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GROWTH AND YIELD RESPONSE OF GINGER (*Zingiber officinale*) TO DIFFERENT APPLICATION LEVELS OF HIGH MOLECULAR WEIGHT CHITOSAN

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ABSTRACT
Purpose: This study examines soaking ginger (*Zingiber officinale* Roscoe) in different High Molecular Weight Chitosan (HMWCHT) concentrations to assess its influence on growth and yield. The study examined the impact of chitosan soaking on ginger growth.
Design/Methodology/Approach: This study employed a randomised complete block design. Three chitosan concentrations (0, 50, and 100 ppm) were used, and growth parameters (plant height, leaf count, and chlorophyll content) were assessed over 12 weeks. Means were separated using the Duncan Multiple Range Test (DMRT) as the significance test at $p \leq 0.05$.
Findings: Weeks 10 and 12 saw remarkable values for plant height (66.3 cm and 69.1 cm), leaf count (20.33 and 22.0), and chlorophyll content (79.0 and 81.0) in ginger soaked in 50 ppm, highlighting the potential of high chitosan concentrations for ginger growth. Moreover, 50 and 100 ppm chitosan resulted in significantly higher yields, with ginger soaked in 100 ppm yielding the most (1830 g).
Research Limitation: The study's controlled conditions and limited chitosan concentrations may not fully capture field variability or broader application ranges.
Practical Implications: Soaking ginger in 100 ppm chitosan significantly enhances growth and yield, offering practical, eco-friendly alternatives to synthetic fertilisers.
Social Implications: Improved ginger yields support food security, farmer income, and sustainable agricultural development through environmentally friendly agricultural practices.
Originality/Value: This study underscores the positive impact of high-molecular-weight chitosan soaking on ginger's growth and yield response. Chitosan, particularly at a concentration of 100 ppm, holds promise as a growth enhancer for commercial ginger cultivation.
Keywords: *Chitosan application. concentrations. ginger. soaked. yield responses*

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INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) is a herbaceous perennial plant known for its pungent rhizome. It originates from Southeast Asia and is a member of the Zingiberaceae family. Ginger has been a staple in oriental spices, reaching Europe early on and is widely cultivated for its culinary and medicinal properties. Its applications extend to the food, beverage and pharmacological industries because of its unique flavour and various health benefits (Siddiqui et al., 2022).

In recent years, sustainable agricultural practices have gained attention to reduce reliance on synthetic chemicals. Natural substances like chitosan have become prominent for their potential to enhance plant growth, increase crop yield and offer eco-friendly alternatives. Chitosan, derived from crab and shrimp processing waste, is an eco-friendly biopolymer with diverse applications, including agriculture. Its biological, chemical, and physical characteristics (like biocompatible, antimicrobial, nontoxic, chelating and biodegradable properties), make it valuable in various fields (Bakshi et al., 2020).

Despite the increasing interest in chitosan for crop enhancement, there is a significant knowledge gap regarding its specific effects on ginger cultivation. High chitosan application levels and their impact on the growth and yield of ginger plants remain relatively unexplored, creating a research gap in this area. This lack of comprehensive research hinders the development of effective and sustainable crop management strategies for ginger cultivation (Karamchandani et al., 2022).

Currently, ginger farmers heavily rely on synthetic fertilisers and chemical pesticides, practices associated with environmental concerns and potential adverse impacts on human health (Siregar et al., 2024). Using synthetic fertilisers and pesticides in ginger cultivation can lead to water pollution, soil degradation, and biodiversity loss. To address these issues and promote food safety, natural resources such as bio-fertilizers and biopesticides are recommended (Kumar & Singh, 2014).

As people become more conscious of the dangers of chemical pesticides, the market for biopesticides is expanding (Mishra et al., 2014). Biopesticides, such as chitosan nanoparticles, have focused impacts on pests while posing reduced environmental risk (Kashyap et al., 2015; Hazafa et al., 2021). However, there is a notable absence of research on the influence of high molecular weight chitosan on ginger growth, yield characteristics, or disease control. Thus, this study aims to explore the effects of different concentrations

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of high molecular weight chitosan on ginger plants' growth and yield characteristics. This study aims to evaluate the growth and yield of ginger rhizomes treated with various concentrations of high-molecular-weight chitosan and identify the underlying mechanisms of chitosan's action on ginger plants.

