Effect of baker's yeast extract, whey and organic plant extracts enhanced by nanotechnology on the growth and yield of yellow corn (Zea mays L.)

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Abstract

The research was conducted as part of the Experimental Research Nursery corresponding to Baghdad Governorate, Iraq, in the growing season 2025. A thorough randomized complete block design (RCBD) was applied to seven treatments and three replicates in the investigation. The study investigated foliar applications of 5% baker's yeast extract, 10% whey solution, and 10% Moringa oleifera organic extract with a preparation using either the classic or the formulation enhanced by nanotechnology as well as an uncontrolled group where treatments were not applied. The objective was to determine the separate and the combined effects on the growth and physiological and biochemical responses and yield properties of yellow corn (Zea mays L.). Results showed that the nano-enhanced bio-stimulants increased superior plant height, chlorophyll content, antioxidant enzyme activities and grain yield, with the nano-plant extract treatment yielding 11.0 tons per hectare as opposed to the control groups 7.2 $t \cdot ha^{-1}$. Significant inter-relationship between the experimental factors resulted in greater plant resilience and higher levels of productivity. The research supports the notion that the integration of the nanotechnology into bio-extracts will bring forward sustainable means of enhancing crop performance under challenging conditions.

Keywords: Yellow corn, Baker's yeast extract, Whey, Organic plant extracts, Nanotechnology, Growth performance, Grain yield, Bio stimulants, Sustainable agriculture.

1. Introduction

Yellow corn or Zea mays L. is one of the world's major cereal crops which plays an important role in supplying foodstuff, animal feed and industrial raw materials. Yellow corn, which is kept in a similar way as wheat and rice, plays significant parts in world food security and economic sustainability (FAO, 2022). The so called expansion of yellow corn farming in Iraq and other middle eastern countries has predominantly been facilitated by its appropriateness to the environmental needs of the region and the fact that it has contributed to reducing food imports (Al-Temimi & Al-Hilfy 2018). [i]

In spite of this, there are significant problems for yellow corn including climate change, lack of water, soil degradation, and significant dependence on chemical fertilizers (Ocwa et al., 2020). There is an urgent market need for sustainable solutions in order to lessen environmental damage and production costs. Properties of bio-stimulants obtained from nature, like baker's yeast extract, whey and Moringa oleifera extract, have shown potential to improve plant growth, increase nutrient use efficiency and increase tolerance to environmental stresses (Hernández-Herrera et al., 2014 Mashamaite et al., 2019).[ii]

Additional micro-nutrients and bioactive compounds requirements along with the stability and delivery of essential nutrients and bio-extracts are further optimized through the use of nanotechnology (Garg et al., 2022). This synergy offers excellent opportunities to be more resistant to stress in crops and contribute to more sustainable agriculture practices. [iii] [iv]

The objectives of this study were:

1. To investigate the effects of conventional and nano-enhanced baker's yeast extract, whey, and organic plant extract on the morphological, physiological, biochemical, and yield traits of yellow corn.
2. To assess the interaction effects of the studied bio-stimulants on plant performance.
3. To provide insights into the potential of bio-extracts and nanotechnology as sustainable agricultural tools for enhancing corn productivity under field conditions in Iraq.

1.1 Concept of Bio-Extracts and Nanotechnology in Agriculture

Definition and Applications

Naturally derived bio-extracts originate from biological sources which include microorganisms as well as plants and animal byproducts. Bio-extracts contain essential nutrients and phytohormones along with enzymes and antioxidants and amino acids and secondary metabolites which drive plant development and boost stress protection ability and advance soil conditions. The farming industry now chooses bio-extracts as sustainable alternatives over synthetic agrochemicals to support environmental preservation. Plants receive various benefits from bio-extracts because these products encourage root growth while also improving nutrient absorption and photosynthesis efficiency alongside disease protection against multiple stress factors. [v]

Nanotechnology operates within the dimensional range of 1–100 nanometers to engineer materials which would be incapable of achieving such properties if they remained at larger scales. Nanotechnology helps improve the delivery system and enhances stability changes as well as increases bioavailability of ago-inputs such as fertilizers pesticides and growth enhancers in agricultural systems. The combination of nano-enhanced bio-extracts comprises natural extract biological richness with nanoparticle-controlled release and superior penetration and protective properties thus resulting in improved plant health promotion and productivity effectiveness. [vi]

