Journal of Kyzylorda Scholarly Review

P-ISSN:3006-0265 | E-ISSN:3007-4681. Published by the Open University of Kyzylorda
Copyright © Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC-BY).
https://bulletin.ouk.kz/index.php/bulletin/index



# EFFECT OF SPRAYING WITH INDOLE-3-ACETIC ACID (IAA) ON SOME PHYSIOLOGICAL TRAITS AND YIELD OF TWO MAIZE (*ZEA MAYS* L.) CULTIVARS

**Afrah Abdul Karim Hussein**
Department of Field Crops, College of Agriculture, Tikrit University, Tikrit, Iraq
Corresponding author: afrah.a.alkarim@tu.edu.iq

**Abstract**: A field experiment was conducted at the College of Agriculture, Tikrit University, Iraq, in the spring season of 2025 to study the effect of two maize (*Zea mays* L.) cultivars (A1 and A2) and three concentrations of the auxin indole-3-acetic acid (IAA): B1, 0 mg $L^{-1}$ (unsprayed control); B2, 30 mg $L^{-1}$; and B3, 60 mg $L^{-1}$, and their interaction, on some physiological traits and yield. The experiment was laid out as a factorial in a randomized complete block design (RCBD) with three replicates, and IAA was sprayed once, two weeks after sowing. Cultivar A1 was significantly superior to A2 in all studied traits, recording the highest means of biomass duration (17,801 g day), crop growth rate (CGR, 0.012230 g $m^{-2}$ $day^{-1}$), plant dry weight (287.1 g), biological yield (861.0 g) and number of ears (8.667 ears $plant^{-1}$), which is attributed to its genetic make-up and its higher efficiency in photosynthesis and dry-matter accumulation. The 60 mg $L^{-1}$ IAA concentration was significantly superior in all traits, giving the highest biomass duration (18,168 g day), CGR (0.01257 g $m^{-2}$ $day^{-1}$), plant dry weight (293.9 g), biological yield (882.0 g) and number of ears (8.67 ears $plant^{-1}$), increases of 172%, 279%, 212%, 212% and 63%, respectively, over the control; this is attributed to the role of auxin in stimulating cell division and elongation, delaying leaf senescence and maintaining leaf area. The interaction was significant: A1 sprayed with 60 mg $L^{-1}$ recorded the highest values in all traits, with biomass duration of 24,157 g day, CGR of 0.017453 g $m^{-2}$ $day^{-1}$, plant dry weight of 398.70 g, biological yield of 1,196.0 g and 11.333 ears $plant^{-1}$, indicating that cultivar A1 was the most responsive to IAA spraying at 60 mg $L^{-1}$.
**Keywords:** auxin; biological yield; crop growth rate; physiological traits; plant growth regulator; *Zea mays*.

## 1. Introduction

Maize (*Zea mays* L.) is the leading cereal in the world by production volume and is projected to become the most widely grown and traded crop within the coming decade; it is primarily a feed crop, while remaining an important staple and an industrial raw material (Erenstein et al., 2022). Global cereal output reached about 3.1 Gt in 2024, a 27% increase since 2010 that was driven mainly by yield gains, and maize, wheat and rice together account for 91% of cereal production, with maize being the principal driver of recent increases (FAO, 2024, 2025). Sustaining this trajectory depends increasingly on raising productivity per unit area rather than expanding the cultivated area.

In Iraq, the gap between maize demand and domestic supply remains wide. National maize output in 2026 was estimated at only about 0.3 million tonnes, whereas maize imports for the 2026/27 marketing year were forecast at about 1 million tonnes, some 13% above the five-year average, largely to meet livestock feed demand (FAO-GIEWS, 2026). Production is constrained by water scarcity, rising evapotranspiration and declining effective rainfall, and maize is more sensitive than wheat to water deficits, particularly during the development and mid-season stages (Al-Shaibani et al., 2026). Heat during grain filling also depresses kernel auxin content and down-regulates auxin response factor (*ZmARF*) genes, with stronger reductions in heat-sensitive genotypes (Li et al., 2025). Building resilient cereal production in Iraq therefore calls for locally validated, low-cost technologies that combine traditional practice with modern tools at every link of the production chain, from field management to seed storage (Khalaf et al., 2027). Practices that extend the photosynthetically active life of the canopy and accelerate dry-matter production are of direct practical value under these conditions.

Indole-3-acetic acid is the principal naturally occurring auxin. It is synthesized mainly in young leaves and shoot apices, transported directionally through the plant, and regulates cell division, cell expansion, vascular differentiation, organogenesis and tropic responses (Taiz et al., 2022). Its transcriptional effects are mediated by the nuclear TIR1/AFB receptors, which promote the degradation of Aux/IAA repressors and release auxin response factors (ARFs) to regulate auxin-responsive genes (Liu et al., 2024); TIR1/AFB receptors also generate cAMP as a second messenger that contributes to auxin-responsive transcription (Wu et al., 2025). In parallel, a cell-surface pathway involving ABP1 and TRANSMEMBRANE KINASE (TMK) proteins activates plasma-membrane $H^+$-ATPases within minutes, acidifying the apoplast and loosening the cell wall, which provides a molecular basis for the classical acid-growth response (Lin et al., 2021; Di & Kriechbaumer, 2026). In maize, auxin biosynthesis (*VT2*|*ZmTAA1*, *SPI1*|*YUCCA*), signalling (*BIF1*, *BIF4*, *ZmARF12*) and transport (*BIF2*) genes are required for the initiation of axillary meristems and lateral organs in both tassel and ear (Cowling et al., 2023), and auxin pathways interact extensively with drought, salinity, heat, cold and waterlogging responses (Gonzales & Kelley, 2025).

Auxin also acts as a negative regulator of leaf senescence, and a decline in leaf auxin increases tissue sensitivity to ethylene, which accelerates senescence (Huang et al., 2022; Panozzo et al., 2025). Delaying senescence is agronomically important because stay-green maize maintains its photosynthetic capacity for longer after flowering, a trait that has contributed to the yield gains of modern hybrids (Chibane et al., 2024), and practices that delay post-silking leaf senescence increase the grain yield of densely planted maize (Guo et al., 2026). Genotypes that sustain a larger leaf area for longer accumulate more biomass and set more kernels (Abo-Hamed et al.,

2025). Nonetheless, the effect of auxin on the photosynthetic apparatus is context-dependent: in *Arabidopsis*, auxin represses chlorophyll biosynthesis genes through an ARF7–IAA14 module (Luo W.-G. et al., 2023).

