UDC 633.33^632.577 https://doi.org/10.15407/biotech17.04.060

IMPROVING COWPEA (*Vigna unguiculata* (L.) Walp.) YIELD WITH GREEN SYNTHESIZED MgO NANOPARTICLES USING *Jatropha tajonensis* LEAF EXTRACT

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Received 2024/06/03
Revised 2024/07/06
Accepted 2024/08/30

The *aim* of this work was to investigate the effect of synthesized magnesium oxide nanoparticles of *Jatropha tajonensis* leaf extract on the growth and yield of cowpea (*Vigna unguiculata* (L.) Walp.).

Materials and Methods. The preparation and planting of the cowpea seeds; The extraction of extract of *Jatropha tajonensis* leaves in aqueous solution. The synthesis of MgO nanoparticles from the extract, followed by characterization to confirm the formation — UV-VIS, FTIR, SEM-EDX and PXRD. The effects of MgONPs on cowpea (*Vigna unguiculata* (L.) Walp.) plants were surveyed under field conditions to assess its uses in improving growth and yield of cowpea.

Results. The results showed that different doses of MgONPs applied to cowpea plant significantly affected all measured parameters of cowpea plantlets under the field condition in a positive way. The best results in growth, yield and the phonological parameters were cowpea plants treated with high MgONP applications (100 mg/L). It has been observed that different MgONPs applications have significant effects on vegetative growth and yield parameters of cowpea. A significant increase in the number of vegetative parameters was observed in the pots with different doses of nano-20, 40, 60, 80 and 100/MgONPs applications compared to the control. Different MgO (with or without NPs) treatments led to significant differences in shoot formation ($P < 0.01$). According to the effect of different doses of magnesium NPs applied to the cowpea, plant height varied between 18.88 ± 2.51 and 21.35 ± 3.25. The highest value in the height was obtained from nano-100 mg/L MgONPs application with 21.35 ± 3.25 and the lowest value was obtained from the salt 17.48 ± 3.83 mg/L MgONPs application.

Conclusion. This study found that MgONPs greatly influenced the plantlets' growth parameters and other measured traits; in addition. There was an indication that the efficiency of growth and yield of cowpea could be improved by increased application of MgO in the form of nanoparticles. Also, highlighted was the possibility of using MgONPs in increasing another crop yield to cater for the ever-growing world population.

Key words: Magnesium oxide nanoparticles, *Jatropha tajonensis,* nano fertilizer, cowpea, phenology.

Cowpea (*Vigna unguiculata* (L.) Walp.) is an essential leguminous crop with a genome size of approximately 620 million base pairs, predominantly cultivated in semiarid regions worldwide [1]. Originating from Africa, it is now grown in over 100 countries, significantly contributing to economic, nutritional, and environmental well-being by providing critical nutrients to humans and livestock, enhancing soil fertility through nitrogen fixation, and offering farmers a source of income [2]. With its high protein content, cowpea is widely used in various formsбю such as seeds, leaves, and pods, thereby playing a crucial role in human and animal diets [3]. Its resilience to diverse climates and soils and its nitrogenfixing capability underscores its importance in promoting food security, soil health, and environmental sustainability in arid and tropical regions [4]. Furthermore, cowpea's integration into mixed cropping systems helps suppress weeds, retain moisture, and support beneficial soil microorganisms, reducing the dependency on synthetic agrochemicals [5].

Cowpea, a versatile leguminous crop, is an essential nutritional source for humans and animals. Fresh cowpea beans contain about 2.0–4.3% protein, while the grains contain 4.5–5.0% protein. The protein content in mature, dry grains ranges from 20.42% to 34.60% . Additionally, cowpea grains comprise 50–67% carbohydrates, 1.3% oil, 3.9% cellulose, and 3.6% ash [6, 7]. Cowpea seeds are notably rich in the amino acids Lysine [8] and Tryptophan [9] compared to cereal seeds, although they have lower levels of Methionine and Cystine relative to animal proteins [10]. Furthermore, cowpea's drought tolerance and adaptability to harsh conditions make it a vital dietary component for humans and livestock in various regions [11].

Cowpea yield in Nigeria is low, particularly in the southern parts where pests and diseases from the forest vegetation are prevalent. A promising strategy to mitigate these challenges involves utilizing early-maturing cowpea genotypes, which have demonstrated yields comparable to or exceeding those of late-maturing varieties [12]. These early maturing varieties are particularly advantageous in areas with inconsistent rainfall patterns, as they are more likely to thrive despite early cessation of rains, thus making them adaptable to various agroecological environments in Nigeria [13].

Yield evaluation is comprehensive, encompassing multiple characteristics that influence the overall performance of cowpea genotypes[14]. Given that yield is a quantitative trait, it is affected by several agronomic factors either individually or through their interactions [15]. Key agronomic traits contributing to seed yield include earliness (measured by days to flowering, pod filling period, and days to physiological maturity), the number of branches per pod, and the weight of 100 seeds [16]. Therefore, understanding these traits and their interrelationships is crucial for efforts aimed at increasing cowpea seed yield.

Nanotechnology is crucial in modern agriculture, offering innovative solutions to various challenges while promoting sustainability and environmental health [17]. Using nano pesticides and fertilizers in precision agriculture has shown promising results in enhancing pest and pathogen control, ultimately leading to increased plant yield [18]. Nanoparticles have been instrumental in plant tissue culture by eliminating microbial contaminants and improving processes like somatic embryogenesis and genetic transformation, highlighting their potential in medicinal product development [19]. Engineered nanoparticles, serving as nano-fertilizers, have proven effective in boosting crop productivity under diverse stress conditions such as drought [20], salinity [21], and heavy metal pollution [22] by enhancing antioxidant defense mechanisms and nutrient absorption [23], ultimately improving photosynthesis, plant growth, and overall yield [24].

