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Analysis of arsenic in rice and domestic water supply in Baguio City, Philippines

[1]Marilou Saong & [2]Ivy May Marbella

Abstract

Numerous studies have found that rice and water, as components of the human diet, are potential pathways of arsenic exposure in humans. Due to the negative health effects linked with arsenic exposure, the quality of drinking water and rice samples must be continually monitored. This research was carried out in Baguio City, a small urban center in the Philippines. Following microwave digestion, arsenic in rice and water samples were determined using Atomic Absorption Spectrometry. The results showed that the National Food Authority (NFA) rice samples had arsenic content below the detection limit, indicating that this commercially available rice does not pose any health risk to Filipino consumers in terms of arsenic exposure. The arsenic value in other rice samples ranged from 8 μg/L to 27 μg/L, with the lowest and highest values found in organic brown rice and white rice varieties, respectively. Despite detectable arsenic in all 20 rice samples, all values were less than the maximum contaminant level (MCL) of 150 μg/L. Despite higher arsenic content in mixed rice than in white and organic colored rice, the mean differences are not significant, as proven by the Kruskal Wallis Test. All drinking water samples bought from water refilling stations had no detectable arsenic, while eight of the 18 (44%) of the spring water samples showed detectable amounts but are far below MCL of arsenic in drinking water. The findings suggest that the amount of arsenic in rice and spring water samples are too low to pose health risks over a short period of time.

Keywords: *arsenic, rice, water samples, health risks, atomic absorption spectroscopy*

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1. Introduction

Metals in the environment are transported by natural processes as well as human activities, where they may enter the food chain and bioaccumulate. This increases the possibility of metal contaminants being ingested by humans, resulting in a variety of health problems. Toxic contaminants in food are regarded as a significant public health challenge for the twenty-first century, as they can cause disorders in a variety of body systems (Hensawang & Chanpiwat, 2017).

Arsenic, an odorless and tasteless metalloid, is a prevalent environmental contaminant, originating from natural geologic processes and pollution (Davis et al., 2017). It has the potential to enter the food system through contaminated soil or water. Inorganic arsenic (i-As) is classified as a human carcinogen by the International Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (EPA) (Lai et al., 2015). High exposure to i-As can lead to adverse health effects, including certain cardiovascular diseases, cancers, diabetes and respiratory conditions (IARC, 2004; Sharma et al., 2014; WHO, 2011). For these reasons, arsenic is one of the ten substances that the World Health Organization (WHO) considers to be a major public health concern.

Arsenic contamination presents a significant dietary concern, with research revealing its prevalence across various sources. Costa et al. (2016) highlighted that 32% of studies on dietary arsenic contamination are linked to fish sample analysis, 39% to food samples like rice, and 29% to drinking water. The primary source of inorganic arsenic (i-As) exposure for humans stems from the consumption of unregulated contaminated water, impacting an estimated 140 million people globally (States et al., 2011; Meharg & Zhao, 2012).

The World Health Organization (WHO) has continuously adjusted guidelines to address arsenic exposure, recommending a maximum arsenic level of 50 μg/L in drinking water since 1963. However, due to the correlation between low arsenic concentrations and cancer risk, the WHO lowered the guideline to 10 μg/L in 1992 (WHO, 2018). Various countries, including the United States, Taiwan, and the European Union, have set similar maximum allowable arsenic concentrations in drinking water. However, some nations maintain a national standard of 50 μg/L, underscoring the global disparity in arsenic regulation.

Rice, a staple cereal crop, has emerged as a major concern due to its ability to accumulate arsenic, particularly in regions with contaminated water sources. Studies indicate that rice grains in arsenic-endemic areas contain approximately 90% inorganic arsenic, making rice a primary dietary source of arsenic exposure in many countries (Chowdhury et al., 2020; Joardar et al., 2020). Even in areas with arsenic-safe drinking water, rice consumption alone can exceed safe thresholds, especially with the rise of global food trade, potentially exposing millions to excessive arsenic levels through imported rice and rice-based meals (Mridha et al., 2022).