Foliar spraying is an efficient route for delivering growth-promoting inputs, but its outcome depends on how the input is applied: in Mosul, northern Iraq, the method of application significantly modified plant height, leaf number, chlorophyll (SPAD) and shoot and root dry weights of senna seedlings, with a significant input × method interaction for all traits (Kahlel et al., 2021). Field evidence on exogenous IAA in cereals is limited and variable. In maize, a single foliar spray of IAA (20–30 ppm), alone or blended with boron, increased leaf area, relative growth rate, chlorophyll, kernels per cob and grain yield per plant, with clear differences between varieties (Hussain et al., 2025). In sorghum, IAA improved growth, chlorophyll, ion balance and antioxidant capacity under cadmium stress (Bibi et al., 2025). In contrast, foliar IAA in canola increased leaf number but produced many empty seed clusters and the lowest seed weight per plant (Hemati et al., 2022), and an excessive IAA supply acted as a stressor in chrysanthemum, raising malondialdehyde and lowering endogenous hormone levels (Wang et al., 2025). Such variability is partly explained by auxin homeostasis: GH3 enzymes conjugate excess IAA to amino acids (Luo P. et al., 2023), and in maize the synthesis of 1-*O*-indole-3-acetyl-*myo*-inositol acts as a reservoir that buffers free IAA levels (Ciarkowska et al., 2023). Cultivar-specific responses to growth regulators have also been reported for Iraqi maize, for example with foliar kinetin (Al-Issawi & Abood, 2024).

Despite this background, few field studies in Iraq have quantified how foliar IAA affects the temporal dynamics of dry-matter production, expressed through growth-analysis indices such as biomass duration and crop growth rate, or whether cultivars differ in their responsiveness to IAA. We hypothesized that a single early foliar application of IAA would prolong biomass duration and accelerate crop growth, thereby increasing biomass and ear production, and that the magnitude of the response would depend on cultivar. The objectives were therefore (i) to evaluate the effect of two IAA concentrations (30 and 60 mg $L^{-1}$) on growth dynamics, biomass and ear number of two maize cultivars, and (ii) to determine whether cultivars differ in responsiveness to foliar IAA.

## 2. Materials and Methods

### 2.1. Experimental site and season

A field experiment was conducted at the research station of the Department of Field Crops, College of Agriculture, Tikrit University, Salah Al-Din Governorate, Iraq (approximately 34°36′ N, 43°41′ E), in the spring season of 2025. The region has a semi-arid climate with hot, dry summers. Seeds were sown on 20 March 2025, and plants were harvested at full maturity. The experimental timeline is shown in Figure 1.

### 2.2. Experimental design and crop management

The experiment was carried out as a factorial experiment (2 × 3) in a randomized complete block design (RCBD) with three replicates. The land was ploughed, harrowed and levelled and divided into three blocks of six experimental units each (18 experimental units in total), each unit measuring 3 $m^2$. Seeds were sown in rows 70 cm apart with 20 cm between plants, at a depth of 4–5 cm and three seeds per hill, and seedlings were thinned to one plant per hill 15 days after sowing. Diammonium phosphate (DAP; 18% N, 46% $P_2O_5$) was added before sowing at 200 kg $ha^{-1}$ (50 kg $donum^{-1}$), and potassium sulphate ($K_2SO_4$) was applied at 320 kg $ha^{-1}$ (80 kg donum-

$^{1}$) in two equal doses. Plots were irrigated according to crop requirements, and weeds were controlled throughout the season.

### 2.3. Treatments

The experiment included two factors. The first factor comprised two yellow maize cultivars, A1 ('Sagunto') and A2 ('KBR'). The second factor comprised three concentrations of the growth regulator indole-3-acetic acid (IAA): B1, 0 mg $L^{-1}$ (control, without spraying); B2, 30 mg $L^{-1}$; and B3, 60 mg $L^{-1}$. The six treatment combinations were A1B1, A1B2, A1B3, A2B1, A2B2 and A2B3. IAA was first dissolved in methanol (20 mL $L^{-1}$ of final solution) and brought to volume with distilled water; no surfactant was added. The solutions were sprayed once on the foliage, two weeks after sowing, with a hand sprayer until full wetting.

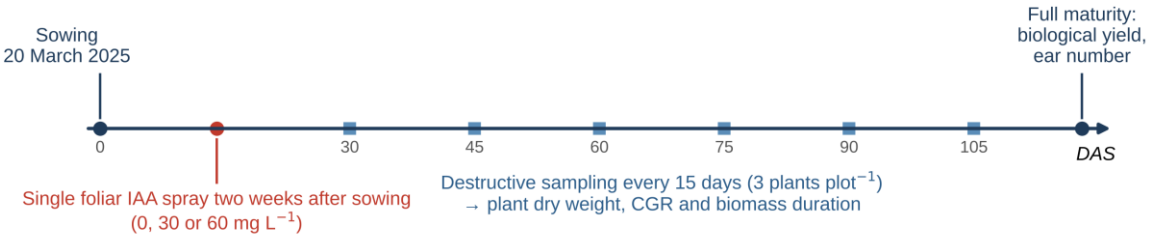


**Figure 1.** Schematic timeline of the experiment (Tikrit, spring 2025). IAA was sprayed once, two weeks after sowing; samples for growth analysis were taken every 15 days starting 30 days after sowing (DAS), and biological yield and ear number were recorded at full maturity. The time axis is schematic.

### 2.4. Studied traits

**Biomass duration (BMD, g day).** Three plants were taken at random from the middle rows of each experimental unit every 15 days, starting 30 days after sowing; they were cut and dried in an oven at 70 °C for 72 h to constant weight and then weighed. Biomass duration was calculated from successive samplings as $BMD = \Sigma [(W_i + W_{i+1}) / 2] \times (t_{i+1} - t_i)$, where W is the plant dry weight at time t (Watson, 1952; Hunt, 1978).

