SOYBEAN GENOTYPIC RESPONSES IN TERMS OF YIELD AND RELATED TRAITS TO PLANT GROWTH REGULATOR TREATMENTS

Rouxléne VAN DER MERWE*; Drikus COERTZEN

Department of Plant Sciences, University of the Free State, Bloemfontein, South Africa

* VanDerMerweR@ufs.ac.za

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Abstract

Plant growth regulators (PGR's) are known to improve the photosynthetic ability and can enhance the effective partitioning of accumulates from source and sink in the field crops. Therefore, these compounds can assist in effective flower formation, seed development and finally increase the yield of field crops. The application of various types of PGR's has shown positive effects on soybean grain yield and related traits. However, results on the use of Stimulate® yield enhancer on soybean under South African production conditions have not been published. Therefore, the aims of this study were to determine if the application of Stimulate® yield enhancer can result in soybean yield improvement and to investigate variability of soybean genotypes in terms of yield traits in the response to Stimulate® yield enhancer. A field experiment was conducted during the summer season of 2018/2019. The trial was a factorial experiment laid out in a randomized completely block design with two factors and three replications. Factor one comprised of five Stimulate® treatments applied at various crop stages and factor two included three commercial soybean genotypes. Data collected on two physiological traits, and 11 yield traits together with grain yield were subjected to analysis of variance and correlation analysis. Significant genotype and treatment effects were observed for 10 and three traits respectively. Significant genotype x treatment interaction effects were observed for five of the traits, indicating that genotypes responded differently to the different treatments. In general, the different treatments did not significantly increase mean photosynthesis capacity, chlorophyll content, yield traits and grain yield compared to the control. However, genotype PHB95Y20R significantly performed better than the control for some yield traits when plants were sprayed at both the V5 and R1 growth stages and genotype PAN1614 showed a significant reduction in percentage shattered pods compared to the control across all treatments.

Resumen

Se sabe que los reguladores del crecimiento de las plantas (Plant growth regulators, PGR) mejoran la capacidad fotosintética y pueden mejorar la división efectiva de los acumulados de la fuente y el sumidero en los cultivos de campo. Por lo tanto, estos compuestos pueden ayudar en la floración, el desarrollo de semillas y finalmente aumentar el rendimiento de los cultivos. La aplicación de varios tipos de PGR ha mostrado efectos positivos sobre el rendimiento del grano de soja y características relacionadas. Sin embargo, no se han publicado resultados sobre el uso del potenciador de rendimiento Stimulate® en soja en las condiciones de producción de Sudáfrica. Por lo tanto, los objetivos de este estudio fueron determinar si la aplicación del potenciador de rendimiento Stimulate® puede resultar en una mejora del rendimiento de la soja e investigar la variabilidad de los genotipos de la soja en términos de características de rendimiento en respuesta al potenciador de rendimiento Stimulate®. Se realizó un experimento de campo durante la temporada de verano de 2018/2019. El ensayo fue un experimento factorial presentado en un diseño de bloques completamente al azar con dos factores y tres repeticiones. El factor uno constaba de cinco tratamientos Stimulate® aplicados en varias etapas del cultivo y el factor dos incluía tres genotipos comerciales de soja. Los datos recopilados sobre dos caracteres fisiológicos y 11 caracteres de rendimiento, junto con el rendimiento de grano, se sometieron a análisis de varianza y análisis de correlación. Se observaron efectos de genotipo y tratamiento significativos en 10 y tres caracteres respectivamente. Se observaron efectos significativos de interacción genotipo x tratamiento en cinco de los caracteres, lo que indica que los genotipos respondieron de manera diferente a los diferentes tratamientos. En general, los diferentes tratamientos no aumentaron significativamente la capacidad de fotosíntesis media, el contenido de clorofila, los rasgos de rendimiento y el rendimiento de grano en comparación con el control. Sin embargo, el genotipo PHB95Y20R se comportó significativamente mejor que el control para algunos caracteres de rendimiento cuando las plantas se trataron en las etapas de crecimiento V5 y R1 y el genotipo PAN1614 mostró una reducción significativa en el porcentaje de vainas rotas en comparación con el control en todos los tratamientos.

