Enhancing Physiological Response of Chickpea Genotypes to Gibberellin for Improved Growth, Yield, and Sustainable Agricultural Production in Semi-Arid Regions

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Abstract

The present research aimed to study the Physiological Response of different Chickpea genotype to Foliar Application of Gibberellin. it was conducted during 2025–2026 growing season as field trial at Al-Bu'aitha Research Station, College of Agriculture, University of Anbar. The experiment was implemented according to a randomized complete block design (RCBD) in a split-plot arrangement with three replicates. The main plots represent four doses of gibberellin (0, 100, 200, and 300) mg l^{-1}, whereas the subplots included three cultivars of chickpea (G1, G2, and G3). The results showed the superiority of the plants of the genetic structure G2 in the traits of dry weight, leaf area, chlorophyll content, relative growth rate, crop growth rate, and net assimilation rate, as it gave averages of 16.21 g $plant^{-1}$, 1116.6 dm^2, 1.82 mg g^{-1}, 0.01720 g day^{-1}, 0.2140 mg cm^{-2} day^{-1}, and 0.3009 mg cm^{-2} day^{-1}, respectively. Gibberellin concentrations significantly affected the studied traits, as the concentration of 100 mg L^{-1} showed significant superiority in all studied traits, reaching 17.36 g $plant^{-1}$, 1207.4 dm2, 2.05 mg g-1, 0.0176 g day^{-1}, 0.2267 mg cm^{-2} day^{-1}, and 0.3295 mg cm^{-2} day^{-1}, respectively. The interaction between the two study factors also significantly affected all studied traits, as the treatment of 100 mg l^{-1} in interaction with the genetic structure G2 gave significant superiority in the traits of dry weight, leaf area, chlorophyll content, relative growth rate, crop growth rate, and net assimilation rate, with averages of 17.97 g $plant^{-1}$, 1226.4 dm2, 2.29 mg g^{-1}, 0.0181 g day^{-1}, 0.2358 mg cm^{-2} day^{-1}, and 0.3430 mg cm^{-2} day^{-1}, respectively.

Keywords: Gibberellin (GA_3), Chickpea, Foliar Application, genotypes

تحسين الاستجابة الفسيولوجية للحمص لإضافة الجبرلين وتباين التراكيب الوراثية لتعزيز النمو والإنتاجية وكفاءة الأداء الزراعي

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المستخلص

هدفت الدراسة الحالية إلى دراسة الاستجابة الفسيولوجية لتراكيب وراثية مختلفة من الحمص للرش الورقي بالجبرلين. نُفذت الدراسة خلال الموسم الزراعي 2025–2026 كتجربة حقلية في محطة أبحاث البوعيثة التابعة لكلية الزراعة، جامعة الأنبار. نُفذت التجربة وفق تصميم القطاعات الكاملة المعشاة (RCBD) بترتيب الألواح المنشقة (Split–Plot) وبثلاثة مكررات. مثّلت الألواح الرئيسية أربعة تراكيز من الجبرلين (0، 100، 200، و300 ملغم لتر⁻¹)، في حين تضمنت الألواح الثانوية ثلاثة تراكيب وراثية من الحمص (G1 و G2 و G3). أظهرت النتائج تفوق نباتات التركيب الوراثي G2 في صفات الوزن الجاف والمساحة الورقية ومحتوى الكلوروفيل ومعدل النمو النسبي ومعدل نمو المحصول وصافي معدل التمثيل الضوئي، إذ أعطت متوسطات بلغت 16.21 غم نبات⁻¹، و1116.6 دسم²، و1.82 ملغم غم⁻¹، و0.01720 غم يوم⁻¹، و0.2140 ملغم سم⁻² يوم⁻¹، و0.3009 ملغم سم⁻² يوم⁻¹ على التوالي. كما أثرت تراكيز الجبرلين معنوياً في الصفات المدروسة، إذ أظهر التركيز 100 ملغم لتر⁻¹ تفوقاً معنوياً في جميع الصفات المدروسة، حيث بلغت القيم 17.36 غم نبات⁻¹، و1207.4 دسم²، و2.05 ملغم غم⁻¹، و0.0176 غم يوم⁻¹، و0.2267 ملغم سم⁻² يوم⁻¹، و0.3295 ملغم سم⁻² يوم⁻¹ على التوالي. كذلك كان للتداخل بين عاملي الدراسة تأثير معنوي في جميع الصفات المدروسة، إذ حققت معاملة 100 ملغم لتر⁻¹ المتداخلة مع التركيب الوراثي G2 تفوقاً معنوياً في صفات الوزن الجاف والمساحة الورقية ومحتوى الكلوروفيل ومعدل النمو النسبي ومعدل نمو المحصول وصافي معدل التمثيل الضوئي، بمتوسطات بلغت 17.97 غم نبات⁻¹، و1226.4 دسم²، و2.29 ملغم غم⁻¹، و0.0181 غم يوم⁻¹، و0.2358 ملغم سم⁻² يوم⁻¹، و0.3430 ملغم سم⁻² يوم⁻¹ على التوالي.