Rice's significance in global diets is indisputable, being a staple for more than half of the world's population and cultivated extensively across more than 100 countries, with Asia contributing a staggering 90% of the total production (Hoang et al., 2021). Its popularity, notably among children, stems from being a high-calorie, cost-effective food with a relatively low allergic potential and high iron content (Signes-Pastor et al., 2016). However, the ubiquitous cultivation of rice presents a significant health concern, particularly in regions where the crop is grown on contaminated land, leading to the uptake and accumulation of toxic elements, notably arsenic, in edible plant parts (Hoang et al., 2021).

Recent studies highlight rice as a significant source of inorganic arsenic in human diets alongside drinking water (Costa et al., 2016; Sobel et al., 2020). With rice serving as the primary food for approximately half of the world's population, particularly in Asia, its contribution to global caloric intake is substantial (Majumder & Banik, 2019). Arsenic accumulation in rice grains is facilitated by its unique physiology and anaerobic growth conditions, where silicon transporters carry arsenic from flooded soil into the plant, resulting in higher arsenic concentrations in rice compared to other grains like wheat or barley (Lai et al., 2015). Recent research highlights the mobility of arsenic in rice, contributing to its elevated transfer from soil to grain (Rokonuzzaman et al., 2022).

Significant variations in total and inorganic arsenic concentrations in rice across different geographic regions have been observed, with studies indicating higher levels in European and US rice compared to Asian varieties (Chen et al., 2017). Investigations by the US Food and Drug Administration revealed elevated arsenic levels in a considerable portion of rice products sold in the US, posing potential health risks (USFDA). Epidemiological studies have further associated higher rice consumption with increased risks of chronic conditions such as type 2 diabetes and cardiovascular diseases, emphasizing the importance of addressing arsenic contamination in rice (Karagas et al., 2019).

The researches conducted in various countries shed light on the presence of potentially toxic metal(loid)s, including arsenic (As), in rice grains and its implications for human health. For instance, Soe et al. (2023) examined white rice samples from rain fed paddy fields in Myanmar, revealing concentrations within acceptable limits for most metals, but with arsenic as a concern, particularly for consumers in areas without groundwater irrigation. Similarly, Jayasumana et al. (2015) found arsenic contamination in rice cultivated in Sri Lanka, emphasizing the need for safer rice varieties. Shraim (2017) expanded this concern globally, highlighting hazardous levels of arsenic and other toxic elements in rice sold in Saudi Arabia. Studies in Vietnam (Nguyen et al., 2020), Bangladesh (Agence France-Press [AFP] News, 2013), and rural Bengal (Biswas et al., 2021) further emphasized the health risks associated with arsenic exposure from rice consumption. The study by Watson and Gustave (2022) found that 2% of rice samples in the Bahamian market had an estimated i-As concentration above WHO's allowable limits. Additionally, Nunes et al. (2022) quantified the global trade flow of arsenic in rice, showing how importing countries may face increased cancer risks. The Philippines, although reported to have low arsenic levels in rice by the FDA (Rettner, 2013), still requires monitoring for potential long-term health risks.

In terms of arsenic pollution in water, studies conducted in various regions, including Italy, Malaysia, Pakistan, and the Philippines, underscore its pervasive nature. For instance, Nuvolone et al. (2023) highlighted the association between chronic exposure to low-level arsenic in drinking water and adverse health outcomes, including mortality and hospitalization, in the volcanic region of Mt. Amiata, Italy. Similarly, Ramly et al. (2023) conducted a comparative cross-sectional study in Malaysia, revealing high arsenic concentrations in drinking water and hair samples, leading to the prevalence of arsenicosis in exposed communities. These findings resonate with broader concerns outlined by Uppal et al. (2019), who emphasized the extensive population exposure to arsenic-contaminated water in Southeast Asia and its link to various health conditions.

