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Research Article

Assessment of Growth, Physiological Efficiency, and Morpho Physiological Parameters Affecting Productivity and Yields in Different Soybean Genotypes

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Article Info

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Abstract

The research conducted at the Research Farm Adhartal, JNKVV, Jabalpur, during the *Kharif* season 2017 aimed to evaluate nineteen soybean genotypes for physiological efficiency. Employing a Randomized Completely Block Design with three replications, the study investigated various parameters, revealing significant variability among genotypes. A consistent linear pattern of total dry matter production was observed across vegetative, flowering, and crop maturity stages. Genotypes JS 20-98, JS 20-29, and NRC 3 exhibited superior performance, accumulating maximum total dry matter throughout the crop growth stages. Leaf Area Index (LAI) demonstrated a progressive increase up to the active pod-fill stage, followed by a decline with advancing crop age. JS 20-98 and JS 20-29 maintained the highest assimilatory surface area during all growth stages. Canopy Growth Rate (CGR) and Relative Growth Rate (RGR) exhibited a similar trend, peaking at 60 days after sowing (DAS), with JS 20-98 leading during the reproductive phase. Significant variations among different genotypes were noted in air temperature, canopy temperature, photosynthetic rate, stomatal conductance, water use efficiency, mesophyll efficiency, quantum efficiency, and carboxylation efficiency. JS 20-98 emerged as the top-performing genotype, boasting the highest values for LAI, Leaf Area Duration (LAD), RGR, CGR, quantum efficiency, carboxylation efficiency, photosynthetic rate, transpiration rate, mesophyll efficiency, and chlorophyll content index. Conclusively, genotype JS 20-34 exhibited the earliest transition from the vegetative to reproductive phase, while JS 20-98 and JS 20-29 showcased superior growth and physiological attributes across all stages, making them promising candidates for soybean cultivation. These findings contribute valuable insights into soybean genotypic variations, aiding future breeding and cultivation strategies for enhanced productivity and efficiency.

Key Words: Soybean, Growth, Physiological Efficiency, Morpho Physiological Parameters, Genotypes

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Introduction

The soybean (*Glycine max*), is a species of legume native to East Asia, widely grown for its edible bean which has numerous uses**.** Soybean (*Glycine max* (L.) Merrill) belongs to family leguminaceae sub family papilionance has been called "Golden bean" or " miracle crop" of the twentieth century. Soybean (*Glycine max* (L.) Merrill] one of nature's most versatile crops is increasingly becoming an important food and cash crop in the tropics due to its high nutrient quality and adaptability to various growing environments. Soybean is a grain legume crop. As food and feed soybean plays an important role throughout the different countries of the world. It provides oil as well as protein to the living beings. This very useful crop is grown in many countries but land coverage is highest in United States of America though it is known that the origin of soybean is in East Asia.

Soybean played significant role in the yellow revolution in India. The Legume crops are rich in protein and improve human nutrition. These crops improve the soil fertility through the process of nitrogen fixation in the root nodules. The cereal pulses crop Intercropping is important for enhancing nutritional food products without causing any loss to the soil structure and health. The crop has a variety of uses including for human food, livestock feed, vegetable oil, and . In order to delimit the constraints an analysis of eco physiological complex is a prerequisite and it is necessary to investigate the extent to which macro and micro fluctuations change the physiological processes and affect the productivity of plant. It is also essential to determine the transfer and sink utilization of assimilates in crop community. Photosynthetic efficiency and its relationship with various environmental parameters enable determination as well as prediction of the productivity potential of the soybean genotypes genotypes.

Keeping the above facts in the present investigation was carried out to consider the above mentioned concept to reach deeper understanding of the variations in plant growth, physiological response and productivity potential of soybean many industrial products and is a major crop in several developing and developed countries [18]. It is one of the most important protein and oil seed crops throughout the world. Its oil is the largest component, highly nutritive and every legume with 43% of biologically effective protein and 20% of edible oil ranks first among the oil seed crops in the country.