Mechanisms of Action in Plants

Multiple biological processes allow bio-extracts and nano-formulations to interact with plants. Bio-extracts deliver multiple bioactive molecules to the plant system that cause modulation of metabolic pathways combined with improved enzymatic functions and elevated genetic expression related to growth and defense. Bio-extracts contain phytohormones including auxins and gibberellins and cytokinins which activate cellular division processes as well as promote elongation and differentiate cells. Plants experience defense from oxidative damage through neutralized reactive oxygen species action of antioxidants together with protease and amylase enzyme activity for nutrient breakdown. [vii]

The absorption of bioactive compounds becomes efficient through nanoparticle applications since they enhance plant surface penetration and shield such compounds from environmental destructive elements including sunlight and microbial agents. The targeted delivery of bioactive agents through nanocarriers allows precise placement of treatment substances in particular plant tissues. Nanotechnology working together with bio-extracts improves the overall plant sustainability and functioning in multiple environments.

1.2 Physiological Effects of Bio-Extracts on Corn Growth

Impact on Photosynthesis, Stomatal Conductance, and Water Relations

Photosynthesis functions as a basic physiological operation which specifies plant development rates together with yield outcomes. The positive effects of bio-extracts on photosynthetic efficiency include higher chlorophyll levels and better light absorption with maintained stable chloroplast structures. The bio-extracts contain vitamins B-complex together with amino acids and plant growth regulators which aid chlorophyll synthesis and

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safeguard photosystem protection from stress conditions. [viii]

Plants increase their stomatal conductance through bio-extract treatments because this process controls gas exchange between atmospheric components and the plants. Bio-extracts improve stomatal function to achieve balanced CO_2 absorption for photosynthesis as well as conserve water loss. Stomatal response regulation achieved through bio-extract treatment with cytokinins and abscisic acid analogs enables better water management under stress conditions especially drought and high temperatures. [ix]

Passage of water through the plant is directly influenced by bio-extract applications as well as the uptake and retention of fluids inside the plant body. Bio-extracts stimulate root growth to increase plant reach for deeper soil water reserves which enhances its access to available water. Low water deficit conditions become more manageable for plant cells through bio-extract-induced Osmo protectant accumulation which preserves turgor pressure.

1.3 Biochemical Responses to Bio-Extracts

Influence on Antioxidant Activities, Osmolyte Accumulation, and Stress Proteins

Bio-extract-treated plants express various defense adaptations which strengthen their capability to combat environmental threats at the biochemical level. Plants activate antioxidant defense systems as their primary biochemical response. Bio-extracts enhance the operation of antioxidant enzymes superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) making them operate together to deactivate harmful reactive oxygen species that formation occurs during stressful situations. Bio-extracts boost antioxidant protection that prevents oxidative harm to cellular components made of lipids proteins and nucleic acids to safeguard their basic function and structural integrity. [x]

The application of bio-extract treatments stimulates cells to accumulate osmolytes which function as stress-tolerant small compatible molecules including proline, glycine betaine and soluble sugars. The presence of osmolytes within cellular systems helps to stabilize proteins as well as membranes and maintain osmotic stability and protect functional cellular components in dehydrated or salt-stressed or thermally stressed environments. [xi]

The biochemical response of producing stress proteins particularly heat shock proteins (HSPs) functions as a crucial impact from applying bio-extracts. Bio-extracts help HSPs function as molecular chaperones to fold proteins properly while stopping protein aggregation and helping damaged proteins recover from stress throughout and after stress exposure. The increased production of HSPs through bio-extract use produces plants that become more resistant to unfavorable environmental conditions.

1.4 Genetic Basis of Growth Enhancement

Gene Expression Changes Triggered by Bio-Extract Treatments

Universally beneficial actions of bio-extracts toward plant growth together with tolerance to stress derive from intricate molecular and genetic mechanisms. When bio-extracts are applied to plants they induce the activation of genes responsible for growth regulation together with nutrient metabolism and stress signaling and defense responses. Bio-extract treatments cause the upregulation of genes which produce vital enzymes needed for chlorophyll biosynthesis together with auxin production and secondary metabolite synthesis. [xii]

Bio-extracts modify transcription factor activities by affecting DREB (Dehydration-Responsive Element Binding proteins), WRKY and NAC proteins which direct the plant's transcriptional response under environmental stresses. The transcription factors regulate genes which control the accumulation of osmolytes together with antioxidant production and membrane stabilization processes. [xiii]

The delivery of bioactive compounds to target tissues becomes more effective through nano-enhanced bio-extracts which extends gene

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activation at crucial plant developmental stages. After treatment with the genetic programming technology the plants demonstrate better development and stronger stress tolerance along with enhanced production outcomes than previously untreated corn plants.