**Crop growth rate (CGR, g $m^{-2}$ $day^{-1}$).** CGR was calculated according to the equation of Watson (1952): $CGR = (W_2 - W_1) / [GA \times (t_2 - t_1)]$, where $W_1$ and $W_2$ are the dry weights at times $t_1$ and $t_2$, and GA is the ground area occupied by the plants (Hunt et al., 2002).

**Plant dry weight (g $plant^{-1}$).** Three plants were taken at random from the middle rows of each experimental unit every 15 days; plants were placed in perforated paper bags and dried in an electric oven at 70 °C for 72 h to constant weight, then weighed on a sensitive balance, and the total dry weight was recorded per plant (Hunt, 1978).

**Biological yield (g).** At full maturity, plants of the middle rows were harvested, and the above-ground parts (stems, leaves and ears) were weighed after air-drying (Donald, 1962).

**Number of ears (ears $plant^{-1}$).** At full maturity, the ears of three randomly selected plants from the middle rows of each experimental unit were counted, and the mean was calculated as the number of ears divided by the number of plants.

### 2.5. Statistical analysis

Data were analysed according to the randomized complete block design (RCBD) as a factorial experiment using the SAS statistical program, and treatment means were

compared using Duncan's multiple range test at a probability level of $P \leq 0.05$ (Al-Rawi & Khalafallah, 2000).

## 3. Results

### 3.1. Biomass duration

The results in Table 1 show significant differences between the two cultivars in biomass duration. Cultivar A1 was significantly superior, recording 17,801 g day compared with 8,877 g day for A2, a difference of 100.5%. Biomass duration increased progressively with IAA concentration, from 6,682 g day in the control (B1) to 15,167 and 18,168 g day at 30 and 60 mg $L^{-1}$, increases of 127% and 172%, respectively, and the three concentrations differed significantly. The gain obtained between 0 and 30 mg $L^{-1}$ (8,485 g day) was almost three times that obtained between 30 and 60 mg $L^{-1}$ (3,001 g day). The interaction was significant: A1B3 recorded the highest biomass duration (24,157 g day), significantly exceeding A1B2 (21,773 g day), whereas A2B1 recorded the lowest value (5,891 g day).

**Table 1.** Effect of cultivars, IAA concentrations and their interaction on biomass duration (g day) of maize.

| IAA (mg $L^{-1}$) | Cultivar A1 | Cultivar A2 | Mean of IAA |
|---|---|---|---|
| 0 (B1) | 7,473.6 d | 5,891.0 e | 6,682 c |
| 30 (B2) | 21,773.0 b | 8,561.0 d | 15,167 b |
| 60 (B3) | 24,157.0 a | 12,178.0 c | 18,168 a |
| Mean of cultivar | 17,801 a | 8,877 b | |

Means followed by the same letter(s) within the interaction cells, within the IAA means column, or within the cultivar means row do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

### 3.2. Crop growth rate

Cultivar A1 was significantly superior to A2 in crop growth rate, recording 0.012230 compared with 0.005227 g $m^{-2}$ $day^{-1}$, an increase of 134% (Table 2). IAA increased CGR from 0.00332 g $m^{-2}$ $day^{-1}$ in the control to 0.01030 and 0.01257 g $m^{-2}$ $day^{-1}$ at 30 and 60 mg $L^{-1}$, increases of 210% and 279%, respectively, with significant differences among the three concentrations. The interaction was significant: A1B3 recorded the highest CGR (0.017453 g $m^{-2}$ $day^{-1}$), followed by A1B2 (0.015301 g $m^{-2}$ $day^{-1}$), whereas A2B1 recorded the lowest value (0.002693 g $m^{-2}$ $day^{-1}$).

**Table 2.** Effect of cultivars, IAA concentrations and their interaction on crop growth rate (g $m^{-2}$ $day^{-1}$) of maize.

| IAA (mg $L^{-1}$) | Cultivar A1 | Cultivar A2 | Mean of IAA |
|---|---|---|---|
| 0 (B1) | 0.003941 e | 0.002693 f | 0.00332 c |
| 30 (B2) | 0.015301 b | 0.005298 d | 0.01030 b |
| 60 (B3) | 0.017453 a | 0.007689 c | 0.01257 a |
| Mean of cultivar | 0.012230 a | 0.005227 b | |

Means followed by the same letter(s) within the interaction cells, within the IAA means column, or within the cultivar means row do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

### 3.3. Plant dry weight

Cultivar A1 was significantly superior to A2 in plant dry weight, with 287.1 g compared with 133.9 g, an increase of 114% (Table 3). Plant dry weight increased

from 94.3 g in the control to 243.3 and 293.9 g at 30 and 60 mg $L^{-1}$ (increases of 158% and 212%), and the three concentrations differed significantly. In the interaction, A1B3 produced the highest plant dry weight (398.70 g), significantly exceeding A1B2 (354.78 g), whereas A2B1 produced the lowest (80.67 g).

**Table 3.** Effect of cultivars, IAA concentrations and their interaction on plant dry weight (g $plant^{-1}$) of maize.

| IAA (mg $L^{-1}$) | Cultivar A1 | Cultivar A2 | Mean of IAA |
|---|---|---|---|
| 0 (B1) | 107.89 e | 80.67 f | 94.3 c |
| 30 (B2) | 354.78 b | 131.89 d | 243.3 b |
| 60 (B3) | 398.70 a | 189.20 c | 293.9 a |
| Mean of cultivar | 287.1 a | 133.9 b | |

Means followed by the same letter(s) within the interaction cells, within the IAA means column, or within the cultivar means row do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

### 3.4. Biological yield

The results in Table 4 show that cultivar A1 was significantly superior in biological yield, recording 861.0 g compared with 401.8 g for A2, an increase of 114%. IAA at 30 and 60 mg $L^{-1}$ increased biological yield from 282.8 g in the control to 730.0 and 882.0 g, increases of 158% and 212%, respectively, with significant differences among concentrations. The interaction was significant: the highest biological yield was recorded by A1B3 (1,196.0 g), followed by A1B2 (1,064.3 g), and the lowest by A2B1 (242.0 g), which indicates that cultivar A1 was the most responsive to auxin spraying.