Since it is rich in oils (17-21%) and protein (38-42%), it is considered suitable for feeding humans as well as animals [11]. There are 5% minerals and several other components including vitamins [15]. Almost all essential amino acid particularly glycine, tryptophan, lysine, fatty acid and vitamins A and D besides support contain considerate

Crop productivity is dependent on its inherent capacity for photosynthesis, photosynthetic area and availability of PAR within the canopy of soybean genotypes. Thus, the genotypic variation in productivity of a crop may be related to various physiological parameters by the canopy and partitioning to total photosynthesis into economic and non-economic sink.

The productivity of soybean crop is limited by genotypic, environmental and physiological interactions. It is essential to investigate the constraints of productivity in soybean in relation to various morpho-physiological parameters and structural yield components genotypes. The discussion on these results would be divided into the following groups.

Material methods

The present investigation was conducted during Kharif season of the year 2017 at Research Farm Adhartal, Department of Plant Breeding and Genetics, JNKVV, Jabalpur (M.P.).Jabalpur has a semiarid subtropical climate. It is situated on 23' 90" N latitude and 79' 58"E longitude at an altitude of 411.78 meter above the mean sea level. It falls under subtropical climatic conditions, which is characterized by the features of hot dry summers and cool dry winters. The 10-years mean annual rainfall of the area is 1284 mm with intermittent dry spells. The maximum and minimum temperature ranged between 37.6 and 17.9 o C with relative humidity of 80-90%. Soil

type of experimental field was vertisol as per US classification of soil. The soils of the region have medium to deep depth and black colour with sandy clay-loam texture and neutral soil reaction.
Field preparation and fertilizer application is done as per recommendation. Seed of nineteen soybean genotype (Table 1) were sown by hand dibbling at a depth of 4-5 cm in open furrow in Randomized complete block design in three replication. Thinning and other intercultural practices were also adopted.

Table 1: List of genotype use for experiment

G1	NRC 2	G11	RBS 2000-24
G2	NRC 12	G12	RKS 24
G3	NRC13	G13	DYS 1
G4	NRC 99	G14	BRAGG
G5	PS 2	G15	JS 95-60
G6	RS1225	G16	JS 20-34
G7	PS 1099	G17	JS 20-68
G8	MACS 62-2	G18	JS 20-98
G9	SLM 25	G19	JS 20-29
G10	PS 1029		

Sampling was done at the fixed interval of growth for obtaining primary data for computation of physiological growth determinants at 30, 45, 60, 75, DAS and at maturity stage. Five plants were randomly selected from each treatment and replication for partitioning into stem and leaf biomass and estimation of leaf area for growth analysis. The observations were recorded on five randomly selected plants from each plant and replication for the following parameters and per plant data was obtained by averaging the values

Physiological Growth parameters:

For estimation of leaf area, dry matter production and its partitioning in Plant parts (leaf, main stem and pods) Sampling was done at the fixed intervals of 15 days after sowing (DAS) onwards from 30 DAS till maturity for computation of data. For determining the leaf area and dry matter production 5 continuous plants were removed from the field and partitioned into main stem, leaves, branches and pods and kept in an electric oven at 80 0C for about 48 hrs till constant weight. The dry weight of individual plant part as well as total and measurement of leaf area were recorded separately. The leaf area was recorded by using Laser area meter (Model LI-300).

Leaf Area Index (LAI) expresses the ratio of leaf surface (One side only) to the ground area occupied by the plant or a crop stand worked out as per specifications of Gardner et al. [6] (1985). Leaf area duration expresses the magnitude and persistence of leaf area or leafiness during the period of crop growth. It reflects the extent of seasonal integral of light interaction and correlated with yield [26]. The daily increment in plant biomass is termed as crop growth rate [26] or productivity rate or rate of dry matter production. The Relative growth rate expresses the dry weight increase in time interval in relation to initial weight [26]. The specific leaf area expresses the ratio between the leaf area (LA) and leaf dry weight (LW) [6]. Specific Leaf Weight (SLW) is the ratio between the leaf dry weight (LW) and the leaf area (LA) it indicates the leaf thickness on the weight basis [6].