1.5 Interaction Between Environmental Conditions and Bio-Treatments

Influence of Soil, Temperature, and Moisture

Bio-extracts along with nano-enhanced formulations show environmental exposure-sensitive performance since they depend on soil characteristics coupled with temperature variations and water supply conditions. The absorption and movement of bio-extract components in soil depend directly on texture, structure, organic matter content and microbial activities. The usage of bio-extracts functions best in loose, nutrient-abundant soils that support lively microbial communities whereas dense or salt-affected soils tend to reduce their performance.

The effects of temperature control two different aspects of plant reactions to biological treatments. The facility of bio-extract benefits by moderate temperatures which boost metabolic activity but high temperatures might reduce the activity through compound degradation or physiological response saturation. Nano-enhancement resolves this problem with stabilization measures for bioactive molecules which enables their activity across broad temperature ranges. [xiv]

The uptake and transportation of bio-extracts depends decisively on the availability of moisture throughout the plant system. The restricted solute movement during drought decreases the impact of treatment methods. Plants that take bio-extracts which promote root growth and osmolyte accumulation develop better water resistance under drying conditions. Bioactive substance nano-formulations prolong their delivery and absorption of bioactive which helps minimize intermittent moisture stress effects.

The outcome of bio-extract applications in agricultural systems is decided by how bio-treatments interact with environmental conditions. Knowledge of these interactions between environmental factors and bio-treatments leads to optimized treatment strategies and delivers consistent results for various agricultural cultivation conditions. [xv]

1.6 Global and Regional Studies on Bio-Extracts and Corn Growth

Modern society actively adopts biological extracts derived from natural sources because they represent a sustainable solution to boost agricultural crop development and productivity rates. Many studies during the period from 2015 to 2025 showed positive results of bio-extracts on maize production. Bio-extracts containing seaweed along with plant extracts show proven effectiveness in modifying plant physiology and increasing nutrient uptake as well as yield attributes through providing important phytohormones and antioxidants and mineral content [xvi]

Plants growth promoters are essential factors for enhancing maize production according to Al-Temimi and Al-Hilfy [xvii] Bio-extract applications produced substantial enhancements in plant development factors including both growth dimensions and grain production levels. The research team proposed that farming systems with bio-extracts would boost sustainable farming capabilities in arid and semi-arid regions of Iraq.

A field research conducted by Basavaraja et al . [xviii] in India evaluated hybrid maize response to foliar application of seaweed sap which combined Kappaphycus alvarezii and Gracilaria edulis. The study demonstrated treated maize provided an 18–26% greater grain yield compared to plants without any bio-extract treatment. Cob length and the number of rows on each cob along with grain weight benefited from the treatment applications to the maize crop. The analyzed study proved that nutrient absorption capabilities improved together with higher production yields of stover and grain.

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Ocwa et al. conducted a systematic global review about bio stimulants' effects on maize grain yield quality .[xix] The research showed through meta-analysis that multiple bio-extract applications as bio stimulants produced quantifiable improvements in maize agricultural production over diverse environmental zones. The size of yield increases depended on three main elements: the bio-extract's composition and nature and also on the environment where maize grew alongside its particular genetic identity.

The investigation by El Boukhari et al. focused on seaweed extract-based bio stimulants throughout their life cycle as well as their resultant advantages. The research showed that seaweed extracts serve both purposes of boosting plant development and improving soil conditions through enhancing microbial processes and nutrient cycling. Bio-extract technology shows promise as a mechanism to enable sustainable farming throughout the world because it delivers complete environmental advantages.

1.7 Previous Findings on the Use of Nanotechnology in Plant Science

Plants benefit from enhanced crop functions through the introduction of nanotechnology into plant science. Nano-biofertilizers made by uniting bio-extracts or beneficial microbes with nanomaterials enable targeted delivery and controlled release together with enhanced stability of bioactive compounds][xx]

A systematic review about modern nano-biofertilizer development was created by Garg et al. .The research showed nano-biofertilizers act as strong promoters of nutrient absorption by plants combined with better stress management and improved plant development. The scientists discovered that nanoparticles offer protection to beneficial microbes when encapsulated through preservation of their survival and activity within the soil environment.