The application of nanomaterials in agriculture has surged in recent years, addressing numerous challenges. The application of nanomaterials in agriculture has surged in recent years, addressing numerous challenges. For instance, nano fertilizers significantly influence crops' physiological and biochemical processes by enhancing nutrient accessibility, improving growth, and increasing photosynthesis [25]. Furthermore, nanocarriers enhance nutrient efficiency by delivering nutrients precisely where and when needed, thereby reducing the accumulation of excess chemicals in plants [26]. The efficacy of nanoparticle applications is influenced by intrinsic factors such as particle size and surface coating [27], and extrinsic factors, including organic matter, soil texture, and soil pH [28].

Metal oxide nanoparticles supply essential elements for crop growth and yield enhancement. These nanoparticles can be synthesized through chemical methods such as co-precipitation [29], thermal decomposition [30], hydrothermal [31], and solvothermal [32] techniques. Despite their efficiency in producing high yields of metal oxide nanoparticles, these methods often encounter challenges related to particle size control, complex experimental setups, and hazardous reagents [33]. Alternatively, green synthesis approaches provide eco-friendly, low-toxicity, and sustainable solutions [34]. These methods employ renewable resources, including plant extracts, to reduce and stabilize metal ions, producing metal oxide nanoparticles with desirable properties [35]. For instance, studies have demonstrated the use of *Carica papaya* [36], *Syzygium samarangense* [37], and *Moringa oleifera* [38] leaf extracts to synthesize metal oxide nanoparticles, which have shown promise in various applications, including agriculture. This green synthesis not only addresses the environmental and safety concerns associated with conventional methods but also leverages the bioactive compounds present in plant extracts to enhance nanoparticle functionality[34]. Consequently, metal oxide nanoparticles synthesized through green methods hold significant potential for improving agricultural productivity sustainably, aligning with current trends toward greener and more efficient agricultural practices [30, 40].

Magnesium plays a critical role in plant development and physiology, being a vital component of the synthetic chlorophyll pathway and regulating key photosynthetic enzymes in chloroplasts [41]. Magnesium deficiency can suppress plant growth and decrease yield [42]. It activates more enzymes than other nutrients [43] and has structural and regulatory functions related to nucleophilic ligands in plants [44]. Magnesium is essential for the function and synthesis of nucleic acids and ATP [45].

Magnesium oxide nanoparticles (MgO-NPs) have been shown to significantly enhance cowpea growth and resistance to biotic stress by promoting tissue growth, callus induction, and shoot regeneration, resembling the effects of plant hormones like cytokinins and gibberellins [46]. Optimal concentrations of MgO-NPs have been found to improve shoot and root development, although higher concentrations can have inhibitory effects [47]. Furthermore, MgO-NPs exhibit potent nematicidal properties against *Meloidogyne incognita*, reducing egg mass and gall formation, thereby enhancing overall plant health and yield [48, 49]. These nanoparticles also increase chlorophyll content and other biochemical markers, improving photosynthesis and nutrient uptake in cowpea plants [50]. Therefore, investigating the effects of green-synthesized magnesium oxide nanoparticles on the in vitro propagation characteristics of cowpea, an essential crop for human and animal nutrition, is a relatively unexplored area. This research aimed to synthesize magnesium oxide nanoparticles from the leaf extract of *Jatropha tajonensis* and evaluate their effects on the growth and yield of cowpea (*Vigna unguiculata* (L.) Walp).

Materials and Methods

Magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), sodium hydroxide (NaOH), ethanol 99.9% of analytical grade (Molychem products) were obtained from a commercial dealer and used without any additional reagents. All the glassware was washed with deionized water and oven dried. *Jatropha tajonensis* leaves were freshly collected from a local farm in Tarka local government of Benue state, Nigeria and were identified in the Department of Botany of Joseph Sarwuan University, Makurdi, Nigeria. The deionized water was used for all the homogenization process.

Dry seeds of cowpea were obtained from the seed and storage Centre in the South Core of the Joseph Sarwuan Tarka University Makurdi (JOSTUM). Olasan Olalekan Joseph (Ph.D.) identified and authenticated the plant seeds in the Department of Botany.

The cowpea seeds were prepared and planted behind Academic Block B at the South Core area of the Joseph Sarwuan Tarkaa University of Agriculture Makurdi, Nigeria (JOSTUM).

Preparation of Jatropha tajonensis Leaf Extract

To prepare the extract of Jatropha tajonensis leaves, the leaves were washed with deionized water to remove impurities, air dried and pulverized. The fine powdered Jatropha tajonensis leaves of 6g was added into 100 mL deionized water, which was heated at 80 °C for 20 to 30 minutes. The obtained extract was filtered using filter paper (Whatman no. 1) and stored at 4 °C for further use [51].

Synthesis of Magnesium Oxide Nanoparticles of Jatropha tajonensis Leaf Extract

In this work 20 mL of the prepared *Jatropha tajonensis* leaf extract in a 250 mL beaker was stirred, heated at 60 °C and 80 mL of aqueous solution of Magnesium Nitrate (5 g, 0.2M) added dropwise. Followed was the addition of a few drops of 1M NaOH, continuously stirred and heated at 80 °C for 4 hours. The Magnesium ion in the solution was reduced and stabilized by the leaf extract to give yellowish-brown precipitates of Magnesium oxide nanoparticles (MgONPs). The solution was centrifuged to separate the supernatant, and the residues were severally washed with ethanol and oven-dried at 70 °C for 3 hours. It was finally calcined in the Muffle furnace at 400 °C for 2 hours to obtain white MgONPs [52].

