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DIRECT AND INDIRECT EFFECTS OF COMPONENT TRAITS ON SOYBEAN SEED YIELD UNDER SEASONAL VARIATION

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Abstract

Soybean is a quantitative short-day plant, which restricts its cultivation to the rainy season in India. But due to increasing demand for soybean oil and protein-rich products, the farmers are cultivating in off-seasons also. A study of fifteen soybean genotypes during rainy, post-rainy and summer seasons differing in photoperiod and temperature regimes indicated differential association between yield components and yield in different seasons. Plant height exhibited a significant positive correlation with seed yield during the post-rainy season but non-significant during rainy and summer seasons. A high positive direct effect of the number of branches per plant and the number of seeds per pod was observed during the rainy season while the number of pods per plant and hundred-seed weight were observed during the summer. Days to maturity exhibited high positive direct effect on seed yield across the seasons. The study highlights the necessity to prioritize selection strategy on days to maturity while breeding soybean varieties suitable for all three seasons.

Introduction

Soybean (*Glycine max* (L.) Merrill) is an important legume and oilseed with a protein content of 38-45% and oil content of 18-22%. Protein is rich in essential amino acids, lysine, tryptophan, methionine, and cysteine, which are beneficial for humans as well as animals (Clarke and Wiseman 2000, Friedman and Brandon 2001). Soybean oil comprised of around 4% stearic acid, 7% linolenic acid, 11% palmitic acid, 23% oleic acid and 53% linoleic acid (Fehr *et al.* 1992).

Soybean has a preference for flourishing in regions with moderate to high latitudes, characterized by warm and humid climates. Presently, soybean cultivation spans latitudes ranging approximately from 35°S to 54°N. The rapid increase in demand for vegetable oils, which currently stands at 200 million metric tons per year, is expected to potentially double by 2050 (Song *et al.* 2023). This projected surge in demand could place significant pressure on the already limited supply of arable land (Msanne *et al.* 2020). The substantial demand for soybeans, coupled with the lucrative returns they offer, has directed the farmers to grow this crop even during off-seasons. Due to the notable expansion of soybean cultivation in recent decades, the soybean sector is currently faced with a range of difficulties. One significant hurdle that the soybean industry must address involves adapting soybean crops to diverse photoperiodic conditions across varying latitudes.

Yield is quantitative trait influenced by many morphological and physiological traits and hence direct selection will not be effective. Hence understanding the interrelation between yield and component traits becomes important especially when grown in different seasons as seasons are characterized by different photoperiod and temperature conditions. Soybeans being quantitative short-day plants are affected by the photoperiod and temperature prevailing in

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different seasons. The statistical tools like correlations and path coefficient analysis can be used for assessing the interrelation between traits. Though correlation gives the relationship between any two traits, it will not give a cause and effect relationship which has to be studied through path coefficient analysis. The path analysis helps in the identification of those components with significant effects on yield for potential use as selection criteria (Samonte *et al* 1998). Hence, understanding the direct or indirect effect of different component traits on seed yield will hasten the selection process for yield especially when soybeans are grown in different seasons. Hence, the present study aims to assess the direct and indirect effects of various component traits on seed yield in a set of soybean genotypes grown in three different seasons *viz.*, rainy, post-rainy and summer differing for both photoperiod and temperature.

Materials and Methods

The material consisted of fifteen soybean genotypes comprising six released varieties (JS 335, JS 93-05, DSb 21, DSb 23, DSb 28 and DSb 34), seven advanced breeding lines (DSb 33, DSb 39, DSb 40, DLSb 1, DLSb 3, DLSb 5 and DLSb 6), a local landrace, Local Black Soybean and a photoperiod insensitive genotype, MACS 330. These genotypes were sown during rainy (17^{th} June, 2022), post-rainy (29^{th} October 2022) and summer (11^{th} January 2023) seasons at Main Agriculture Research Station, Dharwad, Karnataka, India ($15^{\circ}26'$N latitude, $70^{\circ}26'$E longitude and 678 m above the mean sea level). The soil in the experimental field was medium black. Each genotype was sown in four rows of 4m length following a randomized complete block design with three replications with spacing of 30 cm between rows and 10 cm between plants. Recommended agronomic and plant protection practices were followed to raise a good crop. In the rainy season, protective irrigation was provided while during the post-rainy season and summer, the irrigation was given at an interval of 8 - 10 days depending on the soil moisture status. The mean minimum temperature during the cropping period varied from 15.9ºC (post-rainy) to 20.1ºC (rainy) while the mean maximum temperature was 28.3ºC (rainy) to 33.8ºC (summer) in different months (Table 1). Mean day length during rainy 2022 was 12.51 hrs (June 2022 to September 2022), post-rainy 2022-23 was 11.24 hrs (November 2022 to February, 2023), and summer 2023 was 11.72 hrs (January 2023 to April, 2023) which were obtained from the Goddard Institute of Space Studies, NASA.