**Table 4.** Effect of cultivars, IAA concentrations and their interaction on biological yield (g) of maize.

| IAA (mg $L^{-1}$) | Cultivar A1 | Cultivar A2 | Mean of IAA |
|---|---|---|---|
| 0 (B1) | 323.7 e | 242.0 f | 282.8 c |
| 30 (B2) | 1,064.3 b | 395.7 d | 730.0 b |
| 60 (B3) | 1,196.0 a | 567.7 c | 882.0 a |
| Mean of cultivar | 861.0 a | 401.8 b | |

Means followed by the same letter(s) within the interaction cells, within the IAA means column, or within the cultivar means row do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

### 3.5. Number of ears

Cultivar A1 was significantly superior to A2 in number of ears, with 8.667 compared with 5.667 ears $plant^{-1}$, an increase of 53% (Table 5). IAA at 30 and 60 mg $L^{-1}$ increased the number of ears from 5.333 to 7.500 and 8.670 ears $plant^{-1}$ (41% and 63%), and the two concentrations did not differ significantly from each other. The interaction was significant: in A1, the number of ears rose from 5.333 in the control to 9.333 and 11.333 ears $plant^{-1}$ at 30 and 60 mg $L^{-1}$, all significantly different, whereas in A2 it rose only to 5.667 and 6.000 ears $plant^{-1}$, and A2B2 did not differ significantly from either A2B1 or A2B3. Both cultivars recorded the lowest value (5.333 ears $plant^{-1}$) in the absence of IAA.

**Table 5.** Effect of cultivars, IAA concentrations and their interaction on number of ears (ears $plant^{-1}$) of maize.

| IAA (mg $L^{-1}$) | Cultivar A1 | Cultivar A2 | Mean of IAA |
|---|---|---|---|
| 0 (B1) | 5.333 d | 5.333 d | 5.333 b |
| 30 (B2) | 9.333 b | 5.667 cd | 7.500 a |
| 60 (B3) | 11.333 a | 6.000 c | 8.670 a |
| Mean of cultivar | 8.667 a | 5.667 b | |

Means followed by the same letter(s) within the interaction cells, within the IAA means column, or within the cultivar means row do not differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

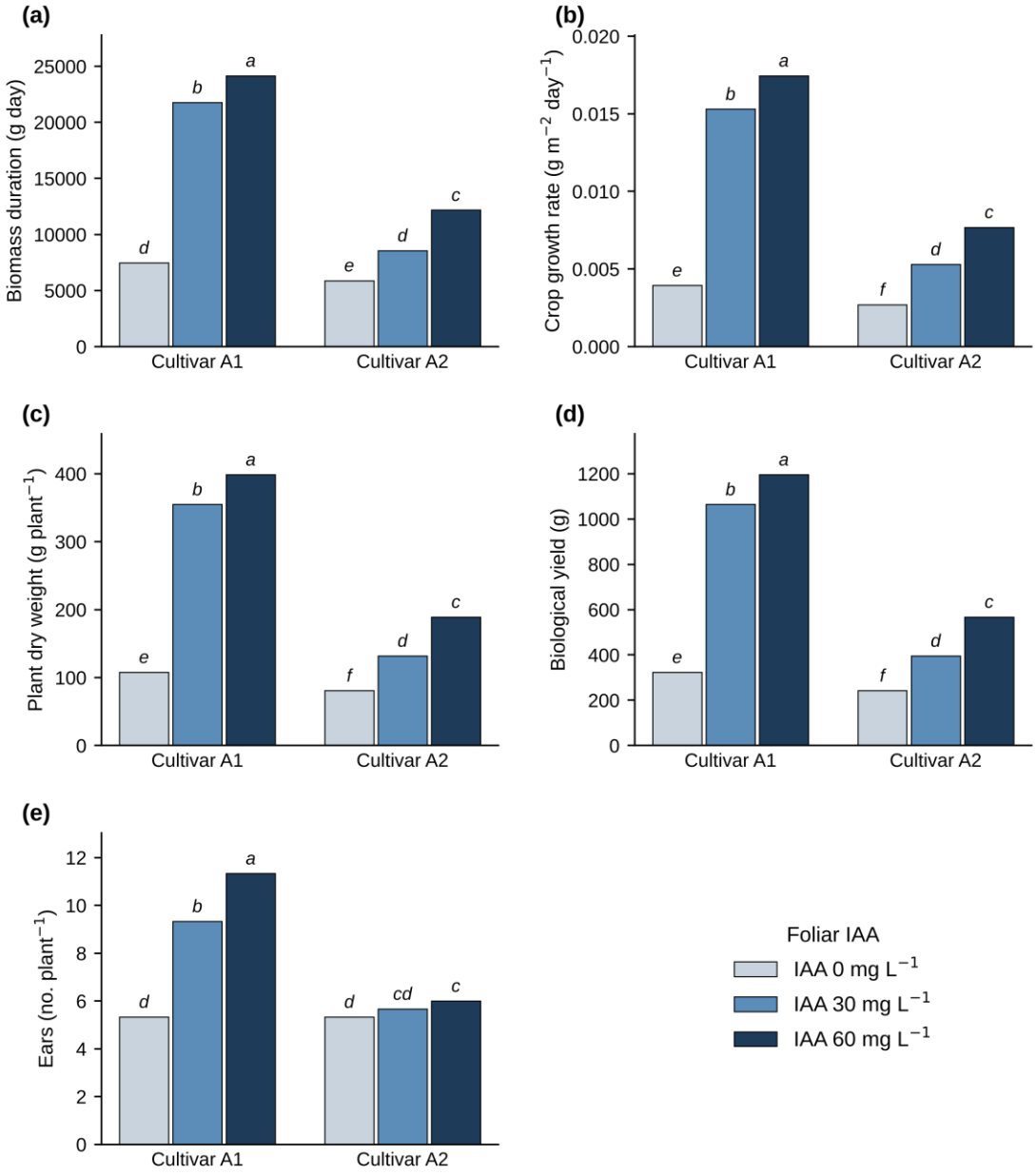


**Figure 2.** Interaction effects of cultivars and IAA concentrations on (a) biomass duration, (b) crop growth rate, (c) plant dry weight, (d) biological yield and (e) number of ears of maize. Bars are treatment means ($n$ = 3); within each panel, bars topped by different letters differ significantly according to Duncan's multiple range test ($P \leq 0.05$).