Introduction

Soybean (*Glycine max* L. Merrill) or soya bean as it is sometimes referred to, is an annual legume crop of eastern Asian origin and is grown mainly for its seed. It is an important source of high-quality protein and vegetable oil in the world (Maestri et al. 1998). The seed contains approximately 38 to 42% protein and 18 to 23% oil at maturity (Dornbos and Mullen 1992; Clemente and Cahoon 2009). Worldwide soybean is a universal food, fodder and industrial crop. Soybean is used for production of animal feed, mainly for broilers and swine, and account for 75% of soybean production, while 19% is processed into biofuel and vegetable oil (Hartman et al. 2011). Soybean oil is the most important vegetable oil and accounts for over 25% of the global edible oil. It is used in margarine, salad dressings, mayonnaise and pharmaceuticals (Tinsley 2009; Wrather et al. 2010). Lecithin, the by-product of oil extraction, is used as an emulsifier in confections, dairy products and instant foods (Kolapo 2011). Soybean as a food accounts for 6% of the world's soybean production. It is consumed whole as a vegetable or it is processed into meat and milk analogues, and a variety of meat and dairy-like products.

South Africa is the 11th largest producer of soybean in the world (FAOSTAT, 2020). High protein meal and soybean oil are the most prominent products used (DAFF 2017). Soybean demand in South Africa is high and mostly surpasses supply. For example, in 2011, 1 759 000 MT of soybean was demanded against an average production of 566 000 MT/year (NAMC 2011); hence South Africa is a net importer of soybean. However, by 2015, the government institutionalized the Industrial Policy and Action Plan (IPAP) to increase soybean crushing capacity. The IPAP was instituted to stimulate domestic soybean production to reduce importation of soybean (Sihlobo 2018). In 2015, 1 000 000 MT of soybean was produced, the highest ever in the history of the crop's production 2015. Although production and area planted increased since 2015, low yield is an impediment to soybean production in South Africa (Dlamini et al. 2013). An average farmer obtains 1.35 t/ha against 3.0 t/ha attained by the Agricultural Research Council in South Africa. Low yield can be attributed to poor choice and use of technologies that are not specific to local conditions, poor choice of cultivars and also, poor precipitation, which is characterized by long dry spells, drought and poor distribution.

In spite of the possibilities that conventional breeding and genetic engineering offer in terms of crop adaptation and yield improvement, the use of plant growth regulators (PGR's) might enable faster and better solutions (Rademacher 2015). PGR's are defined as naturally occurring or synthetic compounds that, mostly at low dosages, affect developmental or metabolic processes in higher plants. These are typically applied via foliar sprays with water as a carrier. The use of growth regulators is becoming popular in agriculture to increase crop yield and decrease susceptibility towards biotic and abiotic stress. These advantages are mainly possible since PGR's allow for active regulation of plant processes. They assist in adjusting a crop plant's genotype to grow at a given location under uncontrollable and unpredictable conditions (Rademacher 2015). A variety of such substances with PGR activities are available in the market. One of these products is known as fortified Stimulate® yield enhancer. It is a PGR that contains a proprietary blend of bioidentical growth-regulating plant hormones, e.g. cytokinin, gibberellin, and two auxins; indole-3-butyric acid and indole-3-acetic acid, which belong to the "classical" groups of plant hormones that are involved in many plant processes. The concentrations of these hormones are formulated such that application of the product can promote vigorous plant growth, development of improved yield traits and ultimately result in optimal yield production (Basuchaudhuri 2016).

However, the claim that Stimulate® yield enhancer can result in soybean yield improvement has not been tested and no results published under South African production conditions. In addition, since PGR's play a role in adjusting a crop's genotype to grow in a particular environment, the response of different soybean genotypes to the PGR need to be evaluated. Therefore, the aims of this study were to determine if the application of Stimulate® yield enhancer can result in soybean yield improvement and to investigate variability of soybean genotypes in terms of seed yield traits in the response to Stimulate® yield enhancer.

