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Growth and yield response of pepper *(Capsicum annuum* L.*)* to foliar application of carrageenan plant growth promoter

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Abstract

The study determined the growth and yield response of pepper (*Capsicum annuum* L.) to varying concentrations and frequencies of Carrageenan Plant Growth Promoter (CPGP). The study was set-up in a split-plot randomized complete block design with three replications. The three varying application frequencies were designated as main-plots, and the four concentrations of CPGP, as sub-plots. Peppers applied with 120 ppm and two to three times application of CPGP significantly matured earlier based on number of days to flowering and number of days to first priming. The same treatment combination resulted in significantly taller plants and higher number of lateral shoots. In terms of yield, however, CPGP at 120 ppm applied three times gave significantly higher number and heavier weight of fruits. The concentration of 120 ppm CPGP applied thrice in growing pepper is shown in the study to be the best treatment combination, thus, is recommended to improve the growth and increase the yield of pepper.

Keywords: *carrageenan, CPGP, application frequency, concentration*

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1. Introduction

With the increasing demand for pepper worldwide, the market is expecting a continuous upward market trend up until 2025. It is projected that at the end of 2025, pepper market volume will be 840,000 T. However, there are indicated fluctuations of pepper production from 2007-2018 (Globe Newswire, 2020). In the Philippines, pepper production is about 15 T/ha as of 2017 (DA-RFO2, 2017).

Depolymerized carrageenan through gamma-irradiation is a polysaccharide and a stimulant that has been a subject for researches in the recent years (Naeem *et al*., 2014; Abad *et al*., 2011, 2016, 2018). Carrageenan is considered to be potent elicitors of plant defense responses (Mercier *et al*., 2001; Kloareg & Quatrano, 1998; Potin *et al*. 1999; Ning *et al*., 2003), as plant growth promoters (Hien *et al*., 2000; Kume *et al*., 2002; Naeem *et al*., 2011, 2012, 2014), inducer of seed germination (Hien *et al*., 2000), shoot elongation (Hien *et al*., 2000 & Natsume *et al*., 1994), root growth (Iwasaki & Matsubara, 2000), flower production (Darvill *et al*., 1992), antimicrobial activity (Luan, 2003), and have prominent effects on the physiological activities of plant (Abad *et al*., 2009; Bi *et al*., 2010; Kume *et al*., 2002; Naeem *et al*., 2011; Relleve *et al*., 2000, 2005). This is commercially known as carrageenan plant growth promoter (CPGP).

This plant stimulant aims to increase the growth and yield of pepper to aid in the projected increase in pepper demand. There has not also been much studies concerning the effects of CPGP on pepper. According to Abad (2018), there have not been studies to credit the effect of carrageenan on vegetables. Factors like dosage and frequency, among others should be considered (MMSU, 2018). Hence, this study aimed to assess the impact of CPGP on Solanaceous crops and propose the ideal concentration and application frequency for farmers' adoption. The findings aim to contribute to the enhancement and stabilization of pepper production nationally. Additionally, the research sought to validate a technology capable of accelerating pepper growth and enhancing production capacity.

2. Literature review

2.1. Characteristics of Pepper

Pepper, a significant crop with diverse uses, is characterized by its genetic and phenotypic variability. The Capsicum genus, which includes pepper, is a valuable resource for breeding programs due to its genetic diversity (Kole *et al.*, 2019). This diversity is evident in Brazilian Capsicum frutescens, which shows variation in morphological and molecular traits, as well as resistance to viruses (Lima *et al.*, 2017). Similarly, the parents and interspecific hybrids of different pepper species exhibit genetic diversity, particularly in fruit length and seed yield (Costa, 2016). This genetic diversity is further highlighted in a collection of Spanish pepper landraces, where differences in fruit characteristics and origin are associated with genetic separation (Pereira-Dias *et al.*, 2019). These studies underscore the importance of understanding and utilizing the genetic diversity of pepper for breeding and conservation efforts.

2.2. Challenges in Pepper Production

Pepper production faces numerous challenges, primarily stemming from pest and disease pressures. Insect pests such as cutworms, aphids, armyworms, and flea beetles, among others, hinder pepper growth and affect fruit quality (Bloomfield, 2020). The challenges in pepper production, including pest and disease pressures, have been addressed in various studies, highlighting the use of integrated pest management, which has increased pepper yields but also led to the exacerbation of certain pest populations. For instance, Doğan (2016) explored alternative production practices and proposed a microbial-based production system for greenhouse-grown peppers. On the other hand, Mathews (2017) evaluated the effectiveness of a polyculture trap crop for organic management of stink bugs in peppers, finding that while it reduced pepper damage, it was not economically viable. These studies collectively underscore the need for a holistic approach to pepper production that addresses both pest and disease pressures and soil quality.

2.3. Seaweed Extracts and Botanicals

The use of seaweed-based biostimulants in agriculture has gained significant attention due to their ability to enhance plant growth and resilience, improve soil health, and mitigate abiotic and biotic stresses (Nanda *et al.*, 2021; Nabti *et al.*, 2017; Mukherjee & Patel, 2019; Begum, 2018). These biostimulants, derived from seaweed extracts, contain a range of beneficial compounds and nutrients, including plant growth regulators, macronutrients, and micronutrients (Nanda *et al.*, 2021; Begum, 2018). They can be applied through various methods, such as foliar treatments, and have been shown to promote soil microflora, increase plant growth-promoting bacteria, and suppress pathogens. Furthermore, seaweed extracts have been found to enhance seed germination, plant growth, and yield, and improve the nutritional quality of agricultural crops (Nabti *et al.*, 2017; Mukherjee & Patel, 2019; Begum, 2018).

Seaweed extracts have been shown to have significant biostimulant properties, impacting seed germination, plant establishment, and growth (Ali, 2021). These extracts contain a range of growth regulators and nutrients, including cytokinins, auxins, gibberellins, and macronutrients, which contribute to their beneficial effects on plant growth and yield (Begum, 2018). They also play a role in mitigating abiotic stress in plants, such as drought, heat, and salinity (Moyo, 2021). However, further research is needed to fully understand their efficacy and chemical interactions for sustainable crop management (Seiber *et al*., 2014; Ertani *et al*., 2013).

2.4. Carrageenan

Carrageenan, a polysaccharide mixture extracted from red seaweeds, has been found to have various applications. Shukla *et al.* (2016) and Zia *et al.* (2017) both highlight its potential in agriculture, with Shukla discussing its role in promoting plant growth and defense responses, and Zia focusing on its use in controlled drug delivery systems. Carrageenan, also comprises water-soluble, linear, sulfated galactans with gel-forming and viscosifying properties. Its structure mainly consists of alternating 3-linked β-D-galactopyranose (G-units) and 4-linked α-D-galactopyranose (D-units) or 4-linked 3, 6-anhydro- α-D-galactopyranose (DA-units) forming the disaccharide repeating unit. Carrageenans are utilized in their oligomer forms in biological applications due to their superior gelling and viscosity properties, often prepared through chemical or enzymatic hydrolysis. However, in recent years, there has been significant interest in radiation processing for carrageenan degradation, resulting in low molecular weight oligomers. This technology has led to the synthesis of value-added products such as plant growth promoters and protectors (Ali, 2014).

2.5. Carrageenan Plant Growth Promoter (CPGP)

The Carrageenan Plant Growth Promoter (CPGP) is a product developed through collaboration of the Philippine Nuclear Research Institute of the Department of Science and

Technology (PNRI-DOST), the National Crop Protection Center of the University of the Philippines-Los Baños, and the Philippine Rice Research Institute. This initiative, under the program "Plant Bio-Stimulant and Elicitors from Radiation-Modified Natural Polymers" of the Research and Development sector, aims to leverage radiation-modified carrageenan (RMC) as a plant growth promoter (PGP) to enhance integrated nutrition management strategies and improve plant health and resistance, ultimately increasing crop productivity. CPGP functions as a foliar growth promoter, enriched with micro and macro elements alongside phytohormones that enhance photosynthetic activity.