الكلمات المفتاحية: الجبرلين، الحمص، الرش الورقي، التراكيب الوراثية.

Introduction

Chickpea (*Cicer arietinum* L.) is an annual winter herbaceous crop and a dicotyledonous plant belonging to the genus Cicereae within the family Fabaceae. This crop is among those adapted to the environmental condition's characteristic of arid and semi-arid regions globally (Jan, 2010). It ranks second in economic importance among legume crops after faba bean. The global cultivated area of chickpea reached about 14.842 million hectares, the majority of which is situated within arid and semi-arid regions globally, producing a 15.084 million tons with an average yield of 1071 kg ha^{-1}, distributed across several countries, most notably India, Australia, Turkey, Myanmar, Ethiopia, Pakistan, Russia, Iran, and Mexico, where India held the foremost position worldwide in both cultivated area and production (FAO, 2022). For Iraq, the cultivated area was just 12.5 hectares, with a total production of 13 tons and an average output /donum amounting to 250 kg. Nineveh Governorate was the leading province by cultivated area (COSIT, 2020).

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Chickpea crop is characterized by a high protein content in its seeds, as well as amino acids such as lysine and arginine, and anti-nutritional compounds. The seeds possess a carbohydrate content ranging from 38 to 55 %. while protein content ranges between (17–22%). The crop represents a good source of protein and carbohydrates, and its protein quality is superior to that of other legumes. It is also considered a good alternative to the more expensive animal protein (Kaur et al, 2005). In addition, it serves as a protein-rich feed source for livestock. Moreover, its cultivation enriches the soil with atmospheric nitrogen due to the efficiency of its roots in biological nitrogen fixation.

Chickpea crop suffers from several production-related problems, including irregular growth and flowering, where one-third of the flowers fail to develop into pods despite the availability of favorable weather conditions for its cultivation in Iraq. Nonetheless, the yield of local chickpea cultivars is very low, and this crop has not received sufficient attention in research studies despite its nutritional and economic importance. Therefore, it is necessary to use introduced cultivars to study their adaptability to environmental conditions in Iraq in general and Al-Anbar Governorate in particular, and the possibility of adopting their cultivation.

Plant growth regulators are capable of improving the physiological efficiency of plants, including photosynthetic capacity and the efficient distribution of absorbed compounds to different sinks within the plant. They can also modify plant growth and development, including gibberellins. Gibberellins (GA_3) are known as growth promoters that regulate many plant responses. Gibberellic acid is one of the most widely used growth regulators due to its major physiological effects, including stimulation of seed germination, its important role in increasing stem elongation, regulating the transition from vegetative to reproductive growth, initiating flowering, increasing the number of flowers per plant, and improving fertility percentage, which ultimately leads to increased pod set (Nair et al, 2024).

This study aimed to evaluate the physiological response of different chickpea genotypes to foliar application of gibberellin at various concentrations, to identify the most efficient genotype in improving growth and physiological traits under arid and semi-arid conditions affected by land degradation and desertification.