### 3.6. Relative response of the cultivars to IAA

Expressed relative to each cultivar's own control, A1 was consistently more

responsive to IAA than A2 (Figure 3). At 60 mg $L^{-1}$, IAA increased biomass duration by 223% in A1 compared with 107% in A2, CGR by 343% compared with 186%, and plant dry weight and biological yield by about 270% compared with 135%, so that the response of A1 was about twice that of A2 for these traits. The contrast was greatest for the number of ears, which increased by 113% in A1 but by only 13% in A2. In both cultivars, CGR was the most responsive trait and the number of ears the least responsive.

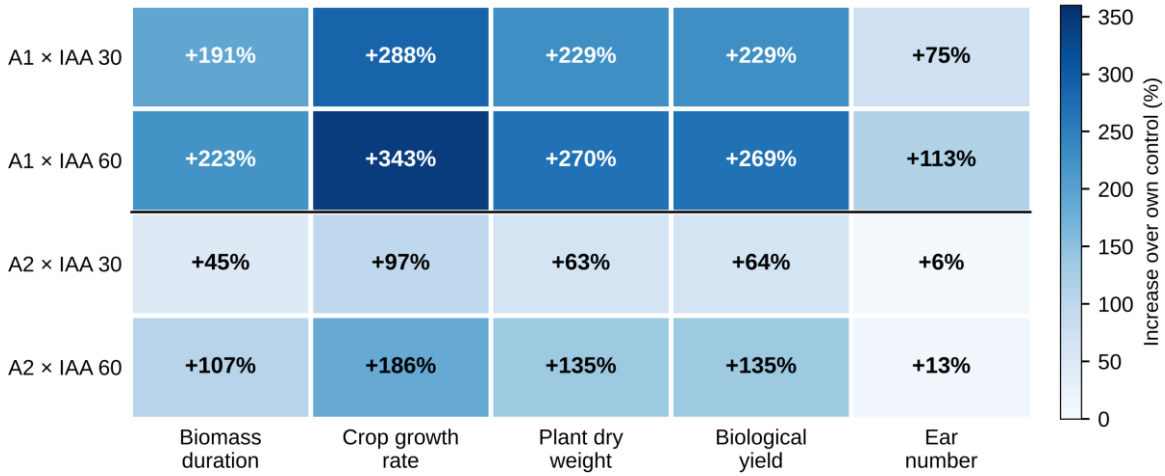


**Figure 3.** Relative response of maize cultivars A1 and A2 to IAA at 30 and 60 mg $L^{-1}$, expressed as the percentage increase over the unsprayed control of the same cultivar. Values were calculated from the treatment means in Tables 1–5.

## 4. Discussion

### 4.1. Cultivar differences in growth dynamics

The two cultivars differed widely in every studied trait, with A1 producing approximately twice the BMD, plant dry weight and biological yield of A2. Because BMD integrates both the amount of standing biomass and the length of time over which it is maintained, the superiority of A1 indicates a combination of faster growth (a 134% higher CGR) and a longer-lived productive canopy. Similar genotypic contrasts have been attributed to differences in source capacity: in a recent field study, the superior maize hybrid maintained more green leaves, a larger leaf area index and leaf area duration, higher leaf chlorophyll and nitrogen, and greater nitrate reductase and glutamine synthetase activities during grain filling, together with faster ear growth and more kernels per ear (Abo-Hamed et al., 2025). Stay-green behaviour is governed largely by internal developmental factors and is expressed consistently across irrigation, nitrogen and density treatments (Chibane et al., 2024), which supports the interpretation that the advantage of A1 is genetically based. Significant cultivar differences in growth, yield and antioxidant activity have likewise been reported among maize cultivars grown in Iraq (Al-Issawi & Abood, 2024).

### 4.2. IAA accelerates crop growth and prolongs biomass duration

Foliar IAA markedly increased both CGR and BMD, and the effect on CGR exceeded that on BMD (279% vs. 172% at 60 mg $L^{-1}$), suggesting that IAA acted primarily by raising the rate of dry-matter production and, secondarily, by maintaining the productive canopy for longer (Figure 4). Notably, these effects followed a single application made two weeks after sowing, indicating that IAA acted during early establishment, when small gains in leaf expansion and light interception compound over time into large differences in canopy size and dry-matter accumulation. At the cellular level, auxin stimulates growth through two complementary routes. The cell-

surface ABP1–TMK module activates plasma-membrane $H^+$-ATPases, acidifies the apoplast and loosens the cell wall within minutes (Lin et al., 2021; Di & Kriechbaumer, 2026), whereas the nuclear TIR1/AFB–Aux/IAA–ARF pathway reprograms the expression of growth-related genes (Liu et al., 2024; Wu et al., 2025). Faster expansion of leaves and internodes enlarges the light-intercepting area early in the season, and a larger canopy compounds into higher CGR (Taiz et al., 2022). Comparable increases in leaf area, relative growth rate and net assimilation rate were reported for maize sprayed with 20–30 ppm IAA (Hussain et al., 2025), and IAA improved growth and pigment content of sorghum under stress (Bibi et al., 2025).

The large gain in BMD is consistent with the role of auxin as a negative regulator of leaf senescence (Huang et al., 2022; Panozzo et al., 2025). By maintaining leaf auxin status, IAA may reduce tissue sensitivity to ethylene and delay the decline in photosynthetic capacity, thereby lengthening the period over which the canopy contributes to dry-matter production. This interpretation agrees with evidence that delaying post-silking leaf senescence increases maize grain yield (Guo et al., 2026) and that sustained leaf photosynthetic performance supports the development of both superior and inferior grains (Cao et al., 2026). Leaf area, chlorophyll content and gas exchange were not measured in the present study, however, and auxin can repress chlorophyll biosynthesis genes in some contexts (Luo W.-G. et al., 2023). The proposed mechanism—enhanced canopy expansion and delayed senescence rather than a direct increase in leaf chlorophyll—therefore remains a hypothesis to be tested by measuring leaf area index, leaf area duration, SPAD and photosynthetic rate.