Material and Methods

A field experiment was conducted during the summer season of 2018/2019 on the farm Barendspan (29°25'19.1"S 25°31'44.5"E), in the southern Free State, South Africa. This region is characterised by warm and dry summers. It received a summer rainfall of 250 mm during the months of November 2018 to April 2019 and the average monthly maximum temperature during the same period ranged between 32 to 35°C (data obtained from the Agricultural Research Council – Institute for Soil Climate and Water). The field trial was a factorial experiment laid out in a randomized completely block design (RCBD) with two factors and three replications. Plots consisted of four rows, spaced 0.70 m apart and 4 m in length and seed were sown to achieve a plant population of 40 0000 plants per hectare. Factor one comprised of five Stimulate® treatments: (i) control treatment (untreated), (ii) Stimulate® seed treatment (D0), (iii) Stimulate® foliar application at V5 growth stage only, (iv) seed treatment and Stimulate® foliar application at R1 growth stage, and (v) Stimulate® foliar application at both V5 and R1 growth stages (Table 1). Irrigation was applied twice a week using a linear overhead irrigation system until all genotypes reached maturity. Factor two included three commercial soybean genotypes (Table 2), which were obtained from Pannar Seed (Pty) Ltd. Seed were sown by hand in furrows, and inoculated with *Bradyrhizobium japonicum* strain WB74 (from Stimuplant CC) at planting. Plants were fertilised using Omnia NPK 2:3:4 (31) + 0.5% Zn, as a top dressing twice during the season. Weed control was done manually as required.

Table 1. Stimulate application directions and concentrations

Treatment	**Dosage rate/ha**	**Per 1 kg**	**2 L (V5) / 5 trifoliate**	**2 L (R1 / flowering)**	**Description**
Control	Untreated				
Seed (D0)	500 ml/100 kg seed	5 ml			Treat seed at planting. No water added to the solution.
Foliar at V5	250 ml/ha	1.67 ml			Foliar spray 300 L/ha
Seed (D0) + foliar at R1	500 ml/100 kg seed 250 ml/ha	5 ml		1.67 ml	Treat at planting foliar spray in 300 L/ha
Foliar at V5 + R1	250 ml/ha		1.67 ml	1.67 ml	Foliar spray in 300 L/ha

Photosynthesis capacity (Pi total) and chlorophyll content readings were taken using Hansatech hand held instruments (Pocket PEA Chlorophyll Fluorimeter and Chlorophyll meter-01). This was done two weeks after the foliar application at the V5 growth stage and again two weeks after the foliar application at the R6 growth stage. Readings were taken early in the morning. The data captured was analysed using appropriate software packages. When genotypes reached harvest maturity, the middle rows of each plot were harvested and used for grain yield (converted to kilograms per hectare) determination once the seeds were below 13% moisture. A total of 12 yield related traits were measured on a sample of 10 plants, which were randomly selected from each plot and the average used for data analysis. Data were subjected to analysis of variance (ANOVA) in order to partition the various sources in the data structure. Means were separated by the least significant difference (LSD) test at 5%. Correlation coefficients between all captured data were calculated and the significance of the correlations were tested against the t-tabulated value (df = 43). All data analyses were performed using Genstat 18th ed. statistical package (VSN International 2015).

Table 2. Soybean genotypes used in the study

Genotype	**Maturity grouping (MG)***	**Growth habit**
LS6248R	4.8	Semi-determinate grower
PHB95Y20R	5.2	Determinate grower
PAN1614R	6.4	Indeterminate grower

*In South Africa, MG IV to MG VII are most often cultivated and indicated as short-, medium- and long growing season

Results and Discussion

Since photosynthetic capacity is positively correlated with crop yield during the reproductive stage (Hao et al. 2012), it was necessary to evaluate the response of soybean genotypes in terms of photosynthesis capacity. In addition, chlorophyll (a major chloroplast component for photosynthesis) has a positive relationship with photosynthetic rate and thus, a higher chlorophyll content in the reproductive stage is essential for increasing crop production. Results indicated significant ($P < 0.01$) differences among genotypes in terms of photosynthesis capacity (Pi total) and chlorophyll content of the leaves (Table 3). This was due to genetic differences between the genotypes selected for this study. Genotype LS6248R had significantly lower Pi and chlorophyll content compared to the other two genotypes (Table 4), indicating that this genotype had lower photosynthesis capacity compared to the other genotypes. This lower photosynthesis capacity in an earlier maturing genotype (LS6248R) can be explained by the association between photosynthetic potential and maturity groups.

Gordon et al. (1982) explained that leaves of early maturing soybean genotypes tend to have a high peak photosynthetic rate but this potential declines rapidly with the onset of pod fill and senescence in the crop, while later maturing genotypes have lower peaks but which persisted longer. Based on the results from the ANOVA, the different Stimulate® treatments did not result in a significant change compared to the control nor did the different treatments differed significantly from each other in terms of photosynthesis capacity and chlorophyll content. Thus, the hypothesis was not rejected that the Stimulate® application approaches will not result in an increase in photosynthesis capacity. Compared to the control, it appeared that all treatments resulted in lower mean Pi values, except for the seed treatment (D0).