Materials and Methods

A field trial was implemented during the winter of 2025–2026 at the First Research Station located in Al-Bu'aitha area, College of Agriculture / University of Anbar, at latitude 33°N and longitude 43°W, to study the response of several chickpea genotype under different levels of gibberellin spraying.

The trial was implemented according to RCBD in a split-plot arrangement with three replicates. four concentrations of gibberellin (0, 100, 200, and 300 mg l^{-1}) allocated to main plot, while the the three chickpea cultivars (G1, G2, and G3) assigned to sub-plot. The experimental field was divided into 36 experimental units, with each unit having an area of 9 m^2.

Diammonium phosphate (DAP) fertilizer, comprising 46% phosphorus and 18% nitrogen, was administered as a basal application prior to planting at a rate of 80 kg P ha^{-1}. Additionally, nitrogen fertilizer was supplied at a rate of 40 kg N ha^{-1} in the form of urea, which contains 46% nitrogen. After calculating the nitrogen supplied from DAP, and was added in two equal doses: the first at planting and the second 40 days after sowing (Ali,2012). Seeds were sown on 1/11/2025 in rows (40×20 cm), at a plant density of 125,000 plants ha^{-1}. The experiment was irrigated immediately after sowing using sprinkler irrigation systems. All agricultural practices, including irrigation, weeding, hoeing, and pest control, were carried out whenever necessary.

Gibberellin was sprayed Two tim: the first at 35 days after emergence and the second before the onset of flowering. Spraying was carried out in the evening using a 15-liter knapsack sprayer. Only distilled water was sprayed to the control treatment. A non-ionic surfactant was added to lower surface tension, keep leaf surfaces wet and increase the uptake of materials into foliage by increasing penetration of spray solution across foliar surfaces.

Data Collection;

1. Dry weight (g $plant^{-1}$): Five plants from the central rows of each experimental unit were taken randomly at soil level. The plants were washed with water, cut and dried in the laboratories of College of Agriculture at 60°C in an oven until constant weight was achieved.
2. Leaf area (dm^2 $plant^{-1}$): Leaf area was estimated using the DIGIMIZER leaf surface area measurement program (Alqaisi et al, 2020) and the average was calculated according to the following equation:
   Leaf area (dm^2 $plant^{-1}$) = number of leaves per plant × leaf area
3. Total chlorophyll content (mg g^{-1} fresh weight): Chlorophyll content was estimated following equation determine by (Lightenhaler, 1987) "using the total chlorophyll content in leaves:
   Chlorophyll (Total) = 20.2 (A645) + 8.02 (A663) × V / (1000 × W)
   A: optical density of chlorophyll at wavelengths 645 and 663 nm.
   V: volume of acetone solution.
   W: fresh leaf weight (mg)."

4. Relative Growth Rate (RGR) (g day^{-1}): Calculated according to (Hunt,1982) "using the following equation:

$$RGR = \frac{Lin\,W2 - Lin\,W1}{T2 - T1}$$

lnW1: natural logarithm of plant dry weight (g) at time T1.
lnW2: natural logarithm of plant dry weight (g) at time T2."

5. Crop Growth Rate (CGR) (mg cm^{-2} day^{-1}): Crop growth rate was calculated using the following equation (Hunt,1982):

$$CGR = \frac{1}{AG} \times \frac{W2 - W1}{T2 - T1}$$

AG: land area occupied by a single plant (cm^2 plant^{-1}).