Moreover, regional studies, such as those conducted in Pakistan (Abbas & Cheema, 2019) and the Philippines (Apostol et al., 2022), provide localized insights into arsenic contamination patterns and associated health risks. Abbas and Cheema (2019) reported a positive correlation between arsenic levels in drinking water and blood samples of females in District Sheikhupura, Pakistan, emphasizing the systemic health implications of arsenic exposure. Meanwhile, Apostol et al. (2022) explored arsenic contamination in groundwater surrounding Taal Volcano in the Philippines, highlighting the need for continuous monitoring and risk communication to safeguard public health. These studies collectively underscore the global significance of arsenic contamination in drinking water and underscore the imperative for evidence-based policies to mitigate its adverse effects and protect vulnerable populations.

The literature presents extensive evidence highlighting the pervasive nature of arsenic pollution in both rice and water sources and its significant implications for public health globally. However, there remains a notable gap in the literature regarding arsenic contamination specifically in water sources within Baguio City, Philippines. Despite the well-documented risks associated with arsenic exposure, including various adverse health outcomes, there is a lack of localized studies addressing this issue in Baguio City. Given the unique environmental and geographical characteristics of Baguio City, there is a pressing need to conduct a study to assess arsenic levels in water samples and understand the extent of contamination in this region. Such research is crucial for informing evidence-based policies and interventions to mitigate arsenic exposure risks and protect the health of vulnerable populations in Baguio City.

2. Methodology

2.1 Design and Locale of the study

The study used of descriptive-analysis method. Specifically, it analyzed the level of As from drinking water and rice samples using Atomic Absorption Spectroscopy.

The study was conducted in Baguio City, a small urban center in the Philippines located approximately 250 kilometers North of Metro Manila and 1,500m above sea level. Baguio City’s water supply comes from springs, wells, surface diversions, and a rain basin (Ciencia et al., 2015). Baguio Water District (BWD) administers the city's water supply system. Seven of the city's 129 barangays are not directly connected to the Baguio Water District (BWD). Moreover, not all households in the remaining 122 barangays are connected to the BWD's pipe system.

The Philippines has three types of potable water systems. Level I water system includes stand-alone water points such as hand pumps, shallow wells, and rainwater collectors. Level II water system covers piped water with a communal water point such as borewell and spring system. Level III water system includes piped water supply with a private water point, such as a house connection (Israel, 2009). In Baguio City, most of the barangays rely on Level III water system with BWD as the water service provider. On the other hand, a significant number of Baguio residents still rely on 'natural' water sources (e.g., springs) or Level II water systems due to the absence of water line from BWD or in the event of a disruption in the water distribution services of the BWD (Ciencia et al., 2015).

The current study was conducted in barangay Lucnab, Baguio City. Its population, as determined by the 2015 Census was 2,120, representing 0.61% of the total population of Baguio (Philippines Statistics Authority). Out of the four Puroks (*district or zone*), only Purok 1 residents have water connections to the BWD's pipeline system. Thus, Puroks 2, 3, and 4 were specifically chosen for this study to assess the quality of water used by the residents, which are from springs and private water delivery trucks.

In terms of Baguio's rice supply, there are some 120 accredited National Food Authority (NFA) outlets in the Baguio-Benguet area that distribute rice to hundreds of retailers in the different public and private markets (See, 2020). The NFA is a Philippine government agency responsible for ensuring food security for the country, as well as rice supply and price (National Food Authority, 2020). Starting November 2018, rice retailers are required by the NFA to sell four varieties of rice labeled only as "regular-milled", "well-milled", "whole grain," and "special" (Layug, 2018). The special rice varieties are either organic or heirloom. Regardless of rice varieties, the white rice samples are all classified by the National Food Authority of the Philippines as well-milled rice. Most of the commercially available rice in the Philippines are sold as well-milled rice.

2.2 Data gathering procedures

The preliminary survey was conducted to gather baseline data on common drinking and household water sources, and common rice varieties consumed among Puroks 2, 3, and 4 residents. The pre-survey employed convenience sampling in the aforementioned areas where a total of 92 completed questionnaires were collected.

The survey revealed that the source of drinking water for the majority (58.7%) was spring water. On the other hand, 41.3% got their drinking water from water refilling stations. Springwater was used for cooking, washing, and other household tasks by the majority (69.6%) of the respondents. A majority of the respondents, or 81.5 percent, consumed commercially available rice, while the rest consumed homegrown rice. The top five most commonly purchased rice varieties included: NFA (30.4%), Sinandomeng (17.4%), Jasmine (10.9%), RC-18 (8.7%), and Bordagol (6.5%).