Other physiological traits

Chlorophyll content which is expressed as grams of chlorophyll per unit ground area and was determined in the 4th leaf of five weeks old plant using a non-destructive method that uses an optical instrument called chlorophyll meter (Model: CCM 200 Made in USA). The quantum efficiency was determined by ratio of net photosynthesis to PAR absorption Pandey et al. [21,22]. Gas exchange rates and other physiological traits were measured on intact leaves using a Infra-Red Gas Analyzer IRGA, LI-6400 (Li cor -6400 (Li cor instruments, USA), fitted with a leaf chamber mounted with a source of light. Fully expended youngest fourth leaves were used for photosynthesis measurements as per method suggest by Kannan [13]. Carboxylation efficiency was derived as the ratio of net photosynthetic rate to intercellular CO2 concentration (Pn/Ci). The water use efficiency was determined as ratio to net photosynthesis to transpiration rate (Pn/E) [13].The mesophyll efficiency was determined as ratio of the intercellular CO2 concentration to the stomatal conductance (Ci/cond). Canopy temperature, Air temperature, Photosynthesis rate (μmol/m2/sec), Stomatal conductance (m mol/m2/sec) and Transpiration rate (m mol/m2/sec) were also recorded.

RESULTS AND DISCUSSION

Physiological Growth Parameters

The findings of the current investigation offer crucial insights into the germination and early growth characteristics of different soybean genotypes, providing valuable information for the optimization of crop productivity. Genotypes G16 and G5 exhibited the highest germination percentages, underscoring the significance of seed viability and vigour in influencing seed germination and subsequent seedling emergence. These results align with prior studies by Kandpal et al. [12] and Bargali Kiran and SS Bargali [2], emphasizing the consistent importance of these parameters, especially under water deficit conditions.

Regarding seedling length, G2 and G18 emerged as the top-performing genotypes, demonstrating superior seedling percentages compared to other genotypes. Conversely, G9 displayed the lowest seedling length, corroborating with previous findings by Omar and Rahhal [20], who reported increased seedling survival through seed coating with thiram, as evidenced by our results.

The investigation into shoot length revealed that G12 possessed the highest shoot length, while G15 exhibited the minimum. These results are based on the evaluation of soybean seed physiological quality conducted by Vanzolini [25], suggesting a link between shoot length and overall seed quality.

Root length analysis highlighted G8 as the genotype with the maximum root length, while G1 displayed the minimum. These findings align with Chikkanna et al. [5], supporting the notion that root development is a crucial determinant of overall plant health and performance.

Furthermore, seedling dry weight varied significantly among genotypes, with G12 showing the highest and G11 the lowest dry weight. Vigour indices I and II further underscored genotype-specific variations, with G2 and G12 displaying the highest values while G9 and G11 exhibited the lowest. These findings support the notion that seed size directly impacts germination and seedling vigour, as suggested by Ahmad and Bano [1], Hoy and Gamble [9].

Phenophasic Development:

Phenology, encompassing the timing of key developmental events in the crop life cycle, significantly influences soybean productivity. Early flowering and maturity, coupled with a short grain-filling period, were identified as contributing factors to poor yield. This emphasizes the need for careful selection of genotypes with optimized phenophasic development to enhance assimilate translocation efficiency during the critical reproductive phases.

Leaf Area Index (LAI):

The leaf area index, a critical parameter reflecting the ratio of leaf surface to ground area, plays a pivotal role in capturing solar energy for photosynthesis. Our study revealed substantial variations in LAI among soybean genotypes, with G19 consistently demonstrating higher values (1.345 at 30 days, 1.67 at 45 days, 4.16 at 60 days, and 4.67 at 75 days) across different growth stages. These findings align with the findings of Khan and Khalil, [14], and Malek *et al.*, [17] emphasizing the positive correlation between LAI and dry matter accumulation. Larger LAI values in high-yielding genotypes, such as G19, underscore the importance of maximizing leaf surface area for enhanced photosynthetic efficiency and, consequently, greater crop productivity.