An analysis conducted by VitalGro, the producer of CPGP, revealed the presence of essential elements within the formulation. The product has been shown to increase rice yield by an average of around 20% and enhance resistance to the tungro virus (Abad 2018). This aligns with the broader perspective of plant growth-promoting microorganisms (PGPM) in rhizosphere engineering for sustainable agriculture, which emphasizes the role of PGPM in improving soil structure, health, fertility, and functioning to support plant growth under normal and stressed environments (Hakim, 2021).

Table 1

CPGP nutrient content

Element	Quantity
Total Nitrogen	1.8%
Calcium	24.8 ppm
Potassium Oxide	933 ppm
Copper	4.6 ppm
Magnesium Oxide	36.7 ppm
Iron	2.7 ppm

Source*:* VitalGro

2.6. Effects of CPGP on Field Crops

Research conducted by Abad *et al*. (2018) at the PNRI-DOST demonstrated that in field experiments conducted in Regions II, III, and IV-A in the Philippines, there was a notable increase in the yield of mungbean and peanut ranging from 16% to 51% with RMC-PGP concentrations ranging from 50 to 200 parts per million (ppm). The study highlighted the variation in the optimal concentration of RMC-PGP depending on the specific varieties of mungbean and peanut suitable for a particular location. Another project led by the Philippine Rice Research Institute (PhilRice) investigated the synergistic mechanism of RMC in promoting the growth of rice under greenhouse and field conditions. Yap (2018) reported higher seed germination rates, increased tiller and panicle production, and higher yields with the application of 300-400 ppm RMC-PGP in rice cultivation. Additionally, Centeno (2016) conducted field trials in Bulacan, suggesting that carrageenan could enhance rice plant resistance against natural disasters, leading to stronger and healthier crops compared to those treated solely with commercial fertilizers. The application of carrageenan PGP, along with chemical fertilizers, resulted in yield increases ranging from 15% to 40%, an increase in grain weight by 65.4%, and improvements in panicle length by 3.5% to 12.5%.

A range of studies have demonstrated the potential of gamma irradiation and carrageenan in enhancing plant growth and yield. El-sayed (2024) found that low doses of gamma irradiation significantly improved the growth and yield of cumin plants, while higher doses had a negative impact. These findings are consistent with the work of Relleve *et al*. (2000), who identified a specific molecular weight range of kappa carrageenan that promoted optimal weight gain in rice seedlings. Bi *et al*. (2010) further explored the effects of k-carrageenan on the growth of chickpea and maize, observing significant enhancements in growth characteristics with various elicitor treatments.

In tobacco plants, Moreno *et al.* (2020) and Kössler (2021) both observed increased biomass and altered plant architecture and metabolism, with Moreno attributing these changes to the expression of a carotenogenic gene, and Kössler to the expression of lycopene β-cyclase. These studies justify the research of Castro *et al.* (2012), whereon carrageenan revealed significant improvements in leaf biomass and physiological parameters of tobacco plants. Oligo-carrageenans (OC), kappa (K), lambda (L), and iota (I) applied to tobacco leaves resulted in increased leaf biomass and chlorophyll levels, as well as upregulation of essential metabolic pathways.

Hashmi *et al*. (2012) investigated the impact of irradiated carrageenan on the performance of fennel, observing significant enhancements in growth attributes, essential oil yield, and active constituents at optimal concentrations. Similarly, Naeem *et al*. (2012) studied the effects of irradiated carrageenan on mint and Madagascar periwinkle, noting significant improvements in growth attributes, herbage yield, and essential oil yield at specific concentrations. This is further supported by Youssef *et al.* (2020), who demonstrated that the combination of chemical nitrogen fertilizers, organic and bio-fertilization, and antioxidants can also improve the herb, fruit, and essential oil yields of fennel.

2.7. Effects of CPGP on Vegetable Crops

In a study by Pamati-an *et al*. (2020), the effects of irradiated carrageenan (IC), commercial foliar fertilizer, and tap water on cherry tomatoes were compared. Various growth parameters such as stem length, stem diameter, leaf area, number of days to flowering, number of days to priming, number of branches, and number of harvested fruits were recorded. The results indicated that irradiated carrageenan had a significant impact compared to the other treatments. The study concluded that IC enhances the growth of cherry tomatoes during the vegetative stage, potentially resulting in earlier harvests and improved production.

2.8. Effects of CPGP on Biochemistry of Growth Enhancement

Mercier *et al*. (2001) found that carrageenans, a type of sulfated polysaccharide, effectively induced signaling and defense gene expression in tobacco leaves. This is consistent with the study by Djami-Tchatchou (2017), which showed that both azelaic acid and hexanoic acid, chemical elicitors, activated genes involved in systemic acquired resistance in tobacco cells. Similarly, Cai (2020) demonstrated that plant-derived compounds, ursolic acid and 4-methoxycoumarin, induced resistance responses in tobacco plants against Tobacco mosaic virus. These studies collectively suggest that various compounds, including carrageenans, azelaic acid, hexanoic acid, ursolic acid, and 4-methoxycoumarin, can elicit plant defense responses.

Gatan *et al*. (2019) conducted experiments to assess the effects of radiation-modified kappa-carrageenan (RMKC) on mungbean plants. They found that foliar application of carrageenan at a concentration of 60 ppm induced flowering, increased plant height, and enhanced seed yield. Additionally, comparisons with other treatments showed that RMKC was more effective than a seaweed-based commercial foliar fertilizer and other seaweed extracts irradiated at different dose levels. In another stuy, Ahmad *et al*. (2018) investigated the relationship between irradiation-mediated molecular weight reduction and structural modification of carrageenan, and its growth-promoting activity. They applied graded concentrations of irradiated carrageenan to peppermint plants and found that 80 mg/L of irradiated carrageenan had the most favorable effects on various growth parameters and enzymatic activities.

Singh *et al*. (2017) studied the influence of different carrageenan concentrations on lemongrass under drought stress conditions. They observed that foliar application of gamma-irradiated carrageenan at a concentration of 80 mg/L alleviated the detrimental effects of drought stress and improved the biochemical characteristics and essential oil content of lemongrass significantly. On the other hand, Mousavi *et al*. (2018) investigated the efficacy of carrageenan in controlling C. campestris invasion in basil plants. They found that carrageenan treatment increased shoot length and leaf area of basil, decreased C. campestris infestation, and stimulated defense responses by activating the phenylpropanoid pathway and increasing PAL activity, phenols, antioxidants, and lignin content.

2.9. Carrageenan Irradiation

In an interview, Dr. Lucille Abad highlighted the irradiation process involved in carrageenan, emphasizing that it breaks down large molecules into smaller ones, making carrageenan more easily absorbed by plant leaves. She also emphasized that irradiated carrageenan is safe because it is not radioactive (MMSU, 2018). Hashmi *et al*. (2012) and Sarfaraz *et al.* (2011) both found that irradiated carrageenan and sodium alginate, respectively, significantly improved the growth and physiological attributes of fennel. However, *Khan et al.* (2015) noted that gamma-irradiation of fennel seeds caused slight variations in volatile flavor compounds, with no significant loss of major flavor compounds. Beyk-Khormizi *et al.* (2022) found that vermicompost, an organic fertilizer, mitigated the adverse effects of salinity stress on fennel, improving various plant characteristics.