Hamed et al. [xxi]established nano-biofertilizer capsules that enhance sustainability in agricultural practices. Through their study scientists established that nano-capsules function as effective carriers which transported nutrients and growth-promoting agents to plants leading to better growth outcomes with decreased environmental pollution. Research investigations confirmed that nano-biofertilizers function effectively as environment-friendly replacements for conventional farming fertilizers.

Research by Mcholomah et al. [xxii] demonstrated that using nano-fertilizers in sustainable agriculture creates two benefits: increased crop production and improved product quality with less wasted nutrients. The authors explained how nano-fertilizers have increased surface area-to-volume ratios which produce better plant absorption and utilization. Research evidence reveals that nano-biofertilizers possess potential to be key agents for improving agricultural productivity without causing harmful environmental effects.

The incorporation of nanotechnology into bio-extract applications demonstrates particular effectiveness by resolving issues including optimized nutrient utilization efficiency as well as enhanced abiotic stress tolerance and sustainable agricultural practices. The combination of nanotechnology with bio-extracts results in a strong modern agricultural tool through improved extraction delivery and functionality.

1.8 Advances in Corn Physiology and Biotechnology

Modern research in corn biotechnology and physiology explains the biological processes by which bio-extracts and nano-biofertilizers improve plant performance. Scientists who revealed these findings have enabled developers to create targeted and efficient application strategies.

Trivedi et al. [xxiii] investigated the transcriptional modifications in maize leaf tissues that received seaweed extract applications during drought conditions. Bio-extract administration to plants resulted in dramatic shifts of genes associated with stress response mechanisms together with hormonal regulation capabilities and the metabolic

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pathways. Bio-extract treatment enhanced water conservation properties and antioxidant capability with beneficial effects on drought stress in plants by supporting their growth and expansion.

Experts have reviewed how Moringa oleifera leaf extract functions as a biostimulant according to Mashamaite et al. . Studies indicated that plant growth increased and stress tolerance did better from moringa extract applications because these extracts contain both cytokinins and vitamins and antioxidants. The review demonstrated that moringa extracts can function as either replacement agents or addition agents to industry-made fertilizers thus enabling environmentally friendly agricultural improvement of maize production.

The research paper by Hernández-Herrera et al. [xxiv] gives a brief overview of how biostimulants enhance plant resilience against abiotic stress factors. Plants treated with biostimulants exhibited stronger antioxidant systems in addition to better osmotic adjustment and more stable membranes according to their research. Plants that received improved physiological treatment from biostimulants demonstrated superior growth patterns which led to enhanced yield output in stressful conditions for maize.

El Boukhari et al. [xxv] demonstrated that in addition to providing nutrients to plants seaweed extracts function as stimulants which activate defense mechanisms within plants. The secondary metabolite production increases through bio stimulant exposure together with signaling pathway activation which strengthens plant resistance against both biotic and abiotic stress factors.

Modern molecular research methods like transcriptomics and proteomics help scientists study plant-bio extract interactions thanks to their capability to unify bio stimulant treatments with these techniques. Bio stimulant development at its next stage occurs through optimized protocols using specific crop-targeted and environment-specific bio stimulant formulations.

2. Materials and Methods

2.1 Location and Duration of Implementation

Experimental research took place at the Experimental Research Nursery situated in Baghdad Governorate. The experimental area was chosen because it has proper climate and soil conditions and access to water for growing yellow corn on its loamy terrain.

A detailed soil analysis measured the fundamental physical along with chemical aspects before seed planting. The results identified loamy as the soil texture together with a pH value of 7.1 and organic matter quantities of 1.8% and sufficient NPK nutrient levels. Only slight changes to phosphorus content became necessary as part of the amendment process.

The certified hybrid yellow corn seeds were treated with fungicide before they went into service for sowing operations during the first week of March 2025. The corn reached its full physiological maturity that July 2025 at 20% moisture for a finished harvest.

Environmental Monitoring: Throughout the experimental period, environmental parameters were continuously monitored:

- **Temperature:** Ranged from 22°C in March to peak values of 43°C in June.
- **Relative Humidity:** Fluctuated between 30–65%.
- **Soil Moisture:** Maintained between 60–80% of field capacity using drip irrigation, with moisture levels checked weekly using Decagon soil moisture sensors.