Leaf Area Duration (LAD) (m2. days)

Leaf area duration, indicating the persistence of leaf area during crop growth, emerged as a crucial factor correlated with yield. The result showed that genotype G5 (11508.43) at 30 days, G19 (21031) at 45 days, G19 (30966.8) at 60 days and G19 (17244.8) at 75 days recorded the maximum LAD among all genotypes of soybean emphasizing its potential for sustaining active leaf growth and photosynthetic activity. The importance of prolonged leaf area duration in contributing to photosynthetic production potential aligns with [19,24], suggesting that a longer active period for leaf growth positively influences soybean crop performance.

Crop growth rate (CGR) (g/cm2/day)
Crop growth rate, an essential indicator of productivity, demonstrated significant genotype-specific variations. G18 consistently exhibited higher CGR values (14.81 at 30 to 45 days, 39.23 at 45 to 60 days and 35.39 at 60 to 75 days) than other genotypes, underscoring its superior ability to convert incident light into dry matter. These results corroborate with Zhou *et al.*, [27] emphasizing the relationship between row spacing, light interception, and overall crop growth. The positive correlation between mean LAI and CGR further highlights the leaf area's critical role in influencing the photosynthesis rate in soybean genotypes.

Relative Growth Rate (RGR) (g/g/day).
The investigation into relative growth rate across different growth stages revealed distinct patterns among soybean genotypes. G19 exhibited significantly higher RGR values during key growth intervals, reinforcing its potential for rapid biomass accumulation. These findings align with Tandale and Ubale, [24] emphasizing the importance of growth parameters, including RGR, in determining soybean seed yield. Hamid et al., [8] observed a decline in RGR during the reproductive stage, suggesting increased assimilates demand by developing seeds, indicating the dynamic nature of growth patterns throughout the crop life cycle.

Other physiological traits
The physiological traits Viz., Carboxylation efficiency, Air temperature, Canopy temperature, Photosynthetic rate and Water use efficiency exhibited significant variations (at 5%) while remaining highly significant (at 1%) variations among different soybean genotypes.

Chlorophyll Content Index (CCI):
The study investigated the chlorophyll content index (CCI) among various soybean genotypes, revealing substantial variability. Genotype G18 exhibited the highest CCI (40.67), emphasizing the role of chlorophyll, a major component of photosynthesis. A positive correlation between relative chlorophyll content and photosynthetic rate was observed, supporting previous findings [10]. However, G12 displayed the lowest CCI (31.30). The study aligns with Betzelberger et al. [3], highlighting the positive correlation between chlorophyll content, photosynthetic parameters, and seed yield. The impact of supplemental UV-B radiation on chlorophyll content and electron transport activity in PSII was acknowledged.

Canopy and Air Temperature(^{o}C):
Genotypes exhibited variations in canopy and air temperatures. G19 recorded the highest canopy temperature (34.19°C), while G5 displayed the lowest (31.81°C). Maximum air temperature was noted in G18 (35.02°C), contrasting with G8, which had the significantly lowest air temperature (31.62°C). Microclimate data, including temperatures, is crucial for crop development models. High transpiration displayed lower leaf resistance, emphasizing the importance of leaf photosynthetic rate, stomatal conductance, and canopy temperature depression.

Net Photosynthetic rate (µmol/m^2/s)
Net photosynthetic rate varied among genotypes, with G18 recording the highest (27.23 µmol/m^2/s) and G1 the lowest (20.72 µmol/m^2/s). The assimilates obtained through photosynthesis were highlighted, emphasizing their role in maintenance of respiration and growth. Crop yields were linked to both the rate and duration of photosynthesis, suggesting a potential approach for improving yield. However, Madhu and Hatfield [16] reported that photosynthetic rate was positively correlated with leaf conductance and intercellular CO2 concentration, while water use efficiency (WUE) was negatively correlated with these factors and transpiration rate.

Stomatal Conductance (mol/m^2/sec)and Transpiration Rate(m mol/m^2/s): Stomatal conductance varied among genotypes, with G18 exhibiting the maximum (0.73) and G17 the minimum (0.48). Reductions in transpiration rate and stomatal conductance, along with increased intercellular CO2 concentration, indicated their roles in reducing photosynthesis [27]. Transpiration rates varied, with G19 having the highest (6.51) and G15 the lowest (4.95). Stomatal control of assimilation and transpiration balance was emphasized, supporting Taiz and Zeiger [23]. Gupta et al. [7] noted decreasing transpiration rates with maturity due to soil moisture decline.