Characterization of Magnesium Oxide Nanoparticles of Jatropha tajonensis Leaf Extract

To confirm and characterize the synthesis of magnesium oxide nanoparticles, a JENWAY 6405 UV-Vis spectrophotometer was employed. The UV-Vis absorption spectrum was validated through a wavelength scan ranging from 200 to 800 nm. Following the green synthesis of MgONPs, UV-Vis spectra of the solution were recorded at various wavelengths.

FTIR analysis was conducted using an Agilent 630 Cary FTIR Spectrometer to provide spectroscopic information about the bond details of the compounds. This spectrometer features an ATR module for liquids and solids and a 'Dial Path' module for absorbance spectra of liquids, films, and gels. Magnesium oxide nanoparticles were prepared on KBr discs using a 4% (w/w) solid/KBr mixture for this analysis. The FTIR spectra were acquired in the range of 400–4,000 cm^{-1}, allowing for the study of vibrational modes and bond details of the compounds, as well as the biomolecules present in the *J. tajonensis* extract on a 1 mm thick re-crystallized KBr disc.

X-ray diffraction (XRD) analysis was performed using a Thermo Scientific ARL 'XTRA' X-ray Diffractometer (serial number 197492086) at Umaru Musa Yar'adua University in Katsina State, Nigeria. As a non-destructive analytical technique, XRD provided information on the crystalline structures, phases, texture, crystal lattice parameters, chemical composition, and other structural parameters such as average grain size, crystallinity, crystal defects, and strain.

Additionally, the materials were analyzed using an EDX Scanning Electron Microscope (SEM), model PRO:X 800-07334 from Phenom World (serial number MVE01570775). This technique provided information on the structures and surface morphology of the materials, including pore and fiber metric analysis and particle sizes of the MgONPs.

Study Area

The study was performed in Makurdi, Benue State, positioned at 8°30′E longitude and 7 °30′N latitude, covering an area of 804 km^2 with an estimated population of 500,797. Makurdi's topography is characterized by low elevation, ranging from 73 to 167 m above sea level, and is primarily composed of highly ferruginous tropical soils. The climatic conditions are categorized as tropical and sub-humid, characterized by distinct rainy and dry periods. The damp season covers the period from April to October of the year, whereas the parched season occurs from November to March. The annual precipitation levels fall within the range of 775 to 1792 mm, averaging at 1190 mm. The relative humidity levels fluctuate from 43% in January to 81% in July and August. The plant life in Makurdi, situated in the Guinea Savannah zone, exhibits tall grasses and deciduous trees that go through leaf shedding in the dry season [53, 54].

Cowpea Preparation/Planting

Sand for planting cowpea seeds was sourced from the botanical garden behind Academic Block B at South-Core. To prepare the planting medium, the sand was sieved using a fine mesh to remove larger stones and plant debris. Approximately 30 kg of the sieved sand was measured using a digital balance and used to fill forty polyethylene pots.

Cowpea seeds were sown into the pots, with four seeds placed at a depth of 3 cm in each pot. After seedling establishment, the seedlings were thinned to one per pot. Watering commenced the following day and continued twice daily, morning and evening until the pods matured. The polypots were covered to prevent rainwater ingress and were protected with mosquito nets to guard against pests and animals.

The cowpea seedlings were first evaluated on day twelve, followed by nanoparticle treatment on day thirteen. Three treatments were applied: MgO-nanoparticles, regular X, and salt fertilizer at concentrations of 20, 40, 60, 80, and 100 ppm. The study aimed to investigate the effects of MgO-nanoparticles on the growth and yield of cowpea (*Vigna unguiculata* L. Walp) under controlled pot conditions. Thirty-day-old seedlings were treated with the specified concentrations of MgO-nanoparticles and a 0.03% adjuvant. Germination percentage was calculated by dividing the number of germinated seeds by the total number of seeds sown, expressed as a percentage. Different growth and yield-related parameters like the number of leaves, leaf width, plant height, number of branches, stem diameter, pod number, and total grain yield were recorded at maturity. The whole plant was uprooted, weighed, and recorded to calculate the biomass.

Growth Parameters Determination of Cowpea

The plant height of cowpea plants was determined by measuring from the base to the apex using a meter rule, with an average height recorded for two selected plants per pot. Stem diameter was assessed by encircling the stem with a small rope, measuring its length with a ruler, and recording the values. The number of branches and leaves on each cowpea plant in every experimental pot was counted. At the same time, leaf width was measured with a meter rule placed precisely on each sampled leaf during the phenological stage to ensure accurate readings for subsequent analysis [55].

Yield Parameters Determination of Cowpea

Various parameters were important in determining the yield of the cowpea plants. The number of pods per plant was evaluated by counting pods on two selected plants per experimental pot. In contrast, pod length was measured using a meter rule on one randomly chosen pod per pot, with two to four pods sampled randomly. Total grain yield was calculated by weighing the harvested grains from the usable area of each experimental pot and adjusting these values to a standard humidity of 13% using established methods [56]:

$$GY = CW\left(\frac{t}{ha}\right) = WW\ x\ [\frac{(100 - RH)}{100 - SH(13\%))}] \quad (1)$$

The equation used is CW = corrected weight, WW = wet weight, RH = real humidity, and SH = standard humidity.

Statistical Analysis

Minitab 16.0 was used to analyze the results. The following tools were applied: Descriptive statistics (mean, standard error,), One-way ANOVA, and Person's correlation) Turkey's method was used to carry out the mean of separation at a 95% confidence limit (P value =0.05 limit).