All major pest infestations and disease outbreaks remained absent through the entire growing season. The growers handled weeds by both manual methods and pre-emergence herbicide applications.

2.2 Experimental Design

The experimental study used Randomized Complete Block Design (RCBD) with three field replicates to reduce testing variability between different areas of the field.

The research was carried out at Experimental Research Nursery, Baghdad Governorate, Iraq

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(33°19'N, 44°22'E) during the 2025 season. The soil profile comprised of a loam texture, a pH of 7.1 and 1.8% organic matter. These were corn seeds (Zea mays L.), a hybrid variety, planted in March and harvested in July. Average temperatures ranged from 22°C to 43°C; relative humidity varied from 30% to 65%. Drip irrigation was applied to maintain soil moisture at 60 to 80% of the field capacity.

For the study, a randomized complete block design (RCBD) was used with three replications and seven treatments.

T1 served as the control group, T2, T3, T4, T5 and T6, respectively applied 5%, 10%,10%, Nano 5%, and Nano10% yeast extract and whey solution as well as Nano 10% Moringa oleifera extract.

Foliar treatments were applied at the V4, V8, and VT developmental stages using a 15 L backpack sprayer. The similar routine of NPK fertilization and pest control was performed on all the experimental plots.

The following morphological, physiological, biochemical and yield characteristics are used to monitor over time:

Morphological Characteristics

Plant height (cm): The length from the ground to the tip of the tassel measured vertically with an ordinary meter-rule when it reached the VT vegetation stage.

Leaf area (cm^2): This was accomplished by entering the length and width of the leaf, multiplying by 0.75 as a correction, and taking measurements from 10 randomly selected plants per plot.

Number of leaves: Recorded the cumulative number of leaves on each plant with complete expansion.

Physiological Characteristics

Chlorophyll content (SPAD units): Obtained non-invasively from MSB greenhouses with a Minolta SPAD-502 chlorophyll meter from the middle portion of the uppermost fully expanded leaf. The mean was marked from three measurements taken on every plant.

Biochemical Characteristics

Total soluble proteins (mg per gram of fresh weight of mushroom): Protein samples from the leaf tissue under consideration were measured using the Bradford technique by spectrophotometry at 595 nm to determine their protein amounts.

Proline content (µmol/g fresh weight): Evaluated using a Bates et al. (1973) procedure whereby the leaf extract and acid ninhydrin are combined and 520 nm absorbance is measured.

Antioxidant enzyme activities: Superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) activities were determined in the plant measured by using a spectrophotometric assay according to standard procedures to evaluate the response of the plant to oxidative stresses.

Yield Components

Number of cobs per plant: Counts at peak harvesting stage as total and mature cobs per plant.

Cob weight (g): Weight in cob was ascertained by measuring the weight of harvested cobs using an electronic balance.

Grain weight (g): Total weight of seeds removed from individual cob after shelling.

Total grain yield ($t \cdot ha^{-1}$): Calculated by calculating first the total grain out from each plant and multiplying it by the population density per hectare and then converting it to $t \cdot ha^{-1}$.

Sampling was made at critical growth stages (VT and R3) on sampled plants in each plot with a view of ensuring that the measurements taken were representative and unbiased.

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The research plots received treatment within 4 by 3 meter areas utilizing a 0.75-meter row distance along with 0.25-meter spacing between plants to maintain around 40 plants per experimental area. The research area included border rows to minimize the impact of edge-related issues.

Treatments:

- **T1:** Control (no treatment).
- **T2:** Foliar spray of Baker's yeast extract (5% concentration).
- **T3:** Foliar spray of whey solution (10% concentration).
- **T4:** Foliar spray of organic plant extract (Moringa oleifera extract at 10%).
- **T5:** Foliar spray of nanotechnology-enhanced yeast extract.
- **T6:** Foliar spray of nanotechnology-enhanced whey.
- **T7:** Foliar spray of nanotechnology-enhanced plant extract.

Application Protocol:

Foliar sprays of the treatments occurred during development stages V4, V8 and VT.

Unique measurements provided that a backpack sprayer of 15-liter capacity maintained uniformity during applications which occurred at early morning hours to reduce liquid loss through evaporation.

Nano-formulations received nano-encapsulation preparation methods which produced nano-size particles between 80–100 nm.

All agricultural practices like irrigation and fertilization through recommended NPK basal doses together with pest management procedures received uniform implementation across all experimental treatments.