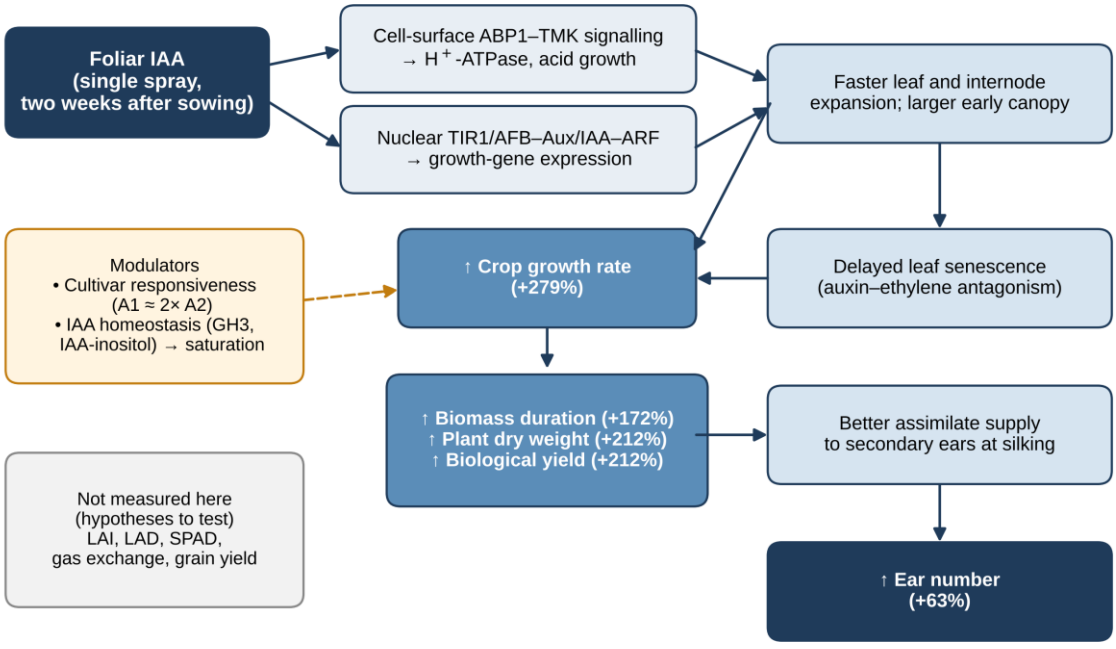


**Figure 4.** Proposed physiological model of the response of maize to a single early foliar application of IAA. Percentages are the mean increases at 60 mg $L^{-1}$ relative to the unsprayed control (Tables 1–5). Blue boxes denote traits measured in this study, light boxes denote processes inferred from the literature, and the grey box lists variables recommended for future validation.

### 4.3. Plant dry weight and biological yield

The increases in plant dry weight and biological yield (212% for both at 60 mg $L^{-1}$) are the cumulative outcome of the higher CGR and longer BMD: a canopy that

grows faster and remains active for longer necessarily accumulates more biomass. The close correspondence among the three growth indices indicates that IAA acted on the overall source capacity of the crop rather than on a single organ. Whether the additional biomass is translated into grain depends on partitioning; in canola, for example, foliar IAA increased vegetative growth but produced many unfilled seed clusters and the lowest seed weight per plant (Hemati et al., 2022), whereas in maize IAA increased kernels per cob and grain yield per plant (Hussain et al., 2025). Grain yield and harvest index must therefore be quantified before the agronomic value of IAA can be fully judged.

### 4.4. Ear number

IAA increased ear number substantially in A1 (up to 113%) but only marginally in A2 (up to 13%). This response is unlikely to reflect a release of apical dominance, since auxin enforces rather than relieves the inhibition of axillary buds. Because IAA was applied once, two weeks after sowing, well before ear shoots are initiated, its effect on ear number was most probably indirect, operating through the carbon status of the plant around flowering. Reproductive development in maize is highly sensitive to assimilate supply around flowering: carbon deficiency at tasseling reduces sucrose in the silks, disturbs hormone balance and arrests silk emergence, so that kernel set fails (Zhang et al., 2025), and subapical ears, which have the lowest priority for assimilates, are the most vulnerable. The larger, faster-growing plants produced by the early IAA application would have improved the assimilate supply to secondary ears and reduced their abortion, which explains why the ear response tracked the growth response of each cultivar. Although auxin biosynthesis, signalling and transport genes are indispensable for axillary meristem initiation and lateral organ formation in the maize ear (Cowling et al., 2023), a direct effect of the applied IAA on inflorescence development is unlikely given the interval between spraying and ear initiation; repeated applications closer to ear initiation would be needed to test this possibility. The identical ear number of the two cultivars in the control, combined with their divergent responses to IAA, indicates that A1 possesses a latent capacity for prolificacy that was expressed only when growth was enhanced.

### 4.5. Cultivar × IAA interaction and the dose–response

The significant interaction for all traits was quantitative rather than a change in ranking: both cultivars responded positively, but the relative response of A1 was about twice that of A2 for the growth traits and about nine times greater for ear number (Figure 3). Cultivars may differ in their sensitivity to exogenous auxin owing to differences in endogenous IAA levels, receptor and ARF expression, and the capacity to inactivate IAA. For example, heat stress reduced kernel auxin content and *ZmARF* expression more strongly in a heat-sensitive than in a heat-tolerant maize genotype (Li et al., 2025), and varietal differences in the response to foliar IAA were also observed in Pakistan (Hussain et al., 2025).

Across both cultivars, the increment between 30 and 60 mg $L^{-1}$ was about one-third of that between 0 and 30 mg $L^{-1}$, and the two concentrations did not differ in mean ear number (Table 5). Such a saturating dose–response is expected from the tight homeostatic control of free IAA. GH3 enzymes conjugate excess IAA to amino acids for storage or degradation (Luo P. et al., 2023), and in maize the formation of 1-*O*-indole-3-acetyl-*myo*-inositol acts as a reservoir that buffers free IAA, particularly under drought and cold (Ciarkowska et al., 2023). Beyond an optimum, exogenous IAA may become a stressor, as shown by increased lipid peroxidation and depressed endogenous hormone levels in chrysanthemum sprayed with IAA (Wang et al., 2025).