Table no. 02: Variability in seed quality traits recorded in various soybean genotypes

Genotype	Field emergence (%)	Seedling length(cm)	Shoot length (cm)	Root length (cm)	Seedling dry weight (gm)	Vigour index-I	Vigour index –II
G1	73.33	8.83	6.97	5.30	0.30	646.00	21.75
G2	77.00	11.23	7.74	6.27	0.38	865.50	29.72
G3	70.00	10.23	7.30	6.23	0.34	716.67	24.23
G4	66.33	8.33	7.30	6.17	0.48	552.70	32.06
G5	78.00	9.07	6.67	6.53	0.40	707.27	32.48
G6	66.00	9.17	7.27	6.00	0.37	604.67	24.78
G7	75.00	9.03	7.60	6.33	0.26	676.50	19.48
G8	76.33	8.37	7.37	6.67	0.39	639.47	29.55
G9	65.00	7.20	6.57	5.60	0.15	467.17	10.15
G10	72.00	9.33	7.27	6.07	0.24	650.71	17.63
G11	59.33	8.47	6.43	5.77	0.15	502.07	9.31
G12	77.67	9.87	7.90	6.40	0.85	767.23	66.05
G13	69.33	9.00	6.83	5.50	0.54	624.33	37.44
G14	64.33	8.30	6.37	5.80	0.65	533.87	41.83
G15	69.67	8.37	6.27	5.53	0.22	582.60	15.56
G16	78.33	10.33	7.07	5.40	0.55	806.13	43.12
G17	68.00	9.03	6.70	5.63	0.35	614.13	24.27
G18	74.67	11.23	6.47	6.17	0.34	838.40	25.93
G19	67.33	10.20	7.40	5.57	0.44	687.07	30.05
Mean	70.93	9.24	7.02	5.94	0.39	656.97	28.18
SEm±	1.631	0.233	0.136	0.159	0.005	15.758	0.915
CDat5%	4.696	0.67	0.391	0.457	0.015	45.379	2.636

Table No. 03. VariabilityinLeaf Area Index recorded in soybean genotypes at different growth intervals.

	LAI				
Genotypes	30days	45days	60days	75days	90days
G1	0.785	0.90	2.97	4.17	0.64
G2	1.001	1.25	3.40	3.36	0.87
G3	0.716	0.93	2.07	2.62	0.60
G4	0.656	0.77	2.12	2.60	0.62
G5	1.301	1.10	3.88	4.11	1.16
G6	0.880	1.38	3.44	3.25	1.05
G7	1.057	0.90	3.98	4.13	1.02
G8	0.940	1.39	3.84	3.45	1.02
G9	0.648	0.63	1.75	2.23	0.73
G10	0.952	1.62	2.25	3.31	0.65
G11	1.226	1.34	3.53	3.81	1.10
G12	1.127	1.64	3.99	4.01	1.11
G13	0.918	1.17	2.82	3.20	0.86
G14	0.806	0.87	2.74	2.34	1.06

G15	0.720	0.87	1.83	1.80	0.84
G16	0.839	0.93	2.27	2.20	0.95
G17	0.719	0.59	1.36	1.90	0.90
G18	0.979	0.98	2.73	2.98	1.01
G19	1.345	1.67	4.92	4.96	1.10
Mean	0.927	1.10	2.94	3.18	0.91
SEm±	0.10	0.11	0.122	0.182	0.072
CDat5%	0.311	0.317	0.351	0.525	0.209

Table N0.04. Variability in Leaf Area Duration recorded in soybean genotypes at different growth intervals.