However, the difference between the control and D0 was not significant. In addition, the control resulted in higher mean chlorophyll contents compared to all the other treatments. However, findings from this study were in contrast to observations made by Khatun et al. (2016) and Solanke et al. (2018) who observed significant differences between different treatments in chlorophyll content of soybean leaves.

Table 3. Analysis of variance showing mean square values of photosynthetic parameters measured on three soybean genotypes at the R6 growth stage after application of five Stimulate® treatments

		Pi total	**Chlorophyll content**
Source of variation	**DF**	**Mean squares**	**Mean squares**
Genotype	2	9.19**	51.57**
Treatment	4	0.65	11.83
Genotype x treatment	8	0.11	6.47
Replication	2	11.55	5.70
Residual	28	1.53	6.50
CV (%)		56.8	23.1
R^2		0.51	0.54

**Significant at P < 0.01, DF = degrees of freedom, CV = coefficient of variation, Pi = photosynthesis capacity

Although it was anticipated that the Stimulate® treated plants would have a higher photosynthetic capacity, it was not the case in this study. Nor was significant differences in photosynthetic capacity observed between the different Stimulate® application approaches. The treated plants did not have parameters that are significantly higher than that of the control plants. It appeared that the Stimulate® foliar treatments had an inhibition effect on photosynthesis capacity of all genotypes but this need further investigation.

Results from the ANOVA indicated significant differences among genotypes in terms of plant height, number of nodes per plant, number of pods on the main stem, harvest index and aborted pod percentage (Table 5a). This was due to genetic differences between the genotypes selected for this study. Genotype PAN1614 generally ranked highest for these traits (Table 6a), while PHB95Y20R was shorter with less nodes, pods on the main stem and a high percentage of aborted pods. Based on the results from the ANOVA, the different Stimulate® treatments did not result in a significant change compared to the control nor did the different treatments differed significantly from each other in terms of all these traits. Thus, the hypothesis was not rejected that the Stimulate® application approaches will not result in an increase in these specific traits. Results (Table 5b) indicated significant differences among genotypes in terms of number of branches per plant, number of pods on branches and percentage shattered pods. These significant differences between genotypes can be ascribed to their genetic backgrounds. Generally, genotype PHB95Y20R ranked in the top position for these traits, while PAN1614 ranked first with the lowest percentage of shattered pods (Table 6b).

Table 4. Mean values of photosynthetic parameters measured on three soybean genotypes at the R6 growth stage after application of five Stimulate® treatments

Means	**Pi total**	**Chlorophyll content**
Genotype		
LS6248R	1.28[b]	8.89[b]
PAN1614	2.74[a]	12.10[a]
PHB95Y20R	2.51[a]	12.10[a]
LSD genotype	*0.93*	*1.91*
Treatment		
Control	2.29	12.15
D0	2.54	9.24
D0 + R1	1.89	10.88
V5	1.94	11.92
V5 + R1	2.24	10.86
Grand mean	**2.18**	**11.03**

Pi = photosynthesis capacity, D0 = seed treatment, V5 = Stimulate® foliar application at V5 growth stage, R1 = Stimulate® foliar application at R1 growth stage

Results further indicated significant differences between Stimulate® treatments for number of branches per plant, number of pods on branches and total number of pods per plant. Khatun et al. (2016) also observed significant variation between treatments and stages of application in terms of plant height and number of branches per plant. However, when comparing means of the different treatments (Table 6b), the control treatment was significantly higher than the specific treatments for these traits. The seed treatment (D0) gave the lowest number of branches and lowest number of pods on branches, respectively while the V5 + R1 foliar applications gave the lowest number of pods per plant. These results were contradictory to the findings that were expected. Thus, the hypothesis was not rejected that the Stimulate® application approaches will not result in an increase in these specific traits. In terms of grain yield, genotypes did not differ significantly and gave a mean yield of 1.39 tons per hectare (Table 5b and Table 6b). In addition, the Stimulate® treatments did not result in a significant change compared to the control and the rest of the treatment approaches. Thus, the hypothesis was not rejected that the Stimulate® application approaches will not result in an increase in grain yield. Thus, results from this study were in contrast with previous reports where application of PGR's resulted in significant increases in soybean grain yield (Kamal et al. 1995; Gulluoglu et al. 2006a; Khatun et al. 2016) and yield related traits (Gulluoglu et al. 2006a).