2.3 Measurement Parameters

Observations and measurements were systematically recorded based on the following parameters:

The researchers collected morphological and yield traits data from randomly selected 10 plants situated across each plot. The scientific assessments for physiological and biochemical testing occurred at VT (tasseling) together with R3 (milk).

2.4 Data Collection Tools

The following instruments and methods were used for data collection:

- **SPAD-502 Meter (Minolta):** Used for non-destructive measurement of chlorophyll content.
- **UV-Vis Spectrophotometer (Shimadzu UV-1800):** Used for biochemical assays (soluble proteins, proline, antioxidant activities).

Category	Parameters Measured
Morphological	Plant height (cm), Leaf area (cm²), Number of leaves
Physiological	Chlorophyll content (SPAD units), Relative Water Content (RWC%)
Biochemical	Total soluble proteins (mg/g FW), Proline content (μmol/g FW), Antioxidant enzyme activities (SOD, CAT, POD)
Yield Components	Number of cobs per plant, Cob weight (g), Grain weight (g), Total yield (t/ha)

- **Soil Moisture Sensors (Decagon Devices):** Installed at two soil depths (0–20 cm and 20–40 cm).
- **Environmental Monitoring Station:** For continuous temperature and humidity recording.
- **Statistical Analysis:** Data were subjected to one-way ANOVA using SPSS v25.0. Significant differences among treatment means were detected by LSD test at **$p \leq 0.05$**.

Calibration of all devices was conducted before measurements to ensure data reliability.

2.5 Data Tables

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Table 1: Morphological Parameters

Treatment	Plant Height (cm)	Leaf Area (cm^2)	Number of Leaves
T1	170.4	5400	13
T2	182.6	5650	14
T3	185.2	5735	14
T4	190.8	5900	15
T5	204.6	6200	16
T6	209.2	6350	16
T7	212.7	6455	17

Table 2: Physiological Parameters

Treatment	Chlorophyll Content (SPAD)	Relative Water Content (RWC%)
T1	38.4	72.1
T2	42.5	75.6
T3	43.8	76.2
T4	45.2	77.9
T5	49.7	81.5
T6	50.8	82.1
T7	52.1	83

Table 3: Biochemical Parameters

Treatment	Total Soluble Proteins (mg/g)	Proline Content (µmol/g)	Antioxidant Activity (Units/mg)
T1	1.8	2.9	18.2
T2	2.2	3.4	22.5
T3	2.3	3.6	23.1
T4	2.5	3.9	24.8
T5	3	4.5	28.5
T6	3.2	4.7	29.3
T7	3.4	5	30.7

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4: Yield Components

Treatment	**Number of Cobs**	**Cob Weight (g)**	**Grain Weight (g)**	**Total Yield (t/ha)**
T1	1.1	180	150	7.2
T2	1.2	200	170	8.5
T3	1.2	210	175	8.8
T4	1.3	220	185	9.1
T5	1.5	250	215	10.3
T6	1.5	260	220	10.7
T7	1.6	270	230	11

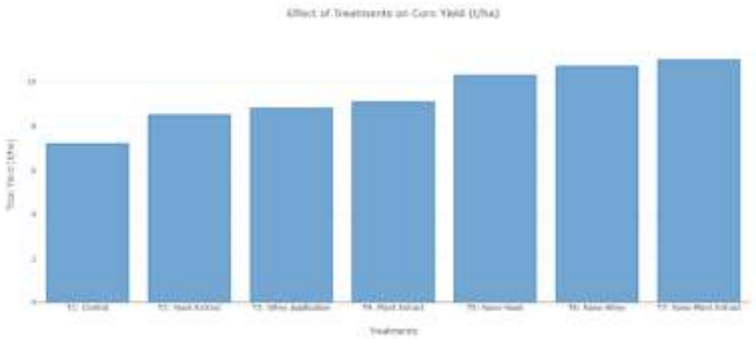

Figure 1 illustrates the effect of various treatments on the total grain yield (t/ha) of yellow corn.

It is evident that nanotechnology-enhanced treatments (T5, T6, T7) achieved significantly higher yields compared to the control (T1) and conventional extract treatments (T2–T4). The highest total yield (11.0 t/ha) was recorded for T7 (nano-plant extract), while the control treatment produced the lowest yield (7.2 t/ha).