LAD				
Genotypes	30days	45days	60days	75 days
G1	7857.36	21031	30966.7	17244.78
G2	9993.1	20129	26334.3	15526.14
G3	6486.94	13367	17449.2	10404.03
G4	6305.88	13025	17416.1	10517.57
G5	6061.62	22841	28580.9	16945.73
G6	9645.64	19460	25674.9	15803.5
G7	7906.99	20481	29670	17096.07
G8	9402.41	20562	27430.5	16534.1
G9	4528.47	10482	14938.2	9460.246
G10	9429.68	12722	16924.8	11421.31
G11	9317.3	18693	24508.4	15281.35
G12	9602.61	20573	26601.9	16144.21
G13	7660.1	16368	21478	12862.4
G14	7016.69	14311	17703.8	11046.54
G15	6192.4	11238	13476.9	8865.269
G16	6540.37	12950	15614.4	9913.361
G17	4612.68	8687	11216.4	8059.334
G18	6106.52	14001	18772.1	11656.5
G19	11508.43	25809	35024.4	18124.39
Mean	7693.43	16670	22093.8	13310.89
SEm±	671.416	666.6	768.835	424.6
CDat5%	1,933.57	1,919.70	2,214.12	1,222.90

Table NO.5. Variability in Crop Growth Rate (g $cm^2 day^{-1}$) recorded in soybean genotypes at different growth intervals

Genotypes	30-45DAS	45-60DAS	60-75DAS
G1	3.50	35.33	24.69
G2	5.39	33.14	26.39
G3	9.37	32.30	28.38
G4	2.50	32.49	28.60
G5	3.53	33.23	35.52
G6	3.88	31.70	29.16

G7	6.81	31.34	31.40
G8	6.48	32.43	21.87
G9	5.89	35.25	26.76
G10	9.76	32.67	29.59
G11	9.78	34.65	29.79
G12	5.82	33.71	35.39
G13	11.78	28.32	34.24
G14	3.84	29.67	26.37
G15	2.56	34.65	28.74
G16	5.83	35.23	28.51
G17	4.90	36.28	27.49
G18	14.81	39.23	35.59
G19	10.44	38.30	31.62
Mean	6.68	33.68	29.48
SEm±	0.053	0.068	0.141
CDat5%	0.152	0.197	0.406

Table No.6. Variability in Relative Growth Rate (g g^{-1} day^{-1}) recorded in soybean genotypes at different growth intervals

Genotypes	30-45 DAS	45-60 DAS	60-75 DAS
G1	0.041	0.078	0.030
G2	0.040	0.090	0.040
G3	0.066	0.090	0.038
G4	0.027	0.094	0.046
G5	0.051	0.093	0.050
G6	0.029	0.090	0.056
G7	0.041	0.082	0.034
G8	0.036	0.074	0.038
G9	0.050	0.104	0.029
G10	0.050	0.062	0.047
G11	0.065	0.083	0.035
G12	0.085	0.076	0.035
G13	0.070	0.073	0.042
G14	0.052	0.070	0.040
G15	0.021	0.091	0.042
G16	0.037	0.089	0.035
G17	0.041	0.087	0.042
G18	0.050	0.076	0.035
G19	0.247	0.117	0.062
Mean	0.058	0.085	0.041
SEm±	0.004	0.005	0.003
CDat5%	0.01	0.013	0.008

Table NO. 7 Variability in physiological parameters recorded in soybean genotypes at actual stage.