Ahmad *et al*. (2018) concluded that irradiated carrageenan has advantages over un-irradiated carrageenan due to reduced molecular weight and certain structural modifications, facilitating improved growth promotion. They found that irradiation-induced molecular weight reduction and structural modification contributed to the growth promotion activity, with 80 mg/L IC showing significant differences in essential oil content and yield compared to the control and un-irradiated carrageenan. On the other hand, Naeem *et al*. (2012) observed similar effects of irradiated carrageenan on plant growth, physiological attributes, herbage yield, and essential oil content and yield in corn mint. They found that un-irradiated carrageenan had no significant effect on these parameters, similar to deionized water.

In a study by Ali (2014), results indicated that un-irradiated carrageenan performed the least among carrageenan-influenced treatments in various parameters related to germination, growth, physiology, biochemical attributes, and yield and quality characteristics of Eucalyptus citriodora. This is consistent with the findings of Singh (2017), who demonstrated that gamma irradiated carrageenan can mitigate the harmful effects of drought stress on lemongrass, improving its biochemical characteristics and essential oil production.

3. Methodology

3.1. Experimental Design and Treatments

The field experiment was conducted in a 6 x 3 split plot arranged in Randomized Complete Block Design (RCBD) with three replications. The main plot indicates the frequency of foliar application and the sub-plot represents different carrageenan PGP concentrations. Fourteen plants were planted in every plot, having two rows and seven hills within each row. A total of 756 plants were used in the study.

The following treatments were used in the study:

Main Plot (Frequency of application)
  A1: Two Times (10 days after transplanting (DAT), and 20 DAT)
  A2: Three Times (10 DAT, 20 DAT, and 30 DAT)
  A3: Four Times (10 DAT, 20 DAT, 30 DAT, and 40 DAT)
Sub-plot (CPGP Concentration)
  B1: Untreated (Negative Control)
  B2: Commercial Foliar Fertilizer (Positive Control)
  B3: 60 ppm CPGP
  B4: 120 ppm CPGP
  B5: 240 ppm CPGP
  B6: 480 ppm CPGP

3.2. Seed Sowing and Seedling Establishment

Seedling trays with 104 holes were used for seed sowing and seed germination. Pepper seeds were primed with water for 12 hours, then air dried before sowing. The growth media was a mixture of garden soil and vermicompost (1:1). One seed was sown per cell with the provision of adequate light and water.

3.3. Transplanting and Replanting

Seedlings were transplanted when they have reached a stable phase, 28 days after sowing. Planting distance was 0.5m x 0.8m. Irrigation followed immediately and replanting of missing hills was done as necessary.

3.4. Foliar Application of Treatments

Application of different treatments started from ten days after transplanting. It was done every ten days (Ali, 2014), in accordance to the designated frequency of application. A hand-held pressurized sprayer was used to apply the different concentrations of CPGP, with the aid of plastic sheets to prevent unwanted spread of applied treatments to other plots. The amount of solution sprayed increased as the plants grow. Treatments were applied early in the morning.

In a personal communication with Dr. Lucille V. Abad, inventor of the Carrageenan Plant Growth Promoter (CPGP), the base concentration is 10,000 ppm. Dilution for treatment application of the CPGP were 60 ppm, 120 ppm, 240 ppm, and 480 ppm with application frequencies of 2x, 3x, and 4x.

3.5. Harvesting

Harvesting was done six times for all treatments, starting when all of the plants per plot have at least one fruit that is ready for harvest. Fruits were harvested at the mature green stage, when the fruits have attained full size and appear waxy and shiny. Fruit picking was done by breaking the pedicel with an upward twist or by cutting the pedicle with a sharp knife or a pair of scissors.

3.6. Data Gathering Procedures

3.6.1. Determination of growth attributes

*Number of days to flowering***.** The number of days to flowering was counted from transplanting to the day when 50 percent of all the plants in each replication have at least three opened flowers.

*Number of days to first priming***.** This was counted from transplanting to the day when 50 percent of all the plants in each replication have at least one fruit ready for harvest.

*Plant height***.** Plant height was measured from the surface of the soil to tipmost part of the main stem. It was done at 60 DAT.

*Number of lateral shoots***.** Lateral shoots were counted at 60 DAT.

3.6.2. Determination of yield attributes

*Number, weight, and percent non-marketable fruits per plot***.** The number and weight of non-marketable fruits per plot were counted. The different indices used to identify damaged or non-marketable fruits were presence of holes, occurrence of alteration in coloration of fruits, the inside of the fruit is hollow and filled with frass, curled fruits, and rotten fruits.

*Number, weight, and percent marketable fruits per plot***.** Fruits without the presence of holes, frass, rot, curling or any damage, per plot, were considered non-infested or marketable fruits, and were counted and weighed.

Total number and weight of fruits per plot and per plant. This is the cumulative (six harvestings) number and weight of infested plus non-infested fruits per treatment.

Computed yield per hectare. The total weight of marketable fruits harvested in a yield plot area (4 m^2) was converted into per hectare basis.

3.7. Ethical Considerations

There were several ethical considerations addressed in the study to ensure the integrity and responsible conduct of the research.

Environmental impact. The use of carrageenan as a plant growth promoter was chosen based on its natural origin and biodegradability. Care was taken to ensure that the application rates used in the study did not exceed environmentally safe levels, thus, minimizing any potential negative impact on the surrounding ecosystem.

Sustainability. The study prioritized sustainable agricultural practices by selecting a plant growth promoter that is derived from renewable resources. Carrageenan, extracted from seaweeds, is considered environmentally friendly and sustainable, aligning with the principles of sustainable agriculture.

Human and animal safety. The safety of researcher, field workers, and any local wildlife was paramount. Personal protective equipment (PPE) was used during the handling and application of the carrageenan solution to prevent any direct contact or inhalation. Additionally, the fields were monitored to ensure that no potential harm came to animals that might come into contact with the treated plants.

Data integrity and reporting. The research was conducted with a commitment to transparency and honesty in data collection, analysis, and reporting. All findings, whether positive or negative, were reported accurately to contribute to the body of scientific knowledge without bias or manipulation.

Compliance with regulations. The study complied with all relevant local, national, and international regulations regarding agricultural research and the use of plant growth promoters.

4. Findings and Discussion

4.1. Number of Days to Flowering

The frequency and concentration of CPGP application significantly influence the number of days to flowering in peppers. Applying CPGP three times resulted in the shortest time to flowering, 35.50 days, followed by twice application with a difference of 1.44 days. Among different concentrations, 120 ppm led to the earliest flowering, 8.67 and 8.44 days earlier than negative and positive controls, respectively. Interaction effects between concentration and application frequency revealed that peppers sprayed two to three times at 120 ppm matured earliest, while four times at 240 ppm and two times at 240 ppm resulted in delayed flowering.

Similar findings from previous studies indicate the potential of carrageenan to induce flowering across various plant species, with concentrations and application frequencies varying according to crop type. However, there is a gap in research regarding the effects of varying application frequencies on flowering time. Other studies suggest that carrageenan application enhances plant growth by influencing nutrient accumulation, enzymatic activity, and metabolic processes, potentially contributing to earlier flowering.