LITERATURE REVIEW

Growth and Yield of Ginger (*Zingiber officinale*)

Ginger (*Zingiber officinale*), a perennial herb belonging to the Zingiberaceae family, is cultivated globally for its rhizomes, which are valued for culinary, medicinal, and industrial purposes. Environmental conditions, soil type, and agronomic approaches affect ginger growth and production (Nettey et al., 2017; Sharma et al., 2016). Warm, humid areas with annual rainfall between 1500 and 3000 mm and temperatures between 25 and 30°C are ideal for development (Mohanty et al., 2018). The plant performs best on loamy, well-drained soils that are 5.5 to 6.5 pH and high in organic matter. Poor drainage or waterlogging can negatively impact rhizome growth, raising the risk of diseases like Pythium spp.-caused rhizome rot (Ali et al., 2015).

Research shows effective planting methods, spacing, and fertiliser management affect ginger productivity. For example, Singh et al. (2017) found that rhizome production was considerably boosted when ginger was planted at a 25 cm × 25 cm spacing with 75 kg/ha nitrogen delivery. According to Kandiannan et al. (2019), employing high-yielding cultivars such as "Varada" and "Himachal" combined with suitable agronomic methods increased production by 20–30% in comparison to local types.

Soil Amendment and Foliar Application on Ginger and Other Rhizomes Growth

In order to increase soil fertility and promote rhizome growth, soil components, including organic manure, biofertilisers, and inorganic fertilisers, are important. For example, ginger's rhizome production and nutrient absorption were enhanced by the application of farmyard manure (FYM) and vermicompost enhanced with microbial inoculants such as Azospirillum and Pseudomonas fluorescens (Ravindran et al., 2016). It has been shown that adding organic amendments and lower amounts of chemical fertilisers will improve ginger growth and slow down soil deterioration (Bhattacharyya et al., 2017). Nutrient foliar spray has become more popular to increase fertiliser efficiency and support plant health. Research indicates that applying foliar sprays of micronutrients such as boron and zinc to ginger plants greatly boosted the size and weight of their rhizomes (Anandaraj et al., 2015).

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Additionally, foliar application of plant growth regulators such as gibberellic acid (GA3) at 100 ppm enhanced shoot elongation and rhizome formation (Palanisamy et al., 2018). Similar trends have been observed in other rhizomatous crops, including turmeric (*Curcuma longa*) and arrowroot (*Maranta arundinacea*). In turmeric, integrating biofertilisers with FYM increased curcumin content and rhizome yield (Muralidharan et al., 2019). For arrowroot, foliar potassium nitrate sprays improved rhizome thickness and carbohydrate content (Patil et al., 2020).

Chitosan Types and Their Applications on Crops Growth and Yield

A possible environmentally friendly approach to enhancing crop development and production is chitosan, a biopolymer made from chitin. According to its molecular weight and degree of polymerisation, it is divided into two categories: high molecular weight chitosan (HMWCHT) and low molecular weight chitosan (LMWCHT) (Kumar et al., 2017). As a biostimulant and plant growth stimulator, HMWCHT shows exceptional promise. It increases photosynthetic efficiency by promoting root elongation, seed germination, and chlorophyll synthesis (Reddy et al., 2018). Due to enhanced nutrient absorption and stress tolerance, foliar application of HMWCHT at a 1.0% concentration increased grain production by 20% in research on rice (Oryza sativa) (Katiyar et al., 2019).

However, LMWCHT is frequently utilised as a protective agent against fungal diseases and demonstrates antibacterial characteristics. For instance, applying LMWCHT to tomato plants increased fruit output by 15% while decreasing the severity of Fusarium oxysporum-caused illness (El Hadrami et al., 2016). Another invention is chitosan nanoparticles (CNPs), which have better solubility and bioavailability than regular chitosan. When CNPs were applied to strawberries (Fragaria × ananassa), the fruit's size, sugar content, and shelf life all increased (Abdel-Mawgoud et al., 2020).