The observations on days to initiation of flowering (DIF), days to 50% flowering (DFF) and, days to maturity(DM) were recorded on the basis of plot. The observations of plant height (PH;cm), number of branches per plant (NBP), number of pods per plant(NPP) and number of seeds per pod(NSP) were recorded on five random plants in each genotype. Seed yield (SY) was taken from the entire plot and expressed as kg per hectare. Hundred seed weight was recorded by weighing 100 seeds in each genotype and expressed in grams. Correlation and path analysis was carried out by the procedure originally proposed by Wright (1921) which was subsequently elaborated by Dewey and Lu (1959) to estimate the direct and indirect effects of the individual traits on yield in each of the seasons using RStudio software (4.3.1).

Results and Discussion

The association and direct or indirect effect of different traits on SY has been studied hitherto during rainy or post-rainy or summer season individually in soybeans with a set of genotypes. In the present study, a set of soybean genotypes have been studied in all three seasons differing in photoperiod and temperature regimes (Table 1). DIF, NBP and NSP exhibited significant positive correlation with SY during rainy season but non-significant during post-rainy and the summer seasons (Table 2). These results suggest that for selection of high SY during the rainy season, the traits DIF, NBP and NSP should be considered which is not necessary during post-rainy and the summer seasons. Non-significant correlation between NPP and SY during the rainy season turned to be positive significant correlation during post-rainy and summer (Table 2). This difference in association could be due to different yield components contributing to SY in different seasons due to varying photoperiod and temperature in different seasons. The photoperiod during rainy 2022 was 12.51 hrs (June 2022 to September 2022), post-rainy 2022-23 was 11.24 hrs (November 2022 to February 2023), and summer 2023 was 11.72 hours (January 2023 to April 2023). The mean minimum temperature was 20.1ºC during the rainy season 15.9ºC during the post-rainy season and 16.8ºC during the summer, while the mean maximum temperature was 28.3ºC during the rainy and was 30.1ºC during the post-rainy season and 33.8ºC during the summer (Table 1).

Table 1. Mean meteorological data during rainy 2022, post-rainy 2022-23 and summer 2023 seasons.

Sl. No	Season	Month	Temperature (ºC)		Relative humidity (%)		Rainfall (mm)	Rainy days
			Maximum	Minimum	Maximum	Minimum		
1	Rainy 2022 (12.51 hrs)	June	29.9	21.0	85.7	76.5	102.8	7
2		July	26.6	20.5	91.7	82.5	186.4	14
3		August	27.4	20.3	90.7	82.4	113.2	14
4		September	28.7	20.0	89.8	74.2	195.6	11
5		October	28.9	18.6	85.6	67.8	208.6	8
Mean/Total			28.3	20.1	88.7	76.7	806.6	54
1	Post-rainy 2022-23 (11.24 hrs)	October	28.9	18.6	85.6	67.8	208.6	8
2		November	29.6	16.5	72.8	45.6	2.8	1
3		December	29.6	15.6	76.6	44.2	3.2	1
4		January	30.0	13.8	70.4	33.6	0	0
5		February	32.6	15.2	63.5	28.1	0	0
Mean/Total			30.1	15.9	73.8	43.9	214.6	10
1	Summer 2023 (11.52 hrs)	January	30.0	13.8	70.4	33.6	0	0
2		February	32.6	15.2	63.5	28.1	0	0
3		March	34.1	17.4	67.0	40.5	0	0
4		April	36.4	18.1	73.6	53.9	26.4	3
5		May	35.7	19.3	74.6	44.4	62.6	7
Mean/Total			33.8	16.8	69.8	40.0	89.0	10

Plant height exhibited a significant positive correlation with SY during the post-rainy season but non-significant during the rainy season and summer seasons (Table 2). This implies that the lower photoperiod (11.24 hrs) could have helped the plants to increase their plant height which is an advantage for effective light interception and hence a suitable trait to obtain higher seed yield especially during the post-rainy season. PH could be regarded as a criterion for selecting soybean genotypes when examined under reduced photoperiod (Nwofia *et al.* 2016, Pallavi *et al.*2016, Umburanas *et al.* 2019, Mandić *et al.*2020).

During rainy, post-rainy and summer, the residual value for path coefficient was 0.18, 0.07 and 0.20, respectively (Table 2), implying that the study covered 82% of characters during rainy, 93% during post-rainy and 80% during summer seasons that influence SY. DM exhibited high positive direct effect on SY across the seasons (Table 2) and hence can be a reliable trait for selection across the seasons for avoiding the extended or reduced juvenile stages. Earlier, a high direct effect of DM and DFF on SY was observed during rainy and post-rainy seasons (Malek *et al.* 2014, Mahbub *et al.* 2015, Mehra *et al.* 2020, Berhanu *et al.* 2021, Saicharan *et al.* 2022).