Table 2

Summary data on the growth of pepper as influenced by frequency of application of CPGP and its concentration

TREATMENTS	NUMBER OF DAYS TO FLOWERING	NUMBER OF DAYS TO FIRST HARVESTING	PLANT HEIGHT	NUMBER OF LATERAL SHOOTS
MAIN PLOT (A)				
A1- 2x	36.94 a	66.79	11.06 c	11.06 c
A2- 3x	35.50 b	66.85	11.94 a	11.94 a
A3- 4x	36.11 ab	67.02	11.50 b	11.50 b
C.V. (%)	2.55	0.88	2.90	2.90
SUB-PLOT (B)				
B1- Control (-)	39.56 a	61.60 d	10.33 d	10.33 d
B2- Control (+)	39.33 a	64.20 c	11.00 c	11.00 c
B3- 60 ppm	37.56 b	68.15 b	11.67 b	11.67 b
B4- 120 ppm	30.88 e	69.74 a	12.56 a	12.56 a
B5- 240 ppm	34.00 d	69.67 a	12.44 a	12.44 a
B6- 480 ppm	35.78 c	67.97 b	11.00 c	11.00 c
C.V. (%)	2.05	0.97	4.52	4.52
INTERACTION (A x B)				
A1B1	39.67 a	61.16 h	10.33 ef	10.33 ef
A1B2	39.00 abc	63.71 f	11.00 cde	11.00 cde
A1B3	38.00 bcd	67.35 e	11.00 cde	11.00 cde
A1B4	31.33 f	70.43 a	11.00 cde	11.00 cde
A1B5	36.67 d	70.00 a	11.67 bc	11.67 bc
A1B6	37.00 d	68.10 de	11.33 bcd	11.33 bcd
A2B1	39.33 ab	61.13 h	10.67 def	10.67 def
A2B2	39.67 a	64.67 f	11.00 cde	11.00 cde
A2B3	37.67 cd	68.37 cde	12.00 b	12.00 b
A2B4	30.33 f	69.40 abc	13.67 a	13.67 a
A2B5	30.67 f	69.60 ab	13.67 a	13.67 a
A2B6	35.33 e	67.93 de	10.67 def	10.67 def
A3B1	39.67 a	62.53 g	10.00 f	10.00 f
A3B2	39.33 ab	64.22 f	11.00 cde	11.00 cde
A3B3	37.00 d	68.74 bcd	12.00 b	12.00 b
A3B4	31.00 f	69.37 abc	13.00 a	13.00 a
A3B5	34.67 e	69.40 abc	12.00 b	12.00 b
A3B6	35.00 e	67.87 de	11.00 cde	11.00 cde
C.V. (%)	2.11	0.92	3.53	

*Means within a column having the same letter(s) is/are not significantly different at 5% level by DMRT test.

4.2. Number of Days to First Priming

The frequency of CPGP application significantly affects the number of days to first priming in peppers, with a highly significant difference observed. Applying CPGP three times resulted in fruits appearing 2.28 days earlier than those sprayed twice. Regarding concentration, peppers treated with 120 ppm CPGP bore fruits 10 days earlier than controls, while variations in CPGP concentrations showed significant differences, with 120 ppm and 240 ppm leading to the earliest priming at 41.33 and 47.11 days, respectively. Interaction effects revealed that the frequency of application had no significant impact on first priming time at 120 ppm concentration, but four times of application across different concentrations showed promise in reducing days to first priming. These findings align with Pamati-an *et al*.'s (2020) research, demonstrating that cherry tomatoes treated with irradiated carrageenan experienced significantly earlier priming compared to controls and those treated with commercial foliar fertilizers. Their study involved five applications of irradiated carrageenan at a one percent solution every 14 days, similar to our findings where earlier flowering resulted in earlier fruiting.

4.3. Plant Height

Regarding plant height, varying frequencies of CPGP application did not yield significant differences. However, concentrations of 120 ppm and 240 ppm showed no significant difference between them, both resulting in heights of 69.73 cm and 69.67 cm, respectively, but differed significantly from control groups and other concentrations. Interaction effects revealed that peppers sprayed two to three times with 120 ppm displayed taller plants, with heights of 70.43 cm and 69.40 cm, respectively. Similar findings in studies by Abad *et al*. (2018), Gatan *et al*. (2019), Bi *et al*. (2010), and Hashmi *et al*. (2012) indicate that carrageenan foliar application significantly influences plant height, with various concentrations and frequencies producing notable effects. Carrageenan application enhances plant height by stimulating photosynthesis, carbon fixation, and enzymatic activity, such as Rubisco, glutamate dehydrogenase, and pyruvate dehydrogenase, leading to increased growth and development. Moreover, the activation of NADP(H)-synthesizing enzymes contributes to enhanced photosynthesis and ancillary plant processes, ultimately promoting growth (Castro *et al*., 2012; Munoz *et al*., 2011).

4.4. Number of Lateral Shoots

In terms of the number of lateral shoots, varying frequencies of Carrageenan Plant Growth Promoter (CPGP) application led to a highly significant difference. Plants treated with CPGP three times exhibited the highest number of lateral shoots at 11.94, comparable to twice and four times application frequencies with differences of 0.89 and 0.44, respectively. Regarding concentration, 120 ppm yielded the greatest number of lateral shoots, not significantly different from 240 ppm, while 480 ppm showed comparable results to the positive control. Interaction effects revealed that the combination of 120 ppm concentration with three foliar applications resulted in the highest lateral shoot count, though not significantly different from treatments with 240 ppm applied thrice or 120 ppm applied four times. This trend aligns with findings by Bi *et al*. (2010) and Pamati-an *et al*. (2019), suggesting that carrageenan-treated plants exhibit significantly higher lateral shoot numbers compared to untreated or commercially sprayed plants. Spray applications of carrageenan have been associated with increased cell division in tobacco, leading to increased cell number without altering cell size.

4.5. Number of Marketable Fruits

The number of marketable fruits demonstrates significant variation influenced by both the frequency and concentration of CPGP application. Notably, applying CPGP three times resulted in a significantly higher yield compared to twice, with a difference of 218.22 fruits, while four-time application showed comparable yields to three-time application. Regarding concentration, 120 ppm CPGP produced significantly more marketable fruits than 240 ppm, with a difference of 119.77 fruits, showing notable disparity from control groups. Interaction effects between frequency and concentration were also significant, with 120 ppm concentration combined with three or four applications yielding the highest fruit counts. Conversely, two-time application with the same concentration resulted in substantially fewer fruits. These findings align with research by Abad *et al*. (2018) and Gatan *et al*. (2019), demonstrating that carrageenan application enhances fruit yield in peanuts by increasing net photosynthesis and the number of seeds per pod.

Table 3

Summary data on the quantity, weight, and computed yield per hectare (CY/H) of marketable and non-marketable fruits as influenced by frequency of application of CPGP and its concentration

TREATMENTS	MARKETABLE FRUITS						NON-MARKETABLE FRUITS			
	QTY		WEIGHT (g)		CY/H OF MARKETABLE FRUITS (TONS)		QTY		WEIGHT (g)	
MAIN PLOT (A)										
A1- 2x	1220.28	b	5413.74	b	13.54	b	136.56		603.11	
A2- 3x	1438.50	a	6163.47	a	15.41	a	133.94		576.09	
A3- 4x	1390.50	a	5885.18	a	14.71	a	132.83		568.74	
C.V. (%)	6.91		5.58		5.58		9.85		7.68	
SUB-PLOT (B)										
B1- Control (-)	916.33	f	3965.25	f	9.91	f	127.22		558.33	a
B2- Control (+)	1149.33	e	4992.87	e	12.48	e	140.33		610.56	a
B3- 60 ppm	1427.00	c	5807.92	c	14.52	c	135.22		551.36	b
B4- 120 ppm	1733.44	a	7824.07	a	19.56	a	136.89		618.51	a
B5- 240 ppm	1613.67	b	6930.52	b	17.33	b	135.44		592.19	ab
B6- 480 ppm	1258.78	d	5404.17	d	13.51	d	131.56		564.92	b
C.V. (%)	8.19		4.95		4.94		12.93		7.48	
INTERACTION (A x B)										
A1B1	904.33	i	3872.47	g	9.6833	g	132.00	ab	563.32	bcde
A1B2	1112.67	fgh	4968.01	f	12.42	f	148.67	a	661.24	a
A1B3	1244.67	ef	5139.33	f	12.85	f	146.00	a	596.77	abcd
A1B4	1555.33	bcd	7182.77	bc	17.9567	bc	137.00	ab	635.40	abc
A1B5	1495.33	cd	6427.69	d	16.07	d	147.33	a	639.50	ab
A1B6	1009.33	ghi	4892.19	f	12.23	f	108.33	b	522.42	de
A2B1	970.00	hi	4205.45	g	10.5167	g	128.00	ab	560.61	bcde
A2B2	1133.67	fgh	4916.50	f	12.2933	f	139.67	ab	607.93	abcd
A2B3	1430.67	de	5830.19	e	14.5733	e	121.00	ab	495.26	e
A2B4	1894.67	a	8614.63	a	21.54	a	140.33	ab	631.98	abc
A2B5	1706.00	ab	7325.11	bc	18.3133	bc	126.67	ab	556.29	bcde
A2B6	1496.00	cd	6088.96	de	15.2267	de	148.00	a	604.47	abcd
A3B1	874.67	i	5094.10	f	9.5433	g	121.67	ab	551.08	cde
A3B2	1201.67	fg	6454.24	d	12.7333	f	132.67	ab	562.52	bcde
A3B3	1605.67	bcd	7674.80	b	16.1367	d	138.67	ab	562.04	bcde
A3B4	1750.33	ab	7038.76	c	19.1833	b	133.33	ab	588.14	abcd
A3B5	1639.67	bc	5231.36	f	17.5967	c	132.33	ab	580.79	abcd
A3B6	1271.00	ef	3817.84	g	13.0767	f	138.33	ab	567.88	bcde
C.V. (%)	8.05		5.04		5.02		12.61		7.50	