The dissimilar results compared to previous reports might primarily occur because of differences between concentrations (in parts per million) and types of PGR's utilised, and differences in the physiological stages at which the different PGR's products are applied (Leite et al. 2003). Contrasting to these reports, an on-farm PGR trial was performed by the Iowa State University (Fawcett et al. 2016) where it was reported that PGR's did not have a significant effect on soybean yield as well.

For photosynthesis capacity, chlorophyll content, six yield traits and grain yield, non-significant genotype x treatment interaction was observed. On the other hand, results indicated significant genotype x treatment interactions (Table 5b) for plant biomass, number of branches per plant, number of pods on branches, seed weight per plant, total number of pods per plant and the percentage shattered pods. This indicated that although the treatments did not necessarily result in a significant change of these traits, the genotypes rankings changed and some genotypes responded differently towards the Stimulate® treatment approaches. In terms of plant biomass, number of branches per plant, number of pods on branches, seed weight per plant and total number of pods per plant, the genotype PHB95Y20R (medium grower) responded better than the control when plants were treated with two foliar applications at both V5 and R1 growth stages (Table 7). Thus, this genotype will respond positively in terms of these yield traits, but it will not result in a grain yield that is increased above the control treatment. Generally, PHB95Y20R was the best grower with the highest means for the yield traits, but due to its high pod shattering percentage, it was not the highest yielding genotype.

Genotype PAN1614 (long grower) showed a positive response in terms of plant biomass and seed weight per plant when both the seeds were treated (D0) and plants were treated with the foliar application at flowering (R1 growth stage). However, increases in these two traits will not result in a grain yield that is increased above the control treatment. In terms of percentage shattered pods, PAN1614 showed a reduction in shattering compared to the control when plants were treated with two foliar applications at both V5 and R1 growth stages. This reduction in percentage shattered pods was in agreement with Gulluoglu et al. (2006b) who reported that the application of PGR's resulted in low shattering rates and yield losses, especially before 10 days after maturity.

In terms of trait correlations (Table 8), photosynthesis capacity (Pi) was not significantly correlated with any of the yield traits analysed and, contradictory to what was expected, showed a significant negative correlation with grain yield. Thus, an increase in photosynthesis capacity will not necessarily result in a change or positive increase in grain yield. This was in contrast to previous findings where a net photosynthetic rate of high yield varieties was higher than those of low yield varieties (Da-Yong et al. 2012). However, the chlorophyll content was positively and significantly correlated with photosynthesis capacity and this indicated that the higher the chlorophyll content, the higher the photosynthesis capacity will be. A positive association between photosynthesis rate and chlorophyll content in soybean was reported by Buttery and Buzzel (1977). Although the chlorophyll content was significantly and positively correlated with plant biomass, number of pods on branches and total number of pods, these yield traits were not positively correlated with grain yield. Thus, by increasing chlorophyll content, the grain yield will not be increased. Out of all traits analysed, only harvest index was significantly and positively correlated with grain yield, thus to improve grain yield, the number of seed per plant (as this is the dominator in the HI equation) should be increased. Results on significant and positive correlations between biomass, respectively with seed weight and total pods per plant were in agreement with results from Gulluoglu et al. (2006a).

Table 5a. Analysis of variance showing mean square values of yield traits measured on three soybean genotypes subjected five Stimulate® treatments

Source of variation	**DF**	**Plant height**	**Nodes per plant**	**Pods on main stem**	**Harvest index**	**Aborted pods**	**Biomass**
Genotype (G)	2	**1467.52****	**33.314****	**84.39****	**35.53***	**0.030***	0.068
Treatment (T)	4	106.95	1.451	13.28	21.40	0.007	0.032
GXT	8	32.44	1.599	12.67	12.85	0.004	**0.051***
Replication	2	272.83	5.065	23.26	12.71	0.007	0.050
Residual	28	66.63	1.751	14.86	9.469	0.006	0.021
CV (%)		10.9	8.30	22.80	3.80	27.5	8.50
R^2		0.69	0.66	0.66	0.52	0.44	0.56

*, **, significant at $P < 0.05$, $P < 0.01$ respectively, DF = degrees of freedom, CV = coefficient of variation, R^2 = coefficient of determination