6. Net Assimilation Rate (NAR) (mg cm^{-2} day^{-1}): This trait was calculated using the following equation (Hunt,1982):

$$NAR = \frac{W2 - W1}{T2 - T1} \times \frac{Lin\,A2 - Lin\,A1}{LA2 - LA1}$$

lnA1: natural logarithm of leaf area (cm^2) at time T1
lnA2: natural logarithm of leaf area (cm^2) at time T2

Statistical Analysis

All analyses were conducted using GenStat software (Steel et al,1980) ، Differences among treatment means were evaluated using the least significant difference (LSD) test at the 0.05 probability level The findings were analyzed with reference to the computed mean values

Results and Discussion

Dry Weight (g plant^{-1})

The results shown in Table 2 indicate the presence of significant differences in the dry weight trait for each of the genetic structures, gibberellin concentrations, and the interaction between them. It is noted that the plants of the Cultivar (G2) were superior, as they gave the highest average of 16.21 g plant^{-1} compared with the plants of the (G1), which gave the lowest average for the trait, reaching 15.28 g plant^{-1}. The observed variation may be attributed to differences in the genetic makeup of the studied genotypes and their ability to respond to the surrounding environmental conditions These findings are consistent with those reported by previous studies (Khan et al., 2024; Laali et al., 2022), The results of the same table show the superiority of the concentration of 100 mg L^{-1} of gibberellin, as it gave the highest average for the trait, reaching 17.36 g plant^{-1}, whereas the control treatment recorded the lowest average, reaching 13.33 g plant-1. The reason for this may be due to the fact that gibberellin (GA3) has a vital role in enhancing the growth traits of chickpea plants, as it acts as a hormonal regulator that stimulates cell division and cell elongation, which is directly reflected in increasing the leaf surface area and light interception efficiency. These contribute to improving the rate of dry weight accumulation by enhancing photosynthetic efficiency and directing assimilates, especially when it is used at optimal concentrations that raise the efficiency of foliar absorption. This agrees with (Sarkar et al, 2023).

It is also noted from the results that there was a significant interaction between the cultivars and gibberellin spray concentrations in the dry weight trait, as the plants of the cultivar (G2), when interacting with the concentration of 100 mg L-1, were distinguished by giving the highest average, reaching 17.97 g plant^{-1}, whereas the interaction of the structure (G3) with the control treatment recorded the lowest average, reaching 12.61 g plant^{-1}.

Table 1. Effect of genotype and Gibberellin concentrations and the interaction between them on the Dry Weight (g plant^{-1}) of Chickpea crop.

Gibberellin Concentrations (mg l^{-1})	genotype			Mean
	G1	G1	G1	
0	13.40	13.97	12.61	13.33
100	17.29	17.97	16.82	17.36
200	15.87	16.08	15.19	15.71
300	16.66	16.81	16.50	16.66
Mean	15.28	16.21	15.80	
L.S.D	genotype	Concentrations	interaction	
0.05	0.071	0.128	0.159	

Leaf Area (dm² plant⁻¹)

Table 2 reveals that there were highly signifi-cant differences in area of leaf among chickpea genotype, gibberellin concentration and interaction. Mean value of cultivar G2 recorded the highest (1116.6 dm² plant⁻¹) and lowest mean value was observed on cultivar G1 (1060.2 dm² plant⁻¹). This increase can be related to genetic diversity between cultivars as well as genetically conditioned differences in the modular efficiency of cell division and leaf cell expansion in response to varying environmental conditions. Recent studies indicate that cultivars with larger leaf area are characterized by a higher ability to allocate photosynthetic products toward the vegetative system during early growth stages, giving them a competitive advantage in improving light interception efficiency and dry matter accumulation compared with sensitive cultivars, which tend to reduce their leaf area as a defense mechanism to minimize transpiration. This is consistent with (Fazeli et al, 2025).

The same table also shows that the 100 mg l⁻¹ gibberellin treatment recorded the highest mean leaf area of 1207.4 dm² plant⁻¹, compared with the control treatment (distilled water), which recorded the lowest mean value of 945.0 dm² plant⁻¹. This may be due to the effect of gibberellin at 100 mg l⁻¹ in increasing cell wall extensibility through the activation of expansin enzymes. This concentration may also provide sufficient turgor pressure to maximize genetically controlled leaf blade expansion, thereby increasing the number of chloroplasts per unit area and supplying the energy required for leaf expansion. This is in agreement with (Perach et al, 2025).