Result and Discussion

Characterization of MgO Nanoparticles

UV-VIS of MgONPs

The UV-Vis absorption spectra for MgONPs (magnesium oxide nanoparticles) and *J. tajonensis* exhibit distinct characteristics reflective of their unique compositions. Both spectra show a prominent absorption peak around 280 nm, indicating electronic transitions likely associated with the nanoparticles' core materials. The MgONPs spectrum (blue line) demonstrates a broad absorption band with a gradual decrease in absorbance beyond 300 nm, suggesting a wide distribution of particle sizes and a relatively homogeneous surface chemistry (Fig. 1). In contrast, the *J. tajonensis* spectrum (red line) peaks around 280 nm. It shows additional pronounced absorption in the 300–400 nm range, which could be attributed to specific organic compounds or secondary metabolites inherent to *J. tajonensis*. This higher absorbance in the UV region indicates a higher concentration of UV-absorbing substances, potentially beneficial for applications requiring UV protection. The overall lower absorbance of MgONPs in the visible range (400–700 nm) suggests it would have minimal interference with visible light, making it suitable for applications where transparency is required [57].

FTIR of MgONPs

The FTIR spectrum of MgONPs (magnesium oxide nanoparticles) presents several distinct absorption bands, indicative of the various vibrational modes of functional groups associated with the nanoparticles. The broad band around 3400 cm^{-1} corresponds to the O–H stretching vibrations, indicating the presence of hydroxyl groups or adsorbed water on the metal oxide nanoparticle surface [58]. The small peak near 1600 cm^{-1} can be attributed to the bending vibrations of water molecules. The strong and sharp peak observed around 1400 cm^{-1} is characteristic of the C=O stretching vibrations, suggesting the presence of carbonate groups, possibly due to atmospheric CO_2 adsorption. The prominent absorption band at approximately 1000 cm^{-1} is associated with the Mg–O stretching vibrations, confirming the formation of MgO nanoparticles. Additionally, minor peaks

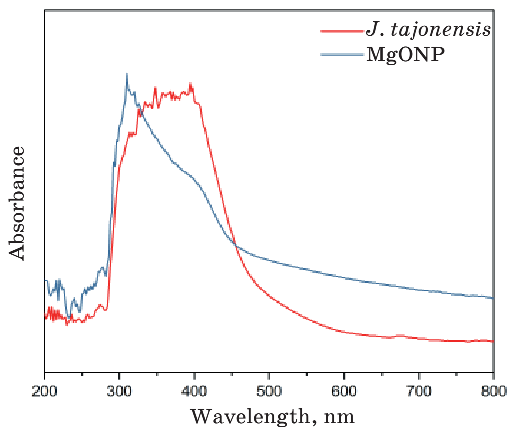

Fig. 1. **UV-VIS of *J. tajonensis* Leaf Extract and the derived Magnesium Oxide Nanoparticles**

observed in the 800–500 cm^{-1} range can be linked to the bending modes of Mg–O bonds, further substantiating the nanoparticulate nature of MgO. This detailed vibrational analysis underscores the functional groups and structural features of MgO nanoparticles, providing insights into their chemical composition and potential surface interactions.

SEM and EDX Analysis of MgONPs

The SEM images in the study of magnesium nanoparticles synthesized from *Jatropha tajonensis* reveal significant insights into their morphological attributes (Fig. 2). The SEM images in Fig. 3 show the magnesium nanoparticles in two distinct magnifications. These images, presented in Fig. 3, are crucial for analyzing the morphology and distribution of the nanoparticles. The photos show that the magnesium nanoparticles exhibit a uniform spherical morphology, often associated with higher stability and surface area. This is typical for metal nanoparticles derived from plant materials like *Jatropha tajonensis* [59]. The surface of the magnesium nanoparticles appears to be smooth and free from significant accumulation, which suggests a high degree of monodispersity. The size distribution, inferred from the SEM images, indicates that the nanoparticles are in the range of nanometers, consistent with other studies on biogenically synthesized magnesium nanoparticles [60].

The EDX spectra in Table 1 show magnesium's atomic and weight percentages (Mg), with values of 46.51% and 46.46%, respectively. The spectra in Fig. 4 confirm that the MgONPs are predominantly magnesium, with negligible contamination from other elements [61].

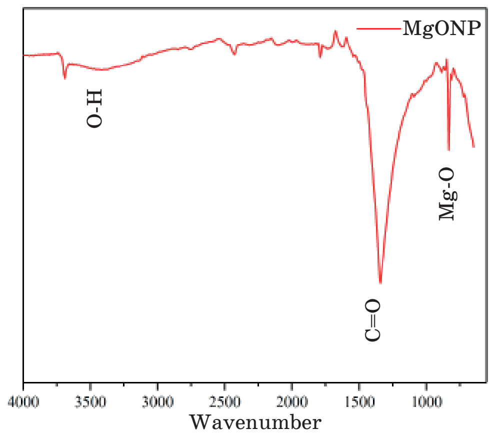

Fig. 2. **UV-VIS of the synthesized Magnesium Oxide Nanoparticles**

Table 1

EDX Weight Ratio of Electrospun MgONPs

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
12	Mg	Magnesium	46.51	46.46
11	Na	Sodium	45.26	42.76

XRD of the MgONPs

The X-ray diffraction (XRD) data for Magnesium oxide (MgO) nanoparticles synthesized from *Jatropha tajonensis* reveals critical insights into the material's crystallographic parameters. This analysis focuses on peak positions (2θ), full width at half maximum (FWHM), and crystallite sizes, which are essential for understanding the structural properties of the synthesized nanoparticles. As shown in Table 2, the data indicates peak positions ranging from 8.64° to 67.31°, corresponding to various crystallographic planes of MgONPs. The diffraction peaks for the MgONPs can be indexed along with JCPDS card No. 00-014-0076. The FWHM values vary significantly, from 0.13° to 1.00°, reflecting differences in crystallite size. Moreso, narrower FWHM values are