Table 5b. Analysis of variance showing mean square values of yield traits measured on three soybean genotypes subjected five Stimulate® treatments

Source of variation	**DF**	**Branches per plant**	**Pods on branches**	**Plant seed weight**	**Total pods**	**Shattered pods**	**Grain yield**
Genotype (G)	2	**5.4188****	**0.29****	634.0	2.72	**1443.55****	0.02
Treatment (T)	4	**2.9949****	**0.16****	404.5	**118.77***	27.35	0.03
GXT	8	**2.2486****	**0.12****	618.3	**94.00***	**27.81***	0.01
Replication	2	0.7526	0.10	613.5	104.02	15.13	0.10
Residual	28	0.6021	0.03	289.0	39.93	10.16	0.03
CV (%)		32.10	22.20	35.20	25.30	25.70	5.70
R^2		0.72	0.72	0.53	0.56	0.92	0.65

*, **, significant at $P < 0.05$, $P < 0.01$ respectively, DF = degrees of freedom, CV = coefficient of variation, R^2 = coefficient of determination

Table 6a. Genotype and treatment mean values of yield traits measured on three soybean genotypes subjected five Stimulate® treatments

	Plant height (cm)	**Nodes per plant**	**Pods on main stem**	**Harvest index (%)**	**Aborted pods (%)**	**Biomass (g)**
Genotype						
LS6248R	75.0	16.79	16.01	81.14	**6.00**	49.7
PAN1614	84.5	16.87	19.61	83.81	8.09	61.9
PHB95Y20R	64.7	14.25	15.13	81.14	10.69	63.3
$LSD_{0.05}$	*6.11*	*0.99*	*2.88*	*2.30*	*3.25*	*NS*
Treatment						
Control	70.7	15.82	17.94	83.20	9.70	69.7
D0	78.4	16.21	16.28	81.52	6.61	52.8
D0 + R1	78.2	16.52	15.76	79.76	9.73	50.9
V5	74.1	15.48	18.48	83.67	8.40	60.6
V5 + R1	72.3	15.83	16.12	81.99	6.85	57.5
$LSD_{0.05}$	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Grand mean	**74.8**	**15.97**	**16.92**	**82.03**	**8.26**	**58.3**

*NS = non-significant, LSD = least significant difference, D0 = seed treatment, V5 = Stimulate® foliar application at V5 growth stage, R1 = Stimulate® foliar application at R1 growth stage

Table 6b. Genotype and treatment mean values of yield traits measured on three soybean genotypes subjected five Stimulate® treatments

	Branches per plant	**Pods on branches**	**Plant seed weight (g)**	**Total pods**	**Shattered pods (%)**	**Grain yield (kg/ha)**
Genotype						
LS6248R	2.75	8.54	40.8	24.55	23.09	1363.1
PAN1614	1.73	5.39	52.1	24.99	3.82	1499.1
PHB95Y20R	2.78	10.27	52.1	25.40	10.27	1303.3
$LSD_{0.05}$	*0.58*	*2.47*	*NS*	*NS*	*2.38*	*NS*
Treatment						
Control	3.36	12.82	58.4	30.77	12.56	1421.0
D0	1.77	5.48	43.5	21.76	12.01	1130.4
D0 + R1	2.34	6.61	41.3	22.37	13.85	1421.7
V5	2.35	7.55	50.7	26.03	9.65	1614.3
V5 + R1	2.28	7.88	47.6	123.99	13.91	1355.2
$LSD_{0.05}$	*0.75*	*3.19*	*NS*	*6.10*	*NS*	*NS*
Grand mean	**2.42**	**8.07**	**48.3**	**24.98**	**12.40**	**1388.5**

*NS = non-significant, LSD = least significant difference, D0 = seed treatment, V5 = Stimulate® foliar application at V5 growth stage, R1 = Stimulate® foliar application at R1 growth stage

Table 7. Three-way mean values of yield traits measured on three soybean genotypes subjected five Stimulate® treatments