Genotypes	Chlorophyll content Index (SPAD)	Canopy Temp. (^{0}c).	Air Temp .(^{0}c).	Photosynthetic Rate (µmol/m^2/s)	Stomatal conductance(mol/m^2/s)	Transpiration Rate (mmol/ m^2/s).	WUE (µmol /mmol)	Mesophyl Efficiency (µ molmol^{-1} (molm$^-$ 2$_s$-1$_)$-1	Quantum efficieny	Carboxylation efficiency (µ mol/m^2/s$^-$ ^{1}(mmolmol$^-$ 11$_)$.
G1	32.67	32.81	32.52	20.72	0.51	5.77	4.21	377.49	0.019	0.078
G2	39.13	34.18	34.35	21.88	0.55	5.83	3.86	486.24	0.02	0.083
G3	35.66	33.34	33.54	21.97	0.57	5.64	3.76	466	0.021	0.083
G4	36.34	33.01	33.28	22.33	0.63	5.9	3.75	422.2	0.021	0.084
G5	38.47	31.81	34.41	25.02	0.58	5.82	4.04	454.29	0.023	0.094
G6	39.57	33.01	34.58	23.62	0.7	6.44	3.95	362.35	0.022	0.089
G7	38.33	32.33	33.87	24.18	0.71	6.5	3.92	370.98	0.023	0.091
G8	37.53	33.93	31.62	22.22	0.68	6.35	3.93	391.82	0.01	0.084
G9	33.03	32.87	34.55	22.91	0.65	5.69	3.92	407.69	0.021	0.086
G10	34.19	32.88	33.72	21.78	0.69	5.9	3.93	384.62	0.017	0.082
G11	33	31.92	34.85	22.82	0.55	5.14	3.94	486.24	0.019	0.086
12	31.3	32.68	33.57	22.21	0.58	5.33	3.94	455.07	0.022	0.084
G13	33.73	32.33	34.03	22.68	0.64	5.75	3.95	416.01	0.024	0.086
G14	33.37	32.93	34.35	23.28	0.72	5.6	3.97	367.89	0.024	0.088
G15	33.07	31.87	34.02	21.58	0.65	4.95	3.93	407.69	0.017	0.081
G16	34.8	33.75	32.91	22.44	0.71	5.6	3.95	375.35	0.016	0.085
G17	35	32.52	33.58	22.92	0.48	5.54	4.1	547.14	0.022	0.086
G18	40.67	32.13	35.02	27.23	0.73	5.86	4.23	523.03	0.0259	0.103
G19	40.24	34.19	34.49	23.75	0.62	6.51	4.19	428.34	0.023	0.09
Mean	35.79	32.87	33.86	22.92	0.63	5.8	3.97	427.92	0.021	0.087
SEm±	0.496	0.307	0.288	0.878	0.018	0.21	0.213	11.575	0.001	0.001
CD at5 %	1.429	0.884	0.829	2.529	0.052	0.605	N/A	33.333	0.003	0.004

Water Use Efficiency (WUE) and Mesophyll Efficiency:
WUE did not show significant differences among genotypes. Critical differences were not observed, but considerations of mesophyll conductance (gm) and stomatal conductance (gs) were noted. Mesophyll efficiency varied, with G18 displaying the maximum (547.14) and G19 the minimum (362.35). Higher mesophyll efficiency indicates better intercellular CO2 utilization, beneficial for varietal improvement [15,4].

Carboxylation and Quantum Efficiency: Carboxylation efficiency exhibited significant variation, with G18 and G5 recording the maximum values (0.103 and 0.094, respectively) and G1 the minimum (0.078). Quantum efficiency showed variability, with G18 displaying the highest (0.025). Findings align with Pandey *et al.*[21] suggesting increased quantum efficiency with waterlogging duration

Conclusion
In conclusion, the comprehensive investigation into the physiological growth parameters of different soybean genotypes provides valuable insights that are pivotal for optimizing crop productivity. The observed variations in germination, seedling characteristics, and phenophasic development underscore the importance of genotype-specific traits in influencing soybean performance. Genotypes G16 and G5 exhibit superior germination percentages, emphasizing the significance of seed viability and vigor, crucial for successful seedling emergence. The link between shoot length, root development, and seedling dry weight with early growth vigor further highlights the multifaceted nature of soybean growth dynamics. Phenophasic

development emerges as a critical factor, where early flowering and maturity, coupled with an optimal grain-filling period, are identified as key contributors to enhanced yield. Leaf area-related parameters, such as Leaf Area Index (LAI) and Leaf Area Duration (LAD), demonstrate substantial genotype-specific variations, underscoring their importance in influencing photosynthetic efficiency and overall crop productivity. The analysis of Crop Growth Rate (CGR) and Relative Growth Rate (RGR) provides insights into the biomass accumulation and growth patterns of different genotypes. The examination of physiological traits, including Chlorophyll Content Index (CCI), stomatal conductance, and water use efficiency, further elucidates the adaptability of soybean genotypes to varying environmental conditions. The integration of these findings into breeding programs and agricultural practices holds promise for enhancing soybean productivity under diverse conditions, ultimately contributing to sustainable and efficient crop management.

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