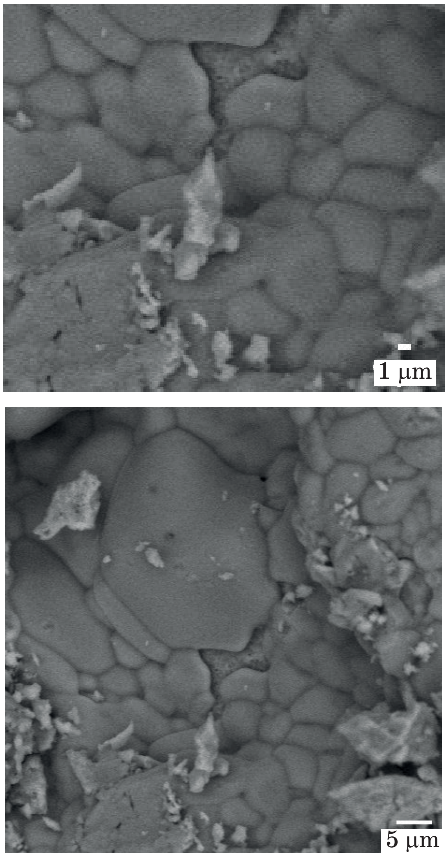

Fig. 3. **SEM images of the synthesized Magnesium Oxide Nanoparticles**

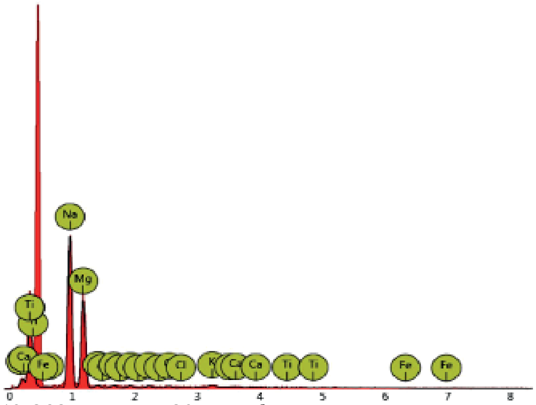

Fig. 4. **EDX of the Magnesium Oxide Nanoparticles**

Table 2

Some Crystallographic Parameters of the Synthesized MgONPs based on the X-Ray Diffraction Pattern

S/N	Peak Position (2θ)	FWHW (β) (degree)	Crystallite size D (nm)	D (Average) (nm)
1	8.64	0.97	8.21	22.33
2	19.58	1.00	8.06	
3	27.41	0.35	23.36	
4	30.34	0.38	21.55	
5	32.7	0.19	43.57	
6	38.77	1.00	8.42	
7	39.71	0.41	20.60	
8	43.56	0.73	11.72	
9	48.58	0.52	16.76	
10	59.26	0.82	11.15	
11	62.87	0.44	21.16	
12	67.31	0.13	73.42	

associated with larger crystallite sizes, as seen at 32.7° (43.57 nm) and 67.31° (73.42 nm). Conversely, broader peaks at 19.58° and 38.77° (with FWHM of 1.00°) correspond to smaller crystallite sizes of approximately 8 nm. The average crystallite size calculated from these values is 22.33 nm, suggesting the presence of nano-sized crystalline domains. Such a size range is typical for nanoparticles and is crucial for their unique physical and chemical properties. The high degree of crystallinity indicated by the sharp peaks and relatively narrow FWHM values underscores the quality of the synthesized MgO nanoparticles [62, 63].

Effect of Biosynthesized MgO Nanoparticles on Cowpea

The study investigated the impact of the metal oxide nanoparticles on various growth, phenological, and yield parameters of cowpea (*Vigna unguiculata* (L.) Walp.) using different concentrations of MgO nanoparticles.

Growth parameters of MgONPs effect on Cowpea

The effects of magnesium oxide (MgO) nanoparticle treatments on various cowpea growth parameters as presented in Table 3 were on plant height, number of leaves, leaf length, number of branches, and stem diameter across different treatments. The control group exhibited a mean plant height of 15.57 cm, while MgONPs treatments, particularly Nano-40 (21.47 cm) and Nano-100 (21.35 cm), significantly enhanced plant height (F = 3.97, P = 0.001). The number of leaves increased substantially with the Nano-20 treatment (91.4 leaves), demonstrating significant treatment effects (F = 2.20, P = 0.044). Leaf length remained relatively consistent across all treatments, with no significant differences observed (F = 0.10, P = 0.998). The number of branches was notably higher in the Nano-20 and Nano-100 treatments (6.500 branches each), with statistical significance (F = 3.96, P = 0.001). Stem diameter showed a trend towards increased size in the Nano-100 treatment (2.244 cm), though this was not statistically significant (F=1.93, P=0.077). Additionally, the variety FUAMPEA-3 recorded higher means in several parameters, including plant height (17.71 cm) and number of leaves (96.9), providing a varietal benchmark. The box plot (Fig. 5) visually confirmed the enhancement in plant height due to MgO nanoparticle treatments, reinforcing the potential of MgO nanoparticles to improve specific growth parameters significantly. These findings suggest that MgO nanoparticles, especially at 40 mg/L and 100 mg/L, can effectively utilized to enhance plant growth [64].