Effects of HMWCHT on Ginger Production in Ghana

With improved growth, productivity, and resistance to biotic and abiotic stressors, the use of HMWCHT in Ghanaian ginger farming has the potential to transform productivity completely. Ginger growing thrives in Ghana's agroclimatic conditions, defined by mild temperatures and seasonal rains. However, obstacles include fungal infections, insect infestations, and declining soil fertility restrict productivity (Appiah et al., 2017). Through stimulating root and shoot growth, boosting nutrient absorption, and improving stress tolerance, HMWCHT might help overcome these obstacles. According to studies

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conducted in comparable tropical climates, HMWCHT enhanced rhizome size and disease resistance, resulting in a 25% increase in ginger output (Owino et al., 2019). Additionally, its biostimulant properties could reduce dependence on chemical fertilisers and pesticides, aligning with sustainable agricultural practices in Ghana (Mensah et al., 2020). The antimicrobial properties of HMWCHT are particularly relevant for managing fungal pathogens such as *Fusarium* and *Pythium* species, which are prevalent in Ghana's ginger-growing regions (Yeboah et al., 2018). Foliar sprays of HMWCHT at 1.5% concentration have been reported to suppress fungal infections while boosting chlorophyll content and photosynthetic activity (Ahmed et al., 2021).

MATERIALS AND METHODS

Experimental Site

The experiment occurred at the Experimental Garden within the Department of Ecological Agriculture at Bolgatanga Technical University, Sumbrungu, in the Upper East Region of Ghana.

Experimental Design

This study employed a randomised complete block design (RCBD). The single primary treatment factor consisted of different high molecular weight Chitosan (HMWCS) application levels, including zero ppm (control), 50 ppm, and 100 ppm. To ensure vigor and reliability, each treatment was replicated three times, resulting in nine experimental plots.

Rhizome Preparation, Soil Amendment, and Treatment Application

This section explains in detail the process of preparing the HMWCS solutions, including the amounts of HMWCS, acetic acid, and distilled water used for each concentration. These solutions were vital for treating the ginger rhizomes in the experiment and studying their responses to different chitosan concentrations.

Preparation of High Molecular Weight Chitosan (HMWCS) Solution

In this section, the researcher describes the method used to prepare the HMWCS solutions for treating ginger rhizomes. These solutions were essential for the subsequent treatment of the rhizomes to study their growth and yield responses.

Preparation of 100 ppm HMWCS Solution: To create the 100 ppm HMWCS solution, the researcher dissolved 10 mg of HMWCS in 5 ml of acetic acid. Subsequently, 90 ml of

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distilled water was added to the mixture (Yashin et al., 2017). The dissolution of HMWCS in acetic acid, followed by adding distilled water, resulted in a 100 ppm HMWCS solution. This solution was specifically formulated to treat ginger rhizomes in the experiment.

A 100 ppm HMWCS solution was made by dissolving 10 mg HMWCS in acetic acid, adding 90 ml of distilled water, and then diluting further with distilled water (Yashin et al., 2017).
Preparation of 50 ppm HMWCS Solution: For the 50 ppm HMWCS solution, 5 mg of HMWCS was dissolved in 5 ml of acetic acid. Similar to the previous solution, 90 ml of distilled water was added (Giller et al., 2021). The 5 mg of HMWCS dissolved in acetic acid and the subsequent addition of distilled water created a 50 ppm HMWCS solution. This solution was also intended to treat ginger rhizomes.

5 mg of HMWCS was dissolved in 5 ml of acetic acid and 90 ml of distilled water to make a 50 ppm HMWCS solution (Giller et al., 2021).