The findings additionally demonstrate a significant interaction between the two factors affecting leaf area. The combination of cultivar G2 with 100 mg l⁻¹ gibberellin recorded the highest value of 1226.4 dm² plant⁻¹, while the interaction between cultivar G1 and the control treatment achieved the least value at 901.8 dm² plant⁻¹.

Table 2. Effect of genotype and Gibberellin concentrations and the interaction between them on the Leaf Area (dm² plant⁻¹) of Chickpea crop

Gibberellin Concentrations (mg l⁻¹)	genotype			Mean
	G1	G1	G1	
0	901.8	993.1	940.1	945.0
100	1184.8	1226.4	1210.9	1207.4
200	1023.1	1092.6	1048.3	1054.7
300	1131.1	1154.3	1138.6	1141.4
Mean	1060.2	1116.6	1084.5	
L.S.D	genotype	Concentrations	interaction	
0.05	7.45	8.52	13.92	

Estimation of total chlorophyll (mg g⁻¹ fresh weight):

The results of the chlorophyll content trait, as shown in Table (3), indicate the presence of significant differences among the genetic structures, gibberellin concentrations, and the interaction between them. The plants of the genetic structure G2 were superior by giving the highest average of 1.82 mg g⁻¹ compared with the plants of the genetic structure G1, which gave the lowest average for the trait, reaching 1.59 mg g⁻¹. The reason for the difference among the chickpea genetic structures may be due to the activity of genes responsible for chlorophyll-building enzymes, such as the ChlH gene. Chlorophyll in chickpea also contains protein complexes called Light-Harvesting Complex II. This means that genetically superior structures produce more stable binding proteins that act as a shield protecting the chlorophyll molecule from photo-oxidation; therefore, the chlorophyll concentration remains high and does not degrade under high light intensity. This agrees with what was found by (Hammad & Ali,2024).

From the same table, significant differences are observed among gibberellin spray concentrations, as the concentration of 100 mg l⁻¹ gave the highest average for the trait, reaching 2.05 mg g⁻¹, whereas the control treatment recorded the lowest average for the trait, reaching 1.08 mg g⁻¹. The reason for this may be due to the action of gibberellin as a strong anti-senescence agent for tissues, which prevents the activity of the enzyme chlorophyllase that breaks down the green pigment, thereby maintaining the sustainability of the molecules for a longer period. This leads to keeping the leaves at the peak of their photosynthetic efficiency for a long period. It also acts as a stimulating dose that increases the rate of incorporation of the magnesium atom into the porphyrin ring, which raises chlorophyll density in the leaf. This agrees with (Kywe et al, 2025).

As for the interaction between the genetic structures and gibberellin spray concentrations, significant differences were observed in this trait, as the interaction of the genetic structure G2 with the concentration of 100 mg l⁻¹ of gibberellin gave the highest value, reaching 2.29 mg g⁻¹, whereas the genetic structure G1, when interacting with the control treatment, recorded the lowest value, reaching 1.02 mg g⁻¹.

Table 3. Effect of genotype and Gibberellin concentrations and the interaction between them on the Total Chlorophyll Content (mg g⁻¹ fresh weight) of Chickpea crop

Gibberellin Concentrations (mg l^{-1})	genotype			Mean
	G1	G1	G1	
0	1.02	1.05	1.17	1.08
100	2.17	2.29	1.77	2.05
200	1.62	1.74	1.81	1.72
300	1.51	2.27	1.81	1.87
Mean	1.59	1.82	1.64	
L.S.D	genotype	Concentrations	interaction	
0.05	0.150	0.274	0.338	

Relative growth rate of the plant (g day^{-1}):

The results of the relative growth rate trait of the plant, as shown in Table (4), indicate the presence of significant differences for the chickpea genetic structures, gibberellin spray concentrations, and the interaction between them in the relative growth rate. It is noted that the plants of the genetic structure G2 were distinguished by giving the highest average for the relative growth rate trait, reaching 0.0172 g day^{-1}, whereas the plants of the genetic structure G3 gave the lowest average for the trait, reaching 0.0168 g day^{-1}. The reason for the increase in relative growth rate (RGR) in certain genetic structures of chickpea may be due to their genetic ability to convert a larger amount of assimilates (sugars) toward building leaf area instead of non-assimilatory tissues, such as thick roots or stems, during the early vegetative stage. This physiological behavior leads to an increase in leaf area, which leads to increased dry matter production, and consequently the relative growth rate doubles. This agrees with (Nahusenay et al, 2024).