*Means within a column having the same letter(s) is/are not significantly different at 5% level by DMRT test.

Table 4

Summary data on the quantity and weight of marketable against non-marketable fruits per plant as influenced by frequency of application of CPGP and its concentration

TREATMENTS	MARKETABLE FRUITS PER PLANT				NON-MARKETABLE FRUITS PER PLANT				TOTAL FRUITS PER PANT			
	QTY		WEIGHT (g)		QTY		WEIGHT (g)		QTY		WEIGHT (g)	
MAIN PLOT (A)									135.78	b	601.68	b
A1- 2x	121.94	b	5413.74	b	13.61		60.31		160.33	a	673.86	a
A2- 3x	147.00	a	6163.47	a	13.44		57.61		152.22	a	645.39	a
A3- 4x	139.06	a	5885.18	a	13.33		56.87		7.37		5.60	
C.V. (%)	7.42		5.58		9.24		7.68					
SUB-PLOT (B)									104.44	d	452.36	f
B1- Control (-)	91.67	d	3965.25	f	12.67		55.83	b	129.00	c	560.34	e
B2- Control (+)	115.00	c	4992.87	e	14.22		61.06	a	156.11	b	635.93	c
B3- 60 ppm	142.78	b	5807.92	c	13.67		55.14	b	187.00	a	844.86	a
B4- 120 ppm	173.22	a	7824.07	a	13.44		61.85	a	181.11	a	752.27	b
B5- 240 ppm	167.44	a	6930.52	b	13.67		59.22	ab	139.00	c	596.91	d
B6- 480 ppm	125.89	c	5404.17	d	13.11		56.48	b	8.94		4.61	
C.V. (%)	9.07		4.95		13.06		7.48					
INTERACTION (A x B)									103.67	hi	443.58	g
A1B1	90.33	hi	3872.47	g	13.00	ab	56.33	bcde	126.33	fghi	562.92	f
A1B2	111.33	efgh	4968.01	f	15.00	a	66.12	a	139.00	defg	573.61	f
A1B3	124.33	de	5139.33	f	14.67	a	59.68	abcd	169.33	bcd	781.82	bc
A1B4	155.33	bc	7182.77	bc	13.33	ab	63.54	abc	164.33	bcde	706.72	d
A1B5	149.33	c	6427.69	d	15.00	a	63.95	ab	112.00	ghi	541.46	f
A1B6	101.00	fghi	4892.19	f	10.67	b	52.24	de	110.00	ghi	476.61	g
A2B1	97.33	ghi	4205.45	g	12.67	ab	56.06	bcde	127.33	fghi	552.44	f
A2B2	113.33	efg	4916.50	f	14.33	a	60.79	abcd	155.00	cdef	632.55	e
A2B3	143.33	cd	5830.19	e	12.33	ab	49.53	e	203.33	a	924.66	a
A2B4	189.33	a	8614.63	a	14.00	a	63.20	abc	202.00	a	788.14	bc
A2B5	189.33	a	7325.11	bc	12.67	ab	55.63	bcde	164.33	bcde	669.34	de
A2B6	149.33	c	6088.96	de	14.67	a	60.45	abcd	99.67	i	436.89	g
A3B1	87.33	i	3817.84	g	12.33	ab	55.11	cde	133.33	efgh	565.66	f
A3B2	120.33	ef	5094.10	f	13.33	ab	56.25	bcde	174.33	abc	701.63	d
A3B3	160.67	bc	6454.24	d	14.00	a	56.20	bcde	188.33	ab	826.29	b
A3B4	175.00	ab	7674.80	b	13.00	ab	58.82	abcd	177.00	abc	761.95	c
A3B5	163.67	bc	7038.76	c	13.33	ab	58.08	abcd	140.67	defg	579.93	f
A3B6	127.33	de	5231.36	f	14.00	a	56.78	bcde	8.77		4.74	
C.V. (%)	8.89		5.02		12.67		7.50					

*Means within a column having the same letter(s) is/are not significantly different at 5% level by DMRT test.

Table 5

Summary data on the total number and weight of fruits, its computed yield per hectare, and the weight per fruit as influenced by frequency of application of CPGP and its concentration

TREATMENTS	TOTAL NUMBER OF FRUITS	TOTAL WEIGHT OF FRUITS	COMPUTED YIELD PER HECTARE (TONS)	WEIGHT PER FRUIT
MAIN PLOT (A)				
A1- 2x	1356.67 b	6016.85 b	15.04 b	4.50
A2- 3x	1572.39 a	6739.56 a	16.85 a	4.29
A3- 4x	1523.56 a	6453.92 a	16.13 a	4.26
C.V. (%)	7.04	5.60	5.60	19.73
SUB-PLOT (B)				
B1- Control (-)	1043.67 e	4523.59 f	11.31 f	4.33
B2- Control (+)	1289.78 d	5603.44 e	14.01 e	4.40
B3- 60 ppm	1563.11 c	6359.28 c	15.90 c	4.22
B4- 120 ppm	1870.33 a	8442.57 a	21.10 a	4.53
B5- 240 ppm	1749.33 b	7522.71 b	18.81 b	4.34
B6- 480 ppm	1390.00 d	5969.09 d	14.92 d	4.38
C.V. (%)	8.28	4.61	4.61	7.33
INTERACTION (A x B)				
A1B1	1036.33 i	4435.79 g	11.09 g	4.28 ab
A1B2	1261.00 fgh	5629.25 f	14.07 f	4.58 ab
A1B3	1390.67 ef	5736.10 f	14.34 f	4.23 b
A1B4	1692.00 bcd	7818.18 bc	19.54 bc	4.63 ab
A1B5	1642.67 cd	7067.19 d	17.66 d	4.35 ab
A1B6	1117.33 ghi	5414.61 f	13.53 f	4.94 a
A2B1	1098.00 hi	4766.06 g	11.91 g	4.34 ab
A2B2	1273.33 fgh	5524.44 f	13.81 f	4.34 ab
A2B3	1551.67 de	6325.45 e	15.81 e	4.10 b
A2B4	2035.00 a	9246.61 a	23.11 a	4.56 ab
A2B5	1833.00 abc	7881.39 bc	19.70 bc	4.33 ab
A2B6	1643.33 cd	6693.43 de	16.73 de	4.09 b
A3B1	996.67 i	4368.92 g	10.92 g	4.40 ab
A3B2	1335.00 efg	5656.62 f	14.14 f	4.28 ab
A3B3	1744.00 bcd	7016.27 d	17.54 d	4.04 b
A3B4	1884.00 ab	8262.94 b	20.65 b	4.41 ab
A3B5	1772.33 bcd	7619.55 c	19.04 c	4.34 ab
A3B6	1409.33 ef	5799.24 f	14.49 f	4.12 b
C.V. (%)	8.15	4.74	4.74	8.01

*Means within a column having the same letter(s) is/are not significantly different at 5% level by DMRT test.