Soil Amendment and Rhizome Treatment
The researchers dug the garden soil to a depth of 15 centimetres. Digging the soil to this specific depth allowed for uniformity across all planting areas, ensuring consistent growing conditions for the ginger plants. Careful attention was paid to removing stones and debris from the soil, ensuring a pristine planting medium. Eliminating stones and debris minimised potential obstacles to root growth and promoted a clean, uncontaminated environment (Yashin et al., 2017). The researchers generated a soil mixture by thoroughly blending two parts of soil with 1 part of poultry manure. The addition of poultry manure enriched the soil with essential nutrients, fostering healthier plant growth (Giller et al., 2021). The soil mixture underwent comprehensive blending, and an appropriate amount of water was added to reach the desired moisture level. Subsequently, it was allowed to stand for 2 weeks to facilitate decomposition before direct sowing. Proper blending ensures an even distribution of nutrients and moisture in the soil, crucial for optimal plant growth. Allowing the mixture to decompose for two weeks stabilised nutrient availability and microbial activity, creating a more favourable environment for ginger growth (Yashin et al., 2017).

Rhizome Treatment
Ginger rhizomes were submerged in the prepared HMWCS solution for 20 minutes (Giller et al., 2021**.** Soaking the rhizomes in the HMWCS solution allows them to absorb the

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chitosan compound, which may influence their growth and development (Chen et al., 2015). Following the soaking process, the rhizomes were air-dried for 30 minutes before being sown into the prepared planting medium. Air-drying the rhizomes helps remove excess moisture, reducing the risk of rot and fungal infections when planted (Chen et al., 2015).

Collection of Vegetative Growth Characteristics

Systematic collection of the important vegetative growth characteristics for the study. Throughout the experiment, these measurements were made every two weeks to monitor the development of the ginger plants. The researcher measured the height of ginger plants, recording their vertical growth regularly. Plant height (cm) measurement provided valuable insights into their overall development (Giller et al., 2021). The count of functional leaves on each ginger plant was recorded during each assessment. This data allowed us to evaluate leaf production and the overall health of the plants. The ginger plants' chlorophyll content (µmol m-2) was quantified to assess their photosynthetic activity, a critical factor in growth and vitality.

Data collection occurred every two weeks throughout the study. The researcher collected data on these growth parameters every two weeks to accurately capture the dynamic changes in plant development. This periodicity allowed the researcher to observe how the treatments influenced these growth characteristics as the ginger plants matured.

Assessment of Yield Characteristics

The researchers measured the weight of ginger rhizomes in each treatment group to directly gauge ginger yield under different conditions. The total ginger yield for each treatment was calculated by aggregating the recorded rhizome weights.

Statistical Data Analysis

The data obtained from the statistical analysis of the experiment was done using analysis of variance (ANOVA) procedures. The analysis was conducted using Mintab Version 16, a reliable statistical software. Means were separated using the Duncan Multiple Range Test (DMRT) as the significance test at $p \leq 0.05$.

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RESULTS AND DISCUSSION

Plant Height

Plant height was measured 4, 6, 8, 10, and 12 weeks after planting (WAP), showing significant differences across the treatments. The highest plant height (29 cm) occurred in the 5mg HMWCS (50 ppm) treatment at 4 WAP, while the control group had the minimum height (14 cm). In subsequent weeks, the CHT50 treatment consistently exhibited the maximum height (66.3 cm), surpassing CHT00 (50.1 cm). These results align with Mondal et al. (2012), indicating that higher chitosan concentrations positively impact plant height. The experiment demonstrated a significant effect of Chitosan on plant height, consistent with existing literature (Yashin et al., 2017). The Concentration-dependent response observed indicates that the growth-promoting effects of Chitosan may be optimised within specific dosage ranges. The variability in growth characteristics over time may be attributed to environmental factors and plant physiology (Kubra & Rao, 2012).