Testing concentrations above 60 mg $L^{-1}$, together with the timing and number of applications, is therefore needed to identify the economic optimum for responsive cultivars. Because auxin pathways interact with drought, salinity and heat responses in maize (Gonzales & Kelley, 2025), the benefit of IAA may also differ between seasons that differ in water and temperature stress, which is particularly relevant to Iraq (Al-Shaibani et al., 2026).

### 4.6. Limitations and future work

The study was conducted in one spring season at a single site, with small plots and two cultivars. Spring-sown maize in central Iraq flowers and fills grain under high summer temperatures, which depress kernel auxin status (Li et al., 2025) and may have constrained growth rates in this season. IAA was applied only once, and the control plants were not sprayed with the methanol–water vehicle; because foliar methanol has been reported to stimulate the growth of some $C_3$ crops (Nonomura & Benson, 1992), future trials should include a vehicle control so that the response can be attributed unequivocally to IAA. In addition, grain yield, yield components, harvest index, leaf area, chlorophyll and endogenous hormone levels were not measured. The magnitude of the responses (up to a 4.9-fold range in plant dry weight among treatment combinations) is large for a foliar growth regulator and should be confirmed in multi-season, multi-location trials. Future work should (i) quantify grain yield and its components, (ii) measure leaf area duration, chlorophyll fluorescence and gas exchange to verify the proposed source-based mechanism (Figure 4), (iii) include a wider range of concentrations, repeated applications at later stages (e.g., before tasseling) and different application methods, since the delivery method itself can modify plant growth responses (Kahlel et al., 2021), (iv) screen a larger set of locally grown cultivars for IAA responsiveness, and (v) evaluate the economic return of the practice.

## 5. Conclusions

Spraying maize once with IAA, two weeks after sowing, significantly improved biomass duration, crop growth rate, plant dry weight, biological yield and number of ears under spring-season conditions in Tikrit, Iraq. The 60 mg $L^{-1}$ concentration gave the highest values in all traits, although it did not differ significantly from 30 mg $L^{-1}$ in the number of ears. Cultivar A1 was superior to A2 in all traits and was the most responsive to IAA, and the combination of A1 with 60 mg $L^{-1}$ IAA gave the best performance in all five traits. Spraying responsive cultivars with IAA at 60 mg $L^{-1}$ is therefore recommended as a promising, low-cost practice, and further studies over several seasons, with higher concentrations, repeated sprays and measurement of grain yield, are suggested.

## Declarations

**Author contributions:** to be completed.

**Funding:** This research received no external funding confirm.

**Conflict of interest:** The author declares no conflict of interest.

**Data availability:** The data supporting the findings of this study are available from the corresponding author on reasonable request.

## References

Abo-Hamed, S., Elghareeb, E. M., El-Shahaby, O., et al. (2025). Monitoring dynamics in ear-leaf physiology during maize grain filling: genotype and nitrogen impact on source–sink relations and yield. *Acta Physiologiae Plantarum*, 47, 34. https://doi.org/10.1007/s11738-025-03775-8

Al-Issawi, N. R., & Abood, N. M. (2024). Response maize cultivars (*Zea mays* L.) to foliar application of kinetin. *Iraqi Journal of Agricultural Sciences*, 55(1). https://doi.org/10.36103/fshxmg04

Al-Rawi, K. M., & Khalafallah, A. M. (2000). *Design and Analysis of Agricultural Experiments*. Dar Al-Kutub for Printing and Publishing, University of Mosul, Iraq (in Arabic).

Al-Shaibani, A. A., Al-Khafaji, M. S., & Shamal, K. (2026). Role of deficit irrigation in sustaining wheat and maize cultivation under harsh climatic conditions in Iraq. *Journal of Engineering*, 32(6), 51–77. https://doi.org/10.31026/j.eng.2026.06.03

Bibi, A., Ullah, M. S., Mahmood, A., Shahzad, M., Javaid, M. M., Nadeem, M. A., et al. (2025). Indole-3-acetic acid improves growth, physiology, photosynthesis, and ion balance under cadmium stress in *Sorghum bicolor*. *Scientific Reports*, 15, 33971. https://doi.org/10.1038/s41598-025-10900-7

Cao, W., Yu, Z., Shi, Y., Zhang, Z., & Zhang, Y. (2026). Photosynthetic performance of spring maize leaves and the development and formation of superior and inferior grains. *Frontiers in Plant Science*, 16, 1732666. https://doi.org/10.3389/fpls.2025.1732666

Chibane, N., Revilla, P., Yannam, V. R. R., Marcet, P., Covelo, E. F., & Ordás, B. (2024). Impact of irrigation, nitrogen fertilization, and plant density on stay-green and its effects on agronomic traits in maize. *Frontiers in Plant Science*, 15, 1399072. https://doi.org/10.3389/fpls.2024.1399072

Ciarkowska, A., Wojtaczka, P., Kęsy, J., et al. (2023). Auxin homeostasis in maize (*Zea mays*) is regulated via 1-*O*-indole-3-acetyl-*myo*-inositol synthesis at early stages of seedling development and under abiotic stress. *Planta*, 257, 23. https://doi.org/10.1007/s00425-022-04058-z

Cowling, C. L., Dash, L., & Kelley, D. R. (2023). Roles of auxin pathways in maize biology. *Journal of Experimental Botany*, 74(22), 6989–6999. https://doi.org/10.1093/jxb/erad297

Di, D.-W., & Kriechbaumer, V. (2026). Recent advances and future perspectives in plant auxin biology. *Plants*, 15, 683. https://doi.org/10.3390/plants15050683

Donald, C. M. (1962). In search of yield. *Journal of the Australian Institute of Agricultural Science*, 28, 171–178.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*, 14(5), 1295–1319. https://doi.org/10.1007/s12571-022-01288-7

FAO. (2024). *Agricultural production statistics 2010–2023*. FAOSTAT Analytical Brief Series. Food and Agriculture Organization of the United Nations, Rome.

FAO. (2025). *Agricultural production statistics 2010–2024*. FAOSTAT Analytical Brief Series. Food and Agriculture Organization of the United Nations, Rome.