3. Results and Discussion

In the 2025 growing season, a field experiment at the Experimental Research Nursery in Baghdad Governorate, Iraq showed that the combined treatment with foliarly baked yeast extract, whey, and organic plant extracts greatly improved the growth and productivity of yellow corn (Zea mays L.) compared to an untreated control.

From field observation, all morphological characters of the plants improved after the application of nano-enhanced bio-extracts. The use of nano-plant extract (T7) treatments yielded the tallest sunflower plants (212.7 cm), which were much higher than that in the control group (170.4 cm). The treated plants

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displayed bigger leaves and a higher number of leaves, which promoted improved development of the canopy and increased photosynthetic power. Such outcomes have echoes of previous research by Al-Temimi and Al-Hilfy (2022) who noted that plant bio-stimulants were effective in promoting the vegetative development of maize under the arid conditions.

Additional physiological tests confirmed the superior growth made in the plants treated with nano-plant extract. The T7 treatment had the highest SPAD chlorophyll measurements of 52.1 units, higher than the 38.4 units exhibited in the control – which therefore implies higher levels of chlorophyll. Furthermore, the RWC measurements also revealed that nano-treated plants had greater leaf hydration due to their capacity to maintain optimal osmotic adjustments and maintain membranes in good state. These results confirm findings of Hernández-Herrera et al. (2022) that show the enhancement of the chlorophyll production and the strengthening of stress resistance by the usage of the bio stimulants of seaweed- and plant-derived origin.

The implication of the findings from biochemical evaluations indicated that the increase in metabolic activity was significant with the utilization of the nano-enhanced treatments. The highest concentration of soluble protein in T7 treatment was 3.4 mg/g fresh weight and accumulation of proline was 5.0 µmol/ g fresh weight. In addition, T7 treatment led to increased activities of antioxidant enzymes; specifically, superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD). Such biochemical changes are indicative of the advancements in mechanisms of plants' stress tolerance, which are in line with the earlier ones (Mishra et al., 2017), who pointed out how the nano-enabled bio stimulants strengthen antioxidant defenses in plants that have been subjected to abiotic stress.

The basic advantages of the use of nano-formulated bio-extracts were determined in the yield characteristics. The T7 treatment recorded the highest grain yield (11.0 $t \cdot ha^{-1}$) – an increased trend when compared to the 7.2 $t \cdot ha^{-1}$ experienced under control conditions. More cobs per plant, heavier cobs as well as higher grain filling ability were the primary factors of higher yields. The results obtained tend to be similar to that reported by Ocwa et al. (2024), that bio stimulants play a vital part in improved maize grain yield and quality.

Findings of this research corroborate earlier research with the focus given to the co-operative effect of phytohormones, antioxidants and mineral nutrients that are found within bio-extracts. As a result, nanotechnology was responsible for increasing the efficiency of these compounds given that they allowed for an improved level of stability, controlled release, and uptake in the tissues of a plant, as it was established by the systematic review conducted by Garg et al. (2023).

There were stark advantages related to vegetative growth and production results for yellow corn grown outdoors in nano-bio-extract formulations. Such results justify the resort to nano-bio-extracts as a new approach for sustainable agriculture in cases when environmental problems are quite common in semi-arid zones.

4. Conclusions

The Baghdad Governorate field study showed that the use of bio-stimulants, especially in nano-formulations significantly increased growth, physiological and biochemical properties, yield of the yellow corn (Zea mays L). The data solely demonstrated how bio-stimulants in their nano-enhanced formats, baker's yeast extract, whey, and Moringa oleifera extract, outperformed conventionally bio-stimulants and the untreated control.

T7, the plant-nano extract treatment, showed highest yield of grain at 11.0 $t \cdot ha^{-1}$, greater than that of the control at 7.2 $t \cdot ha^{-1}$. Increased plant tolerance to environmental stress was observed when the use of bio-stimulants was combined, as indicated by increased chlorophyll, antioxidant enzyme, and proline responses.

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This study has shown how the use of natural bio-extracts and nanotechnology is a viable sustainable environmental method for increasing crop productivity in arid and semi-arid regions. The results indicate that nano-bio stimulants can serve as efficient substitutes for chemical fertilizers and contribute to the development of sustainable agriculture, and can also promote increased crop yield and growth.

More research is required to determine the long-term environmental impact of growing these bio-stimulants on a larger scale in various crops and areas that are economically viable to grow on a big scale.

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