Table 4.1: Effect of Different Concentrations of HMWCHT on Plant Height

Treatment	Weeks	Growth Characteristics Plant height	No. of leaves	Chlorophyll content
CHT 00	4	13.9^{a}	2.67^{a}	5.4^{a}
CHT 50		29.0b	6.00^{b}	21.6^{b}
CHT 100		14.4^{ab}	6.33^{b}	26.0^{b}
CHT 00	6	25.5^{a}	5.33^{a}	9.6^{a}
CHT 50		39.2^{ab}	10.00^{b}	32.7^{b}
CHT 100		27.5^{b}	8.67^{b}	40.7^{b}
CHT 00	8	43.0^{a}	10.00^{a}	19.7^{a}
CHT 50		59.6^{ab}	14.67^{b}	56.3^{b}
CHT 100		49.0^{b}	14.67^{b}	54.3^{b}
CHT 00	10	55.6^{a}	14.33^{a}	32.00^{a}
CHT 50		66.3^{ab}	20.33^{b}	79.0^{b}
CHT 100		51.2b	17.00^{b}	58.0^{b}
CHT 00	12	50.1a	12.67^{a}	41.4^{a}
CHT 50		64.1ab	22.00^{b}	50.0^{b}
CHT 100		58.8b	23.00^{b}	57.7^{b}
P-values; CV%; SED		**0.021; 32.0%; 5.04**	**<.001;30.3%; 1.39**	**<.001;46.5%;6.62**

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Number of Leaves

The number of leaves significantly increased in Chitosan-treated plants compared to the control at all time points. The highest leaf count (23) was observed in CHT100, followed by CHT50 (22), while the control recorded the lowest value (12.67) at week 12. This supports the notion that Chitosan enhances leaf growth in ginger plants, consistent with previous research (Giller et al., 2021).

The results emphasise Chitosan's positive influence on leaf growth in ginger plants, supporting the idea that Chitosan acts as a growth enhancer (Giller et al., 2021). The sustained increase in leaves over the 12 weeks suggests a prolonged impact, contributing to the overall plant development.

Chlorophyll Content

Chitosan treatments significantly impacted chlorophyll content, indicating enhanced photosynthetic activity. The highest chlorophyll content (79.0 µmol m^{-2}) was noted in CHT50, while CHT00 (the control) exhibited the minimum (32 µmol m^{-2}). The Concentration-dependent response suggests that Chitosan optimally influences chlorophyll content within specific dosage ranges, aligning with the findings of Yashin et al. (2017).

Chitosan treatments significantly impacted chlorophyll content, indicating enhanced photosynthetic activity. The Concentration-dependent response highlights the importance of dosage considerations. The increased chlorophyll content suggests improved photosynthesis, contributing to overall plant health and growth (Yashin et al., 2017).

Ginger Yield

The yield of ginger rhizomes showed substantial variations among treatments. CHT100 exhibited the highest yield (3130g), significantly surpassing CHT00 (550g), while CHT50 demonstrated an intermediate yield (notably lower than CHT100 but higher than CHT00). These findings emphasise the positive effect of Chitosan on ginger rhizome yield, in line with Kamruzzaman (2016).

Table 2. HMWCHT Effects on Ginger Yield

Treatment	Yield Characteristics (g)
CHT 00	550
CHT 50	2200
CHT 100	3130

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The substantial increase in ginger yield with Chitosan application aligns with Kamruzzaman's (2016) findings. The Concentration-dependent response emphasises the importance of optimal Chitosan dosage for maximising yield. The positive effect on ginger rhizome yield further supports the potential of Chitosan as a bio-based growth enhancer in agricultural practices.

CONCLUSION

Chitosan application exhibited concentration-dependent effects on ginger plants, enhancing plant height, leaf count, chlorophyll concentration, and yield. The CHT 50 treatment showed optimal growth, while variability among treatments suggested external factors influenced plant height. Chitosan's long-term impact on leaf development was evident, particularly in the CHT 100 treatment. Increased chlorophyll concentration indicated sensitive photosynthetic activity and overall plant health, with higher concentrations yielding a concentration-dependent increase. The substantial improvement in ginger yield, especially with the CHT 100 treatment, holds the potential for enhanced crop output in agriculture. The study underscores the need for precise Chitosan concentration consideration to optimise benefits while preventing overuse. This study significantly enhances growth and yield, offering practical, eco-friendly alternatives to synthetic fertilisers. This supports food security, farmer income, and sustainable agricultural development through environmentally friendly agricultural practices.This study underscores the positive impact of high-molecular-weight chitosan soaking on ginger's growth and yield response.

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