4.6. Weight of Marketable Fruits

The weight of marketable fruits is significantly influenced by both the frequency and concentration of CPGP application. While three-time and four-time applications did not significantly differ, three applications resulted in 6163.47 g of fruits, notably more than four-time and two-time applications. Concentration also played a crucial role, with 120 ppm yielding 3858.82 g more than the negative control and 2831.20 g more than the positive control. Interaction effects showed that the combination of three-time application and 120 ppm concentration resulted in the heaviest fruit weight at 8614.63 g, consistently producing the highest growth attributes and yield components. These findings are consistent with local studies documenting increased crop yield at various concentrations of carrageenan, such as *'pechay'* at 60 ppm and rice at 200 ppm. Hashmi *et al*. (2012) also noted increased yield attributes in Foeniculum vulgare Mill, attributed to enhanced water and nutrient uptake from the soil and efficient translocation of photosynthates and metabolites to plant sinks.

4.7. Number and Weight of Non-Marketable Fruits

Regarding the number of non-marketable fruits, neither the frequency of application nor the concentration of CPGP showed significant differences. Similarly, for the weight of non-marketable fruits, there were no significant effects observed for either frequency or concentration, although 120 ppm concentration yielded the heaviest weight at 618.51 g. Interaction effects did not show any significant interactions between application frequencies and CPGP concentrations, although three-time application at 60 ppm concentration resulted in the lowest weight of non-marketable fruits. These findings suggest that while CPGP application may not affect the quantity of non-marketable fruits significantly, certain concentrations may influence their weight, albeit without statistical significance.

4.8. Total Number of Fruits

Regarding the total number of fruits, both the frequency and concentration of CPGP application played significant roles in influencing yield. Notably, three-time application consistently yielded the highest total number of fruits, closely followed by four-time application, with no statistically significant difference between them. Concentration-wise, 120 ppm CPGP resulted in the highest accumulation of fruits, surpassing control groups by a substantial margin. Interaction effects further underscored the effectiveness of the combination of three-time frequency and 120 ppm concentration, yielding the highest fruit count among all treatments. These findings are consistent with research by Abad *et al*. (2018), suggesting that RMKC-treated plants exhibit improved flower and fruit development, particularly at a concentration of 60 ppm. Similarly, Gatan *et al*. (2019) demonstrated significant yield increases with the application of 60 ppm RMKC, highlighting the potential for enhanced yield with CPGP application.

4.9. Total Weight of Fruits

Regarding the total weight of fruits, both the frequency and concentration of CPGP application significantly impacted yield. Notably, three-time application consistently yielded the highest total weight of fruits at 6739.56 g, followed closely by four-time application at 6453.92 g, with no statistically significant difference between them. Concentration-wise, 120 ppm CPGP resulted in the largest accumulation of fruit weight, surpassing control groups by 3918.98 g and 2839.13 g more than negative and positive controls, respectively. Interaction effects further emphasized the effectiveness of the combination of three-time frequency and 120 ppm concentration, yielding the highest fruit weight at 9246.61 g, significantly differing from all other treatments. These findings parallel those of Akhter *et al*. (2018), where three-time application of a plant growth regulator (PGR) resulted in maximum yield for sweet pepper, significantly differing from other treatments presented.

5. Conclusion

Based on the results, this study concludes that the interaction of three-time frequency of application and 120 ppm concentration of CPGP shortened the number of days to flowering and first priming. It also gave the highest plant height, number of branches, number and weight of marketable and non-marketable fruits, total weight of fruits per plot and computed yield per hectare. The concentration of 120 ppm CPGP foliar spray gave the best results in all growth and yield parameters tested in the study. Among the three frequencies tested, foliar application of CPGP three times in pepper yielded best results. Lastly, the foliar application of CPGP at 120 ppm and 240 ppm reduced the rate of fusarium wilt infection in pepper plants.

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References

Abad, L.V., Aurigue, F.B., Montefalcon, D.R., Manguiat, P.H., Carandang, F.F., Mabboraong, S.A., Hizon, M.G.S., & Abella, M.E.S. (2018). Effect of radiation-modified kappa-carrageenan as plant growth promoter on peanut (Arachis hypogaea L.). *Radiation Physics and Chemistry*, 153, 239-244. https://doi.org/10.1016/j.radphyschem.2018.10.005

Abad, L.V., Aurigue, F.B., Relleve, L.S., Montefalcon, D.R.V., & Lopez, G.E.P. (2016). Characterization of low molecular weight fragments from gamma-irradiated κ-carrageenan used as plant growth promoter. *Radiation Physics and Chemistry*, 118, 75-80. https://doi.org/10.1016/j.radphyschem.2015.03.001

Abad, L.V., Dean, G., Magsino, G.L., Cruz, R.M., Tecson, M.G., Abella, M.E., & Hizon, M.G. (2018). Semi-commercial scale production of carrageenan plant growth promoter by E-beam technology. *Radiation Physics and Chemistry*, 143, 53-58. https://doi.org/10.1016/j.radphyschem.2017.07.009

Abad, L.V., Kudo, H., Saiki, S., Nagasawa, N., Tamada, M., & Katsumura, Y. (2009). Radiation degradation studies of carrageenans. *Carbohydrate Polymers*, 78, 100–106. https://doi.org/10.1016/j.carbpol.2009.04.009

Abad, L.V., Saiki, S., Nagasawa, N., Kudo, H., Katsumura, Y., & De La Rosa, A.M. (2011). NMR analysis of fractionated k-carrageenan oligomers as plant growth promoter. Radiation *Physics and Chemistry*, 80, 977-982. https://doi.org/10.1016/j.radphyschem.2011.04.006

Ahmad, B., Jahan, A., Sadiq, Y., Shabbir, A., Jaleel, H., & Khan, M. M. (2018). Radiation-mediated molecular weight reduction and structural modification in carrageenan potentiates improved photosynthesis and secondary metabolism in peppermint

(Mentha piperita L.). *International Journal of Biological Macromolecules*, 124, 1069-1079. https://doi.org/10.1016/j.ijbiomac.2018.12.022

Akhter, S., Mostarin, T., Khatun, K., Akhter, F., & Parvin, A. (2018). Effects of plant growth regulator on yield and economic benefit of sweet pepper (Capsicum annuum L.). *The Agriculturists*, 16, 58-64. https://doi.org/10.3329/agric.v16i02.40343

Ali, A., Khan, M., Moinuddin, A., Naeem, M., Idrees, M., & Hashmi, N. (2014). Radiolytically depolymerized sodium alginate improves physiological activities, yield attributes and composition of essential oil of Eucalyptus citriodora Hook. Carbohydrate Polymers, 112, 134-144. https://doi.org/10.1016/j.carbpol.2014.05.070

Ali, O., Ramsubhag, A., & Jayaraman, J. (2021). Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production. *Plants*, 10. https://doi.org/10.3390/plants10030531

Begum, M., Bordoloi, B.C., Singha, D.D., & Ojha, N.J. (2018). Role of seaweed extract on growth, yield and quality of some agricultural crops: A review. *Agricultural Reviews*, 39(4), 321-326. https://doi.org/10.18805/ag.R-1838