	Control	**D0**	**D0 + R1**	**V5**	**V5 + R1**
Biomass (g) (LSD=32.40)					
LS6248R	68.00	39.90	43.80	65.20	31.50
PAN1614	62.80	57.60	73.30	60.80	54.70
PHB95Y20R	78.50	60.80	35.50	55.70	86.30
Branches per plant (LSD= 1.30)					
LS6248R	3.97	2.53	2.57	2.99	1.70
PAN1614	2.17	1.13	2.70	1.53	1.10
PHB95Y20R	3.93	1.63	1.77	2.53	4.05
Pods on branches (LSD= 5.52)					
LS6248R	16.5	5.47	7.00	9.25	4.50
PAN1614	7.00	4.23	8.27	4.30	3.13
PHB95Y20R	14.97	6.73	4.57	9.10	16.00
Plant seed weight (g) (LSD= 28.44)					
LS6248R	56.60	32.30	35.30	54.60	25.20
PAN1614	52.90	48.50	61.80	51.40	45.80
PHB95Y20R	65.60	49.80	26.90	46.10	71.90
Total pods (LSD= 10.57)					
LS6248R	34.13	20.37	22.07	29.09	17.10
PAN1614	26.73	22.83	29.03	23.93	22.43
PHB95Y20R	31.43	22.07	16.00	25.07	32.45
Shattered pods (%) (LSD= 5.33)					
LS6248R	25.53	22.09	24.38	15.30	28.17
PAN1614	3.77	3.25	5.40	4.61	2.07
PHB95Y20R	8.37	10.69	11.77	9.03	11.51

LSD = least significant difference, D0 = seed treatment, V5 = Stimulate® foliar application at V5 growth stage, R1 = Stimulate® foliar application at R1 growth stage

Table 8. Simple correlation coefficients for photosynthetic parameters and yield traits measured on three soybean genotypes subjected five Stimulate® treatments

	Plant height	Nodes	Pods MS	HI	Branches	Seed weight	Total pods	Shattered pods	Biomass	Aborted pods	Pods BR	Grain yield	Pi
Nodes	0.73**	-											
Pods MS	0.51**	0.64**	-										
HI	0.16	0.18	0.61**	-									
Branches	-0.30*	0.14	0.24	0.28*	-								
Seed weight	0.10	0.32*	0.77**	0.69**	0.64**	-							
Total pods	0.04	0.41**	0.76**	0.57**	0.72**	0.90**	-						
Shattered pods	-0.24	0.05	-0.41**	-0.43**	0.24	-0.36*	-0.18	-					
Biomass	0.12	0.30**	0.77**	0.72**	0.60**	0.97**	0.89**	-0.41**	-				
Aborted pods	-0.35*	-0.37*	-0.30*	-0.35*	-0.14	-0.28	-0.19	-0.29	-0.26	-			
Pods BR	-0.34*	0.09	0.29	0.37*	0.89**	0.69**	0.81**	0.08	0.69**	-0.06	-		
Grain yield	0.15	0.10	0.22	0.31*	0.06	0.20	0.15	-0.16	0.25	-0.17	0.05	-	
Pi	0.05	0.01	0.17	0.01	-0.14	0.18	0.13	-0.43**	0.16	0.13	0.01	-0.39**	-
Chlorophyll	0.12	0.05	0.25	0.19	0.24	0.37*	0.33*	-0.51**	0.41**	0.15	0.30	0.06	0.36*

*, **, significant at $P < 0.05$, $P < 0.01$ respectively, Nodes = nodes per plant, Pods MS = pods on main stem, HI = harvest index, Branches = branches per plant, Seed weight = plant seed weight, Pods BR = pods on branches, Pi = photosynthesis capacity; Chlorophyll = chlorophyll contex

Conclusions

Generally, the different Stimulate® treatment approaches did not significantly increase mean photosynthesis capacity, chlorophyll content, yield traits and grain yield compared to the control when analyses were done across three soybean genotypes. However, some genotypes have shown different responses in terms of some yield traits but not grain yield. Genotype PHB95Y20R significantly performed better than the control for some yield traits when plants were sprayed at both the V5 and R1 growth stages. Genotype PAN1614 showed a significant reduction in percentage shattered pods compared to the control across all Stimulate® treatment approaches. Although a strong positive correlation was observed between chlorophyll content and some yield traits, no correlations were observed between photosynthesis capacity and these yield traits. In addition, most yield traits were not positively correlated with grain yield and this is contradictory to results expected. It is recommended that this study should be repeated across more than one season and more testing locations, since soybean growth and yield is largely influenced by environmental conditions. In addition, more research on the application approaches in terms of proper timing, concentration and growth stages of the soybean crop are needed.

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