FAO-GIEWS. (2026). *GIEWS Country Brief: Iraq* (reference date 1 September 2026). Global Information and Early Warning System, FAO, Rome. https://www.fao.org/giews/countrybrief/country.jsp?code=IRQ

Gonzales, C. F., & Kelley, D. R. (2025). Interplay between auxin and abiotic stresses in maize. *Journal of Experimental Botany*, 76(7), 1879–1887. https://doi.org/10.1093/jxb/eraf079

Guo, Z., Liu, G., Guo, D., Liu, D., Wu, Z., Ma, Z., et al. (2026). Split nitrogen application increases grain yield of densely planted summer maize by delaying post-silking leaf senescence. *Frontiers in Plant Science*, 17, 1871425. https://doi.org/10.3389/fpls.2026.1871425

Hemati, A., Alikhani, H. A., Babaei, M., Ajdanian, L., Asgari Lajayer, B., & van Hullebusch, E. D. (2022). Effects of foliar application of humic acid extracts and indole acetic acid on important growth indices of canola (*Brassica napus* L.). *Scientific Reports*, 12, 20033. https://doi.org/10.1038/s41598-022-21997-5

Huang, P., Li, Z., & Guo, H. (2022). New advances in the regulation of leaf senescence by classical and peptide hormones. *Frontiers in Plant Science*, 13, 923136. https://doi.org/10.3389/fpls.2022.923136

Hunt, R. (1978). *Plant Growth Analysis*. Studies in Biology No. 96. Edward Arnold, London.

Hunt, R., Causton, D. R., Shipley, B., & Askew, A. P. (2002). A modern tool for classical plant growth analysis. *Annals of Botany*, 90(4), 485–488. https://doi.org/10.1093/aob/mcf214

Hussain, K., Ghaus, H., Amin, R., Nawaz, K., Ahlawat, Y., Elhindi, K. M., et al. (2025). Straight vs blended applications of IAA (indole acetic acid) and boron (B) for the improvement of crop productivity in maize (*Zea mays* L.). *BMC Plant Biology*, 25, 1648. https://doi.org/10.1186/s12870-025-07719-9

Kahlel, A. M. S., Abdulla, A. A., Saadalla, H. A., & Hamed, M. H. (2021). Effect of nano fertilizers and its applying methods on growth parameters of senna (*Cassia angustifolia*) seedling plant. *IOP Conference Series: Earth and Environmental Science*, 923(1), 012003. https://doi.org/10.1088/1755-1315/923/1/012003

Khalaf, B. H., Saadallah, H. A., & Al-Krdoshi, M. A. (2027). Traditional and modern seed storage methods for sustainable agriculture in Iraq: a systematic review of local evidence and global comparators. *Journal of Stored Products Research*, 120, 103272. https://doi.org/10.1016/j.jspr.2026.103272

Li, X., Zhuge, S., Du, J., Zhang, P., Wang, X., Liu, T., et al. (2025). The molecular mechanism by which heat stress during the grain filling period inhibits maize grain filling and reduces yield. *Frontiers in Plant Science*, 15, 1533527. https://doi.org/10.3389/fpls.2024.1533527

Lin, W., Zhou, X., Tang, W., Takahashi, K., Pan, X., Dai, J., et al. (2021). TMK-based cell-surface auxin signalling activates cell-wall acidification. *Nature*, 599, 278–282. https://doi.org/10.1038/s41586-021-03976-4

Liu, L., Salifu, Y. B., Li, J., & Wu, F. (2024). Enigmatic role of auxin response factors in plant growth and stress tolerance. *Frontiers in Plant Science*, 15, 1398818. https://doi.org/10.3389/fpls.2024.1398818

Luo, P., Li, T.-T., Shi, W.-M., Ma, Q., & Di, D.-W. (2023). The roles of GRETCHEN HAGEN3 (GH3)-dependent auxin conjugation in the regulation of plant development and stress adaptation. *Plants*, 12(24), 4111. https://doi.org/10.3390/plants12244111

Luo, W.-G., Liang, Q.-W., Su, Y., Huang, C., Mo, B.-X., Yu, Y., et al. (2023). Auxin inhibits chlorophyll accumulation through ARF7-IAA14-mediated repression of chlorophyll biosynthesis genes in *Arabidopsis*. *Frontiers in Plant Science*, 14, 1172059. https://doi.org/10.3389/fpls.2023.1172059

Nonomura, A. M., & Benson, A. A. (1992). The path of carbon in photosynthesis: improved crop yields with methanol. *Proceedings of the National Academy of Sciences of the USA*, 89(20), 9794–9798. https://doi.org/10.1073/pnas.89.20.9794

Panozzo, A., Bolla, P. K., Barion, G., Botton, A., & Vamerali, T. (2025). Phytohormonal regulation of abiotic stress tolerance, leaf senescence and yield response in field crops: a comprehensive review. *BioTech*, 14(1), 14. https://doi.org/10.3390/biotech14010014

Taiz, L., Møller, I. M., Murphy, A., & Zeiger, E. (2022). *Plant Physiology and*



*Development* (7th ed.). Oxford University Press, New York.

Wang, Y., Duan, Y., Chen, N., Ding, W., Liu, Y., & Xing, S. (2025). Integrated physiological, transcriptomic, and metabolomic analyses of *Chrysanthemum* 'Boju' under excessive indole-3-acetic acid stress. *Frontiers in Plant Science*, 16, 1531585. https://doi.org/10.3389/fpls.2025.1531585

Watson, D. J. (1952). The physiological basis of variation in yield. *Advances in Agronomy*, 4, 101–145.

Wu, L., Kriechbaumer, V., & Di, D.-W. (2025). Emerging roles of cAMP: a transcriptional master regulator in the canonical TIR1/AFB-mediated auxin signaling. *Plant Hormones*, 1, e018. https://doi.org/10.48130/ph-0025-0018

Zhang, Y., Ren, J., Liu, S., Zhang, X., Liu, G., Du, X., et al. (2025). Low light stress at tasseling threatens high-density maize production by impairing silk emergence. *Journal of Integrative Agriculture*, advance online publication. https://doi.org/10.1016/j.jia.2025.12.010