From the same table, significant differences are observed among gibberellin spray concentrations, as the treatment of 100 mg l^{-1} was superior by giving the highest average of relative growth rate, reaching 0.0176 g day^{-1}, whereas the control treatment recorded the lowest average of relative growth rate, reaching 0.0164 g day^{-1}. The reason for this may be due to the ability of gibberellin to maximize the activity of the Rubisco enzyme and increase the chlorophyll content in the leaves. This physiological stimulation led to an increase in the plant's ability to produce dry matter per unit of the already existing plant mass and per unit time. This agrees with (Kywe et al, 2025؛ Obada et al, 2023).

It is also observed from the results of the same table that there were significant differences in the interaction between the genetic structures and gibberellin spray concentrations, as the genetic structure G2 with the concentration of 100 mg l^{-1} recorded the highest interaction value, reaching 0.0181 g day^{-1}, whereas the plants of the genetic structure G1 in interaction with the control treatment recorded the lowest interaction value, reaching 0.0163 g day^{-1}.

Table 4. Effect of genotype and Gibberellin concentrations and the interaction between them on the R.G.R (g day^{-1}) of Chickpea crop

Gibberellin Concentrations (mg l^{-1})	genotype			Mean
	G1	G1	G1	
0	0.0163	0.0164	0.0166	0.0164
100	0.0175	0.0181	0.0170	0.0176
200	0.0180	0.0177	0.0170	0.0175
300	0.0167	0.0166	0.0164	0.0166
Mean	0.0171	0.0172	0.0168	
L.S.D	genotype	Concentrations	interaction	
0.05	0.0003	0.0003	0.0006	

Crop growth rate (mg cm^{-2} day^{-1})

It was observed from the results of the crop growth rate trait in Table 5 that there was a significant effect of the, gibberellin concentrations, and the interaction between them on this trait. It is noted that the plants of the genetic structure G2 were superior in this trait by giving the highest average of 0.2140 mg cm^{-2} day^{-1} compared with the plants of the genetic structure G1, which recorded the lowest average for the same trait, with an average of 0.2039 mg cm^{-2} day^{-1}. The reason for this may be due to the high ability of this genetic structure to intercept and assimilate light energy per unit area. This agrees with (Singh & Patel, 2025).

The results of Table 5 also show that the spray treatment at a concentration of 100 mg l^{-1} gave the highest average for the trait, reaching 0.2267 mg cm^{-2} day^{-1}, whereas the control treatment recorded the lowest average, reaching 0.1808 mg cm^{-2} day^{-1}. The reason for this may be attributed to the fact that gibberellin facilitates the transfer of assimilates (sugars) from the leaves (source) to the growing tips and pods (sink), which reduces energy loss and makes the rate of building new tissues in the plant higher than the rate of respiratory breakdown, leading to the highest crop growth rate without hormonally stressing the plant. This agrees with what was reached by (Siddiqui et al, 2024; Rahman et al,2025).

It is noted from the same table that the interaction between the two study factors had a significant effect on this trait, as the plants of the genetic structure G2, when interacting with the concentration of 100 mg l^{-1}, gave the highest value, reaching 0.2358 mg cm^{-2} day^{-1}, whereas the plants of the genetic structure G1 with the control treatment gave the lowest average for the interaction, reaching 0.1737 mg cm^{-2} day^{-1}.