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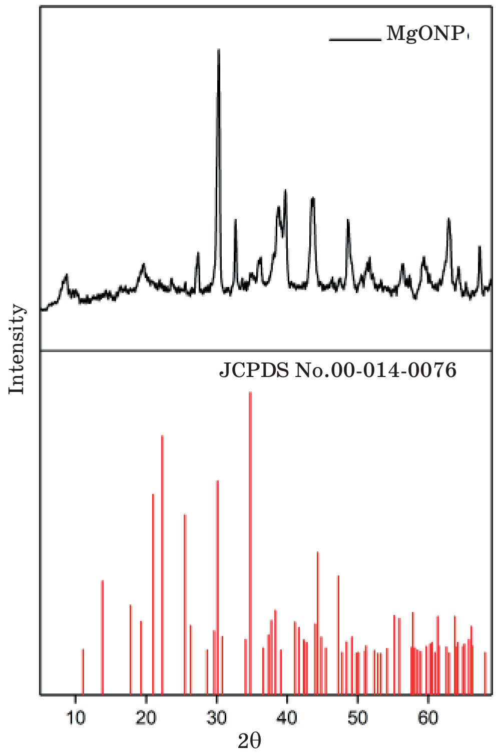

Fig. 4. **XRD Pattern of the Magnesium Oxide Nanoparticles derived from *Jatropha tajonensis***

Phenological Parameters of MgONPs effect on Cowpea

Table 4 illustrates the influence of magnesium oxide (MgO) nanoparticle treatments on phenological parameters, highlighting significant enhancements in plant development. These phenological parameters indicated that the number of flowers did not significantly differ among treatments (F = 0.99, P = 0.446), nor did the days to flowering (F = 0.38, P = 0.910), with the highest flower count observed in the Nano-80 treatment (7.700). These findings corroborate the growth parameters and suggest that MgO nanoparticles can enhance specific parameters, particularly at certain concentrations, offering potential agronomic benefits [65].

Yield Parameters

The effect of MgONPs treatments on the cowpea pod and seed yield parameters, according to Table 5, had the control treatment exhibited a moderate performance across all parameters, with an average pod length of 11.28 cm and a total seed weight of 12.73 g. In contrast, the Nano-20 treatment significantly enhanced the yield, showing improvements in pod number (7.10), pod length (12.30 cm), and a significant increase in both total pod weight (47.03 g) and seed weight (33.75 g). The Nano-40 treatment displayed mixed results; although the pod length and the number of seeds per pod increased, the total pod weight saw an abnormal spike to 356 g, likely indicating an outlier or experimental error. Nano-60 treatment

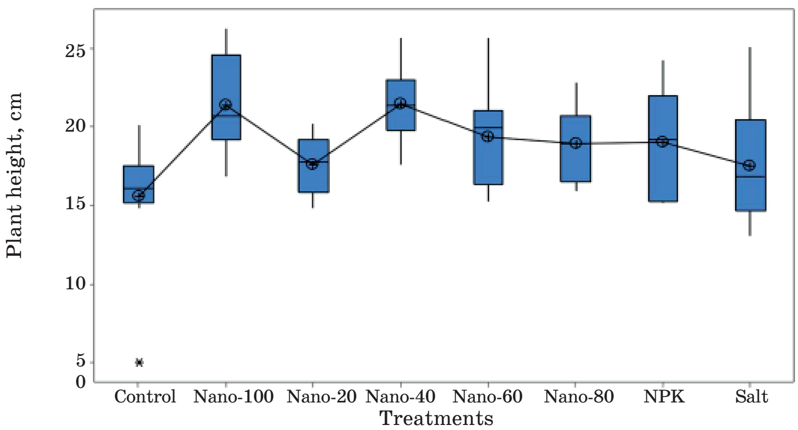

Fig. 5. **Box Plot Showing Responses of Plant Height to Different Treatments**

Table 3

Effects of MgO Nanoparticles Treatments on Growth Parameters

Treatments	Plant height, cm Mean ± SD	Number of leaves	Leaf Length, cm	Number of branches	Stem diameter, cm
Control	15.57 ± 4.04	72.80 ± 13.75	7.130 ± 0.955	5.700 ± 1.494	2.0800 ± 0.1751
Nano-20	17.60 ± 1.932	91.4 ± 31.8	7.350 ± 1.075	6.500 ± 1.650	2.1600 ± 0.1713
Nano-40	21.47 ± 2.467	88.9 ± 32.7	7.030 ± 1.338	6.200 ± 1.549	2.0500 ± 0.1269
Nano-60	19.32 ± 3.36	86.5 ± 34.5	7.180 ± 0.728	5.200 ± 1.687	2.1400 ± 0.2171
Nano-80	18.88 ± 2.512	87.90 ± 28.33	7.260 ± 0.715	5.100 ± 0.994	2.1300 ± 0.2406
Nano-100	21.35 ± 3.25	81.30 ± 31.15	7.120 ± 1.422	6.500 ± 1.434	2.244 ± 0.305
Salt	17.48 ± 3.83	66.70 ± 14.80	7.170 ± 0.770	4.900 ± 1.197	1.9700 ± 0.1494
NPK fertilizer	18.96 ± 3.21	56.30 ± 15.90	7.230 ± 0.615	4.000 ± 0.943	1.9600 ± 0.2914
F (Treatment)	F = 3.97, P = 0.001	F = 2.20, P = 0.044	F = 0.10, P = 0.998	F = 3.96, P = 0.001	F = 1.93, P = 0.077
T (Variety) FUAMPEA-3	17.71 ± 2.17	96.9 ± 22.3	7.705 ± 0.098	5.83 ± 1.55	2.118 ± 0.027

Note: Means that do not share a letter are significantly different.