Beyk-Khormizi, A., Hosseini Sarghein, S., Sarafraz-Ardakani, M., Moshtaghioun, S.M., Mousavi-Kouhi, S.M., & Ganjeali, A. (2022). Ameliorating effect of vermicompost on Foeniculum vulgare under saline condition. *Journal of Plant Nutrition*, 46, 1601-1615. https://doi.org/10.1080/01904167.2022.2092513

Bi, F., Iqbal, S., Arman, M., Ali, A., & Hassan, M. (2010). Carrageenan as an elicitor of induced secondary metabolites and its effects on various growth characters of chickpea and maize plants. *Journal of Saudi Chemical Society*, 15, 269–273. https://doi.org/10.1016/j.jscs.2010.10.003

Bloomfield, C. (2020). *Common pepper plant problems - Pepper plant diseases and pests*. Gardening Know How. https://www.gardeningknowhow.com/edible/vegetables/pepper/common-pepper-plant-problems.htm

Bragard, C., Caciagli, P., Lemaire, O., Lopez-Moya, J. J., Macfarlane, S., Peters, D., Susi, P., & Torrance, L. (2013). Status and prospects of plant virus control through interference with vector transmission. *Annual Review of Phytopathology*, 51, 177–201. https://doi.org/10.1146/annurev-phyto-082712-102346

Cai, L., Zhang, W., Jia, H., Feng, H., Wei, X., Chen, H., Wang, D., Xue, Y., & Sun, X. (2020). Plant-derived compounds: A potential source of drugs against Tobacco mosaic virus. Pesticide biochemistry and physiology, 169, 104589. https://doi.org/10.1016/j.pestbp.2020.104589

Calvo, P., Nelson, L., & Kloepper, J. W. (2014). Agricultural uses of plant biostimulants. *Plant and Soil*, 383, 3–41. https://doi.org/10.1007/s11104-014-2131-8

Castro, I., Vera, L., Gonzalez, A., & Moenne, A. (2012). Oligo-carrageenans stimulate growth by enhancing photosynthesis, basal metabolism and cell cycle in tobacco plants (var. Burley). *Journal of Plant Growth Regulation*, 31, 173-185. https://doi.org/10.1007/s00344-011-9229-5

Centeno, G. (2016). *Carrageenan plant growth promoter to help small-scale farm in the country*. www.pcaarrd.dost.gov.ph/home/portal/index.php

Costa, M.A., do Rêgo, M.M., da Silva, A.G., do Rêgo, E.R., & Barroso, P.A. (2016). Characterization and genetic diversity of pepper (Capsicum spp) parents and interspecific hybrids. *Genetics and molecular research*: *GMR*, 15 2. https://doi.org/10.4238/gmr.15027652

Craigie, J. S. (2011). Seaweed extract stimuli in plant science and agriculture. *Journal of Applied Phycology*, 23, 371–393. https://doi.org/10.1007/s10811-010-9560-4

Craigie, J. S., MacKinnon, S. L., & Walter, J. A. (2008). Liquid seaweed extracts identified using 1H NMR profiles. *Journal of Applied Phycology*, 20, 665–671. https://doi.org/10.1007/s10811-007-9232-1

Dagnoko, S., Diarisso, N. Y., Sanogo, P. N., Adetula, O., Nantoume, A. D., & Toure, K. G. (2013). Overview of pepper (Capsicum spp.) breeding in West Africa. *African Journal of Agricultural Research*, 8(13), 1108-1114.

DA-RF02 [Department of Agriculture-Regional Field Office 02. (2017). *Pepper production guide*. Value Crops Development Program-Pepper Production in Region 02.

Darvill, A., Auger, C., Bergmann, C., Carlson, R. W., Cheong, J. J., & Eberhard, S. (1992). Oligosaccharins-oligosaccharides that regulate growth, development and defense response in plants. *Glycobiology*, 2, 181-198. https://doi.org/10.1093/glycob/2.3.181

Djami-Tchatchou, A.T., Ncube, E.N., Steenkamp, P.A., & Dubery, I.A. (2017). Similar, but different: structurally related azelaic acid and hexanoic acid trigger differential metabolomic and transcriptomic responses in tobacco cells. *BMC Plant Biology*, 17. https://doi.org/10.1186/s12870-017-1157-5

Doğan, A., Erler, F., Erkan, M.M., Ates, A.O., Sabanci, H.S., & Polat, E. (2016). Microbial-based production system: A novel approach for plant growth and pest and disease management in greenhouse-grown peppers (capsicum annuum l.). *Journal of Agricultural Science and Technology*, 18, 371-386.

El-sayed, T., Shala, A.Y., & Tawfik, O. (2024). Effect of gamma irradiation on vegetative growth and biochemical changes of cumin plants. *Journal of Productivity and Development*, 29(1), 35-55. https://doi.org/10.21608/JPD.2024.346236

Ertani, A., Schiavon, M., Muscolo, A., & Nardi, S. (2013). Alfalfa plant-derived biostimulant stimulates short-term growth of salt-stressed Zea mays L. plants. *Plant and Soil*, 364, 145–158. https://doi.org/10.1007/s11104-012-1335-z

Gatan, M. G., Montefalcon, D. R., Aurigue, F., & Abad, L. (2019). Effect of radiation-modified kappa-carrageenan on the morpho-agronomic characteristics of mungbean (*Vigna radiata* (L.) R. Wilczek). *Philippine Journal of Science*, 149, 135-143.

Globe Newswire (2020). *World pepper market 2020: Historic review of 2007-2018 with projections to 2025.* https://www.globenewswire.com/news-release/2020/02/05/1980349/0/en/World-Pepper-Market-2020-Historic-Review-of-2007-2018-with-Projections-to-2025.html

Hakim, S., Naqqash, T., Nawaz, M.S., Laraib, I., Siddique, M.J., Zia, R., Mirza, M.S., & Imran, A. (2021). Rhizosphere engineering with plant growth-promoting microorganisms for agriculture and ecological sustainability. *Frontiers in Sustainable Food Systems*, 5, 617157. https://doi.org/10.3389/fsufs.2021.617157

Hashmi, N., Khan, M., Moinuddin, A., Idrees, M., Khan, Z. H., Ali, A., & Varshney, L. (2012). Depolymerized carrageenan ameliorates growth, physiological attributes, essential oil yield and active constituents of Foeniculum vulgare Mill. *Carbohydrate Polymers*, 90, 407-412. https://doi.org/10.1016/j.carbpol.2012.05.058

Hien, N. Q., Nagasawa, N., Tham, L. X., Yoshii, F., Dang, H. V., & Mitomo, H. (2000). Growth promotion of plants with depolymerized alginates by irradiation. *Radiation Physics and Chemistry*, 59, 97–101. https://doi.org/10.1016/S0969-806X(99)00522-8

Iwasaki, K., & Matsubara, Y. (2000). Purification of alginate oligosaccharides with root growth-promoting activity toward lettuce. *Bioscience, Biotechnology, and Biochemistry*, 64, 1067–1070. https://doi.org/10.1271/bbb.64.1067

Khan, N., Jamila, N., Choi, J.Y., Nho, E.Y., Hussain, I., & Kim, K.S. (2015). Effect of gamma-irradiation on the volatile flavor profile of fennel (*foeniculum vulgare* mill). *Pak. J. Bot.*, 47(5), 1839-1846.

Kloareg, B., & Quatrano, R. S. (1988). Structure of the cell walls of marine algae and ecophysiological functions of the skeletal and matrix polysaccharides. *Oceanography and Marine Biology Annual Review*, 26, 259–315.

Kole, C., Ramanna, R.K., & Ramchiary, N. (2019). *The capsicum genome*. Compendium of Plant Genomes. Springer.