Table 5. Effect of genotype and Gibberellin concentrations and the interaction between them on the C.G.R (mg cm^{-2} day^{-1}) of Chickpea crop

Gibberellin Concentrations (mg l^{-1})	genotype			Mean
	G1	G1	G1	
0	0.1737	0.1860	0.1826	0.1808
100	0.2184	0.2358	0.2258	0.2267
200	0.2058	0.2147	0.2182	0.2129
300	0.2178	0.2197	0.2192	0.2189
Mean	0.2039	0.2140	0.2114	
L.S.D	genotype	Concentrations	interaction	
0.05	0.00285	0.00221	0.00454	

Net Assimilation Rate (mg cm^{-2} day^{-1})

The results presented in Table 6 indicate significant differences among chickpea genotype, gibberellin concentrations, and their interaction in net assimilation rate (NAR). genotype G2 showed superiority by recording the highest mean value of 0.3009 mg cm^{-2} day^{-1}, while cultivar G1 recorded the lowest mean value of 0.2872 mg cm^{-2} day^{-1}. The superiority of genotype G2 in NAR may be attributed to its high efficiency in managing carbon and physiological resources, meaning that the plant is able to produce greater amounts of (dry matter) in a shorter time and with less use of light energy, thereby increasing NAR compared with other cultivars that exhibit lower enzymatic activity. This is consistent with (Zubair & Gupta, 2024).

Given the same tabulated results, we can also note that gibberellin concentrations also affected positively as the highest mean value of 0.3295 mg cm^{-2} day^{-1} was obtained with the use of gibberellin in a dose of 100 mg l^{-1} and controlled treatment resulting in the lowest mean value (0.2658 mg cm^{-2} day^{-1}). The results show that increasing the concentration of gibberellin increased net assimilation rate significantly. This may be due to the role of gibberellin in increasing effective leaf area and improving light use efficiency, as well as stimulating an increase in total chlorophyll content in the cultivars, which provided greater chemical energy for carbon fixation processes. This ultimately enhanced the plant's efficiency in converting light energy into stored dry matter. This is in agreement with (Ibrahim et al, 2024).

Regarding the interaction between cultivars and gibberellin concentrations, the combination of cultivar G2 with 100 mg l^{-1} recorded the highest value of 0.3430 mg cm^{-2} day^{-1}, while cultivar G1 under the control treatment recorded the lowest mean value of 0.2578 mg cm^{-2} day^{-1}.

Table 6. Effect of genotype and Gibberellin concentrations and the interaction between them on the N.A.R (mg cm^{-2} day^{-1}) of Chickpea crop

Gibberellin Concentrations (mg l^{-1})	genotype			Mean
	G1	G1	G1	
0	0.2578	0.2635	0.2660	0.2658
100	0.3291	0.3430	0.3165	0.3295
200	0.2957	0.2642	0.2654	0.2751
300	0.2660	0.3327	0.3033	0.2973
Mean	0.2872	0.3009	0.2878	
L.S.D	genotype	Concentrations	interaction	
0.05	0.00488	0.00711	0.00988	

Conclusion

It can be concluded from this study that chickpea genotypes showed variation in growth and physiological traits, with cultivar G2 exhibiting superiority in most of these traits, which was positively reflected in overall plant performance. The study also concluded that the optimal concentrations positively affected all growth and concluded that spraying with gibberellin at a conce optimum concentration that achieved maximum pl successfully balanced the biological processes. It was also observed that cultivar G2 showed better tolerance to environmental conditions and a positive response to gibberellin concentrations, which was reflected in its superior performance.

Sustainability Statement

This study contributes to sustainable agricultural production by evaluating the physiological responses of chickpea (*Cicer arietinum* L.) genotypes to gibberellin application under semi-arid conditions. The research highlights the role of plant growth regulators in improving crop growth, yield stability, and stress adaptation, thereby promoting efficient resource utilization and supporting resilient and sustainable food production systems in water-limited environments.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. All data generated or analyzed during this study are included in the published article and its supplementary materials, where applicable.

Author Contributions (CRediT)

First author: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft. Second author: Supervision, Validation, Methodology, Writing – review & editing. Third author: Supervision, Resources, Project administration, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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