Table 4

Effects of MgO Nanoparticles Treatments on Phenological Parameters

Treatments (Mean ± SD)	No of flower	Day to flowering
Control	6.700 ± 1.829	34.500 ± 0.972
Nano-20	7.200 ± 1.398	34.200 ± 0.632
Nano-40	7.200 ± 1.687	34.300 ± 0.949
Nano-60	6.700 ± 1.494	34.200 ± 1.135
Nano-80	7.700 ± 1.252	34.400 ± 0.966
Nano-100	6.700 ± 2.751	34.500 ± 1.080
Salt	6.800 ± 2.044	34.00 ± 0.816
NPK fertilizer	5.700 ± 1.889	34.500 ± 0.850
F (Treatment)	F = 0.99, P = 0.446	F = 0.38, P = 0.910
T (Variety) FUAMPEA-3	7.30 ± 1.45	34.775 ± 0.768

Note: Means that do not share a letter are significantly different.

improved the number of pods (8.10) and stable seed weight (22.34 g), while Nano-80 also performed well with a total pod weight of 42.25 g and seed weight of 23.86 g. Interestingly, the Nano-100 treatment decreased all yield parameters, with values close to or lower than the control, suggesting a potential inhibitory effect at higher concentrations. Comparatively, the salt and NPK fertilizer treatments had lower performance, especially the NPK treatment, which resulted in the lowest number of pods (4.20) and seed weight (8.89 g). The statistical analysis indicated significant differences among treatments for the number of pods and total seed weight, with the highest F-values ($F = 3.23$, $P = 0.005$ and $F = 4.96$, $P = 0.000$, respectively), underscoring the efficacy of specific nano treatments in enhancing yield parameters (Table 5, Fig. 6). Figure 6 illustrates the responses of total seed weight to different treatments through a box plot, further emphasizing the superior performance of metal oxide nanoparticle treatments over control and other conventional treatments in agricultural

Table 5

Effects of Nano Treatments on Pod and Seed Yield Parameters

Treatments (Mean ± SD)	Number of pods/fruit	Pod length, cm	Number of seeds per pod	Total pod weight, g	Total seed weight, g
Control	6.100 ± 1.287	11.28 ± 5.86	9.50 ± 6.22	16.48 ± 17.58	12.73 ± 9.42
Nano-20	7.100 ± 2.025	12.30 ± 6.17	13.10 ± 8.21	47.03 ± 7.17	33.75 ± 3.94
Nano-40	6.900 ± 2.079	12.02 ± 6.27	13.80 ± 9.72	356 ± 1035	20.42 ± 21.90
Nano-60	8.100 ± 3.071	11.63 ± 5.58	11.20 ± 6.86	33.04 ± 24.24	22.34 ± 12.13
Nano-80	7.500 ± 2.718	11.94 ± 5.28	13.40 ± 8.95	42.25 ± 13.80	23.86 ± 4.07
Nano-100	5.900 ± 2.025	10.51 ± 5.71	11.70 ± 8.87	16.557 ± 3.156	13.974 ± 2.040
Salt	5.600 ± 2.011	10.68 ± 5.23	10.40 ± 7.50	21.46 ± 13.40	15.78 ± 11.65
NPK fertilizer	4.200 ± 1.619	10.27 ± 5.51	10.70 ±6.70	19.97 ±15.06	8.89 ± 10.33
F (Treatment)	F = 3.23, P = 0.005	F = 0.18, P = 0.989	F = 0.38, P = 0.909	F = 1.00, P = 0.441	F = 4.96, P = 0.000
T (Variety) FUAMPEA-3	7.22 ± 2.86	6.33 ± 1.05	5.03 ± 0.18	27.9 ± 20.3	12.9 ± 2.0

Note: Means that do not share a letter are significantly different.

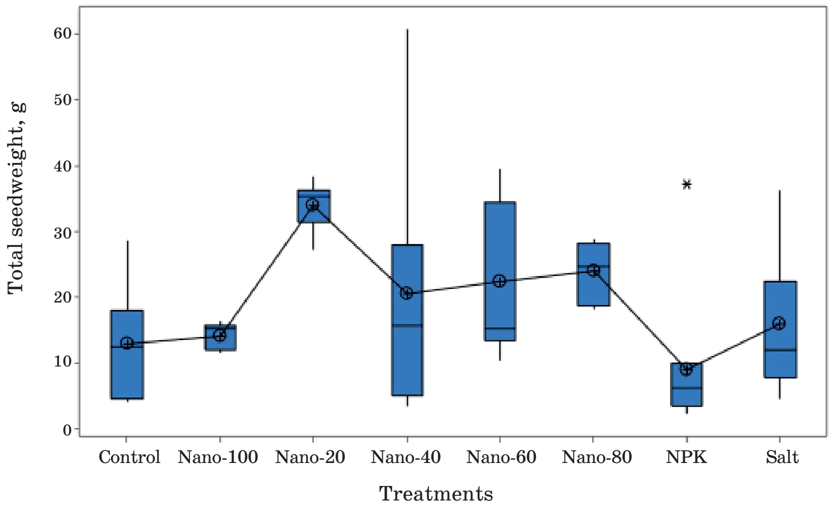

Fig. 6. **Box Plot Showing Responses of Total Seed Weight to Different Treatments**

practices, especially at optimal concentrations, to improve crop yield and quality [66].