Table 2. Path coefficient analysis showing the direct and indirect effects of various traits on soybean seed yield at the phenotypic level across rainy 2022, post-rainy 2022-23 and summer 2023 seasons.

Season	Trait	DIF	DFF	DM	PH	NBP	NPP	NSP	HSW	SY
Rainy 2022	DIF	-0.45	0.47	0.47	-0.04	0.05	-0.09	0.14	-0.18	0.56*
	DFF	-0.44	0.47	0.48	-0.05	0.05	-0.09	0.13	-0.17	0.58*
	DM	-0.37	0.39	0.58	-0.04	0.02	-0.07	0.12	-0.14	0.64**
	PH	-0.13	0.16	0.16	-0.14	-0.03	-0.05	-0.01	-0.03	-0.08
	NBP	-0.16	0.18	0.10	0.03	0.14	-0.03	0.14	-0.10	0.54*
	NPP	-0.40	0.42	0.40	-0.06	0.04	-0.10	0.12	-0.16	0.42
	NSP	-0.20	0.20	0.22	0.005	0.06	-0.04	0.31	-0.09	0.57*
	HSW	0.37	-0.38	-0.39	0.02	-0.06	0.08	-0.13	0.21	-0.54*
Post-rainy 2022-23	DIF	-0.37	0.51	-0.12	0.001	-0.10	0.15	-0.09	-0.05	-0.01
	DFF	-0.17	1.08	0.17	-0.08	0.04	-0.30	-0.05	-0.04	0.76**
	DM	0.13	0.53	0.34	-0.06	0.08	-0.31	0.05	0.05	0.81**
	PH	0.004	0.68	0.17	-0.13	0.15	-0.39	-0.02	-0.04	0.49*
	NBP	0.16	0.16	0.11	-0.08	0.25	-0.33	0.03	-0.01	0.31
	NPP	0.11	0.64	0.21	-0.10	0.16	-0.51	0.02	-0.03	0.62*
	NSP	0.20	-0.31	0.09	0.01	0.04	-0.06	0.18	0.06	0.10
	HSW	0.15	-0.37	0.15	0.04	-0.01	0.11	0.09	0.12	0.13
Summer2023	DIF	-0.72	0.44	0.48	0.29	-0.28	-0.05	0.05	-0.11	0.01
	DFF	-0.72	0.44	0.48	0.28	-0.28	-0.03	0.05	-0.11	0.03
	DM	-0.59	0.36	0.59	0.26	-0.31	0.07	0.09	-0.05	0.16
	PH	-0.31	0.18	0.22	0.69	-0.31	-0.08	-0.07	-0.32	-0.22
	NBP	-0.43	0.27	0.39	0.46	-0.47	0.10	0.02	-0.15	0.24
	NPP	0.06	-0.03	0.08	-0.10	-0.09	0.52	0.04	0.09	0.51*
	NSP	-0.19	0.12	0.29	-0.25	-0.06	0.12	0.19	0.19	0.45
	HSW	0.22	-0.13	-0.09	-0.61	0.20	0.13	0.10	0.36	0.38

Residual effect for Rainy season: 0.18, Post-rainy season: 0.07 and Summer season: 0.20; * and ** significant at 5 % and 1 % level of probability, respectively.

DIF=Days to initiation of flowering, DFF= Days to fifty per cent flowering, PH=Plant height, DM= Days to maturity, NSP=Number of seeds per pod, HSW= Hundred seed weight, NBP=Number of branches per plant, NPP=Number of pods per plant, SY = Seed yield.

High negative direct effect on SY was exhibited by DIF across the seasons (Table 2) which indicates that a reduction in the DIF increases SY which can be attributed to increased PH, NPP and HSW due to a longer reproductive phase. Earlier, a high negative direct effect of DIF on SY was reported during post-rainy (Mahbub *et al.* 2015) and rainy (Mehra *et al.* 2020) seasons. High positive direct effect of NBP and NSP was observed during the rainy season (Table 2). Similarly, a high positive direct effect of NSP (Mehra *et al.* 2020) and NBP (Saicharan *et al.* 2022) was reported in soybean genotypes during the rainy season. The traits NPP and HSW had a high positive direct effect on SY during summer (Table 4). Positive direct effect of NPP and HSW on SY was also reported earlier during the summer (Akram *et al.* 2011). The primary factor contributing to the strong association of these traits with seed yield appears to be their high direct effect. Consequently, selecting for these traits, which are component traits of seed yield, directly would be an effective strategy during respective seasons.

The high negative direct effect of NPP during the post-rainy season and NBP during summer (Table 2) implies that indirectly selecting for these traits could prove to be an effective strategy for improving seed yield during respective seasons (Table 2). This assertion is supported by earlier findings that showed a high negative direct effect of NPP during post-rainy (Mahbub *et al.* 2015) and NBP (Malik *et al.* 2007) during the summer season. The results of the present study highlight the importance of employing a selection strategy that prioritizes trait days to maturity across the seasons as they had a significant direct effect on seed yield.

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