Kössler, S., Armarego-Marriott, T., Tarkowská, D., Turečková, V., Agrawal, S., Mi, J., de Souza, L.P., Schöttler, M.A., Schadach, A., Fröhlich, A., Bock, R., Al-Babili, S., Ruf, S., Sampathkumar, A., & Moreno, J.C. (2021). Lycopene β-cyclase expression influences plant physiology, development, and metabolism in tobacco plants. *Journal of Experimental Botany*, 72, 2544–2569. https://doi.org/10.1093/jxb/erab029

Kume, T., Nagasawa, N., & Yoshii, F. (2002). Utilization of carbohydrates by radiation processing. *Radiation Physics and Chemistry*, 63, 625–627. https://doi.org/10.1016/S0969-806X(01)00558-8

Lima, M.F., Carvalho, S.I., Ragassi, C.F., Bianchetti, L.D., Faleiro, F.G., & Reifschneider, F.J. (2017). Characterization of a pepper collection (Capsicum frutescens L.) from Brazil. *Genetics and molecular research*, 16 3. https://doi.org/10.4238/gmr16039704

Mathews, C.R., Blaauw, B.R., Dively, G.P., Kotcon, J.B., Moore, J.L., Ogburn, E.C., Pfeiffer, D.G., Trope, T., Walgenbach, J.F., Welty, C., Zinati, G., & Nielsen, A.L. (2017). Evaluating a polyculture trap crop for organic management of Halyomorpha halys and native stink bugs in peppers. *Journal of Pest Science*, 90, 1245–1255. https://doi.org/10.1007/s10340-017-0838-z

Mercier, L., Lafitte, C., Borderies, G., Briand, X., Esquerre-Tugaye, M.T., & Fournier, L. (2001). The algal polysaccharide carrageenans can act as an elicitor of plant defense. *New Phytologist*, 149, 43–51. https://doi.org/10.1046/j.1469-8137.2001.00011.x

MMSU [Mariano Marcos State University]. (2018). *Carrageenan PGR: A safe and effective yield booster*. https://extension.mmsu.edu.ph/news/show/69/carrageenan-pgr-a-safe-and-effective-yield-booster

Moreno, J.C., Mi, J., Agrawal, S., Kössler, S., Turečková, V., Tarkowská, D., Thiele, W., Al-Babili, S., Bock, R., & Schöttler, M.A. (2020). Expression of a carotenogenic gene allows faster biomass production by redesigning plant architecture and improving photosynthetic efficiency in tobacco. *The Plant journal: for cell and molecular biology*, 103(6), 1967-1984. https://doi.org/10.1111/tpj.14909

Mousavi, E.A., Kalantari, K.M., Nasibi, F., & Hakimeh, O. (2018). Effects of carrageenan as elicitor to stimulate defense responses of basil against Cuscuta campestris Yunck. *Journal of Plant Interactions*, 12(1), 286–294.

Moyo, M., Aremu, A.O., & Amoo, S.O. (2021). Potential of seaweed extracts and humate-containing biostimulants in mitigating abiotic stress in plants. *Biostimulants for Crops from Seed Germination to Plant Development*, 297-332. https://doi.org/10.1016/B978-0-12-823048-0.00013-7

Mukherjee, A., & Patel, J.S. (2019). Seaweed extract: biostimulator of plant defense and plant productivity. International Journal of Environmental Science and Technology, 17, 553-558. https://doi.org/10.1007/s13762-019-02442-z

Nabti, E., Jha, B.K., & Hartmann, A. (2017). Impact of seaweeds on agricultural crop production as biofertilizer. *International Journal of Environmental Science and Technology*, 14, 1119-1134. https://doi.org/10.1007/s13762-016-1202-1

Naeem, M., Idrees, M., & Aftab, T. (2014). Employing depolymerized sodium alginate, triacontanol and 28-homobrassinolide in enhancing physiological activities, production of essential oil and active components in Mentha arvensis L. *Industrial Crops and Products*, 55, 272–279. https://doi.org/10.1016/j.indcrop.2014.01.052

Naeem, M., Idrees, M., Aftab, T., Moinuddin, T., & Varhney, L. (2011). Depolymerized carrageenan enhances physiological activities and menthol production in Mentha arvensis L. *Carbohydrate Polymers*, 87, 1211–1218. https://doi.org/10.1016/j.carbpol.2011.09.002

Nanda, S., Kumar, G., & Hussain, S. (2021). Utilization of seaweed-based biostimulants in improving plant and soil health: current updates and future prospective. *International Journal of Environmental Science and Technology*, 19, 12839-12852. https://doi.org/10.1007/s13762-021-03568-9

Natsume, M., Kamao, Y., Hirayan, M., & Adachi, J. (1994). Isolation and characterization of alginate derived oligosaccharides with root growth promoting activities. *Carbohydrate Research*, 258, 187–197. https://doi.org/10.1016/0008-6215(94)84085-7

Ning, J., Kong, F., Lin, B., & Lei, H. (2003). Large-scale preparation of the phytoalexin elicitor glucohexatose and its application as a green pesticide. *J. Agric. Food Chem*, 51, 987–991. https://doi.org/10.1021/jf020683x

Pamati-An, S., Miraflores, C., Galino, J., & Oberio, Z. (2020). Improving the growth of cherry tomatoes (Solanum lycopersicum L. var. cerasiforme) using irradiated carrageenan. *Publiscience*, 2, 1.

Pereira-Dias, L., Vilanova, S., Fita, A.M., Prohens, J., & Rodríguez-Burruezo, A. (2019). Genetic diversity, population structure, and relationships in a collection of pepper (Capsicum spp.) landraces from the Spanish centre of diversity revealed by genotyping-by-sequencing (GBS). *Horticulture Research*, 6. https://doi.org/10.1038/s41438-019-0132-8

Potin, P., Bouarab, K., Kupper, F., & Kloareg, B. (1999). Oligosaccharide recognition signals and defense reactions in marine plant–microbe interactions. *Current Opinion in Microbiology*, 2, 276–283. https://doi.org/10.1016/S1369-5274(99)80048-4

Relleve, L. S., Abad, L. V., de la Rosa, A. M., Molenda, M., & Rho, D. (2000). Radiation-modified polysaccharides for agricultural applications. *Radiation Physics and Chemistry*, 59, 143–148.

Sarfaraz, A., Naeem, M., Nasir, S., Idrees, M., Aftab, T., Hashmi, N., Khan, M.M., Moinuddin, & Varshney, L. (2011). An evaluation of the effects of irradiated sodium alginate on the growth, physiological activities and essential oil production of fennel (Foeniculum vulgare Mill.). *Journal of Medicinal Plants Research*, 5, 15-21.

Shukla, P.S., Borza, T., Critchley, A.T., & Prithiviraj, B. (2016). Carrageenans from red seaweeds as promoters of growth and elicitors of defense response in plants. *Frontiers in Marine Science*, 3, 81. https://doi.org/10.3389/fmars.2016.00081

Singh, M., Khan, M., Uddin, M., Naeem, M., & Qureshi, M. I. (2017). Proliferating effect of radiolytically depolymerized carrageenan on physiological attributes, plant water relation parameters, essential oil production and active constituents of Cymbopogon flexuosus Steud. under drought stress. *PLOS ONE*, 12, e0180129. https://doi.org/10.1371/journal.pone.0180129

Youssef, A. S. M., Zarad, M. M., Abd El-Ghany, N. M., Osman, S. M., & El-Mahdy, T. S. (2020). Effect of organic and bio-fertilization on fruit yield, bioactive constituents, and estragole content in fennel fruits. *Agronomy*, 10(11), 1727. https://doi.org/10.3390/agronomy10111727

Zia, K.M., Tabasum, S., Nasif, M., Sultan, N., Aslam, N., Noreen, A., & Zuber, M. (2017). A review on synthesis, properties and applications of natural polymer based carrageenan blends and composites. *International journal of biological macromolecules*, 96, 282-301. https://doi.org/10.1016/j.ijbiomac.2016.11.095