Conclusion

This study demonstrates the significant potential of magnesium oxide nanoparticles (MgONPs) to enhance crop yield by positively influencing various growth and yield parameters. This study demonstrates the significant potential of magnesium oxide nanoparticles (MgONPs) to enhance crop yield by positively influencing various growth and yield parameters. This is evidenced by the reduced time from germination to maturation and the improved quality and quantity in cowpeas treated with different doses of MgONPs. Specifically, this study highlights the effects of MgONPs on *in vitro* cowpea culture, suggesting their applicability in cowpea tissue culture. The findings indicate that varying doses of MgONPs significantly and positively affected all measured parameters of cowpea plantlets under in vitro conditions. This investigation into the effects of MgONPs on cowpea (*Vigna unguiculata* (L.) Walp.) revealed significant improvements in growth and yield parameters, including plant height, number of leaves, leaf length, stem diameter, number of flowers, days to flowering, number of pods, pod length, seeds per pod, and total pod weight. To further elucidate the role of MgONPs in plant tissue culture, the following recommendations are proposed: investigate the influence of different concentrations and combinations of MgO-NPs on other plant parameters such as shoot induction, shoot propagation, and rooting media; explore the role of MgO-NPs in callogenesis, micropropagation, and cell culture elicitation; and conduct detailed studies to understand the mechanisms underlying the promotive or inhibitory effects of MgO-NPs on each growth parameter.

Specifically, this study highlights the effects of MgONPs on in vitro cowpea culture, suggesting their applicability in cowpea tissue culture. The findings indicate that varying doses of MgONPs significantly and positively affected all measured parameters of cowpea plantlets under in vitro conditions. This investigation into the effects of MgONPs on cowpea (*Vigna unguiculata* (L.) Walp) revealed significant improvements in growth and yield parameters, including plant height, number of leaves, leaf length, stem diameter, number of flowers, days to flowering, number of pods, pod length, seeds per pod, and total pod weight. To further elucidate the role of MgONPs in plant tissue culture, the following recommendations are proposed: investigate the influence of different concentrations and combinations of MgO-NPs on other plant parameters such as shoot induction, shoot propagation, and rooting media; explore the role of MgO-NPs in callogenesis, micropropagation, and cell culture elicitation; and conduct detailed studies to understand the mechanisms underlying the promotive or inhibitory effects of MgO-NPs on each growth parameter.

Author Contributions

All the authors planned the work, contributed to the article's conception, manuscript article writing, and editing. Fayomi Omotola Michael did the synthesis of MgO nanoparticles. Fayomi Omotola Michael, Olasan Joseph Olalekan and Aguoru Celestine Uzoma saw to the characterization of the material. Angor Anita Seember did the experiments to determine growth and yield parameters on the cowpea plants. All authors contributed to the reading, revision and approval of the submitted version.

Funding Sources

Not Applicable.

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ПІДВИЩЕННЯ ВРОЖАЙНОСТІ ВІГНИ СПАРЖЕВОЇ (*Vigna unguiculata* L. Walp.) ЗА ДОПОМОГОЮ ЗЕЛЕНОГО СИНТЕЗУ НАНОЧАСТИНОК МАГНІЮ (MgO) З ВИКОРИСТАННЯМ ЕКСТРАКТУ ЛИСТЯ *Jatropha tajonensis*

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Метою роботи було дослідити вплив синтезованих наночастинок оксиду магнію з екстракту листя *Jatropha tajonensis* на ріст і врожайність вігни спаржевої (*Vigna unguiculata* (L.) Walp.).

Матеріали та методи. Підготовка і посадка насіння коров'ячого гороху; екстракція екстракту листя *Jatropha tajonensis* у водному розчині. Синтез наночастинок оксиду магнію (MgO) з екстракту, а також їхня характеристика для підтвердження утворення — методи УФ-ВІС, Фур'є-ІЧ-спектроскопія (FTIR), сканувальна електронна мікроскопія з енергетично-дисперсійним рентгенівським аналізом (SEM-EDX) та рентгенівська дифрактометрія (PXRD). Вивчено вплив MgONPs на рослини *Vigna unguiculata* (L.) Walp. в польових умовах для оцінювання їх використання з метою покращення їхнього росту і врожайності.

Результати показали, що різні дози наночастинок MgO (MgONPs), застосовані до рослин *Vigna unguiculata* (L.) Walp., суттєво впливали на всі вимірювані параметри розсади *Vigna unguiculata* (L.) Walp. в польових умовах позитивним чином. Найкращі результати щодо росту, врожайності та фенологічних параметрів було отримано у рослин, оброблених високими дозами MgONPs (100 мг/л). Зазначено, що різні дози MgONPs мають значний вплив на вегетативний ріст і врожайність *Vigna unguiculata* (L.) Walp. Значне збільшення кількості вегетативних параметрів спостерігалося у горщиках із різними дозами MgONPs (20, 40, 60, 80 та 100 мг/л) у порівнянні з контролем. Різні обробки MgO (з наночастинками або без них) призвели до суттєвих відмінностей у формуванні пагонів ($P < 0{,}01$). Відповідно до впливу різних доз наночастинок магнію на вігну спаржеву, висота рослин варіювалася від $18{,}88 \pm 27{,}51$ до $21{,}35 \pm 3{,}25$ см. Найвищу висоту, $21{,}35 \pm 3{,}25$ см, було отримано при застосуванні MgONPs у дозі 100 мг/л, а найнижча висота, $17{,}48 \pm 3{,}83$ см, спостерігалася при застосуванні MgONPs у дозі 17,48 мг/л.

Висновки. Встановлено, що наночастинки оксиду магнію (MgONPs) значно вплинули на параметри росту рослин та інші вимірювані характеристики. Крім того, було виявлено, що ефективність росту та врожайність *Vigna unguiculata* (L.) Walp. можна покращити шляхом збільшення застосування MgO у формі наночастинок. Також було підкреслено можливість використання MgONPs для підвищення врожайності інших культур, що може задовольнити потреби зростаючої чисельності населення світу.

Ключові слова: наночастинки оксиду магнію, *Jatropha tajonensis*, нанодобриво, *Vigna unguiculata* L. Walp., фенологія.