genetic advance as percentage of mean was recorded for most of the traits under stress conditions. High heritability (≥95%) combined with high genetic advance as percentage of mean of root fresh weight, root dry weight and root shoot ration by weight than other traits indicating that simple selection would be effective for these traits among superior genotypes than other traits under water stress conditions (Burton, 1952; Morsy et al., 2015).

4. CONCLUSION

It may be concluded that there is ample scope of direct selection for most of the traits because this exhibited high genetic variability. Under stress conditions, high broad sense heritability (≥95%) together with high genetic advance of root fresh weight, root dry weight and root shoot ratio by weight than other traits demonstrated that these traits would grant more superior genotypes through phenotypic based selection than other traits in future soybean crop improvement activity in relation to drought stress.

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DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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