Twenty-eight (28) water samples were collected from strategic locations in Puroks 2, 3, and 4. Ten (10) were purified while 18 were spring water samples. The purified water samples collected from the households were bought by the residents from Water Refilling Stations and were used as drinking water. On the other hand, spring water samples collected were used mainly by the residents for cooking, cleaning, and other household activities. The study also analyzed 22 rice samples consisting of organic rice, homegrown rice, and commercially available rice of different varieties. The varieties include Angelica, Jasmine, Sinandomeng, Dinorado, R160, Bordagol, and NFA rice. For comparison purposes with commercially available rice, the collected samples included organic rice and homegrown rice.

2.3 Sample collection and preservation

Polyethylene bottles were used to collect spring water and purified water samples from selected households. Upon collection, the samples were treated immediately with 3-5 drops of analytical grade nitric acid. Most trace metals are preserved by acidification to below pH=2. This decreases precipitation and sorption losses to the container walls. An icebox containing a mixture of water and ice was used to maintain the temperature from 10C to 40C (EPA, 2000). The samples were kept at this condition during transport to the laboratory. In addition, around 20 g of rice were collected from the volunteer residents and immediately placed in zip-lock plastic containers.

2.4 Analysis of water and rice samples using Atomic Absorption Spectrometry

The rice and water samples were brought to the Department of Science and Technology laboratory for arsenic analysis using Atomic Absorption Spectrometry after Microwave digestion. The methods used were based on the official methods of analysis of AO/AC International (20th ed) (2016) and in accordance with Milestones Microwave and PinAAle 900Z Methods Manual.

2.5 Data processing and Statistical analysis

The Philippines has not set a maximum arsenic level for rice yet. Australia and New Zealand (1000 µg/L or ppb of total cereal arsenic), and China (150 ppb of inorganic arsenic for rice and rice products) established limits. For purposes of interpretation, the study adopted the limit set by China. Thus, if the mean concentration of As detected from the rice samples is higher than 150 ppb, the value is interpreted as high level, otherwise, it is interpreted as low. The maximal allowable concentration of As in drinking water set by WHO is 10 µg/L (or ppb). Thus, if the determined mean concentration of As in drinking water is above the allowable limit, it will be interpreted as high; otherwise, the mean will be interpreted as low.

Kruskal Wallis (KW) test was used to determine if there was a significant difference in the level of As according to rice varieties. All statistical analyses conducted in this study were two-tailed at a significance level of 0.05, using SPSS software.

3. Results and Discussion

3.1 Levels of arsenic in different rice varieties

Table 1 shows the arsenic content of the rice samples collected from 22 households. The two NFA rice or the so-called "cheap" rice in the Philippines had an arsenic content below the detection limit, which means that, apart from being affordable, this commercially available rice does not pose any health risk to Filipino consumers in terms of exposure to arsenic. For the remaining 20 rice samples, the arsenic value ranged from 8 µg/L to 27 µg/L, with the lowest and highest values found in organic brown rice and white rice varieties. Despite detectable arsenic in the 20 rice samples, all values were below the maximum contaminant level of 150 µg/L. The results imply that the arsenic levels in rice are low to pose health risks over a short period. The results underscore the importance of monitoring arsenic levels in rice varieties, given rice's status as a staple food in the Philippines. While the detected arsenic levels may not pose immediate health risks, the potential for long-term health effects cannot be ignored, especially considering rice's role as a dietary mainstay for Filipinos. The ability of arsenic to bioaccumulate in the body over time raises concerns about cumulative exposure, particularly among vulnerable populations such as pregnant women, infants, and adolescents.

Table 1

Arsenic analysis of different rice varieties using Atomic Absorption Spectrophotometry

Sample no.	Rice Varieties	Arsenic content, μg/L or ppb	Interpretation
White Rice			
1	Angelica	14.8	Low
2	Bordagol	11.0	Low
3	Dinorado	15.7	Low
4	Jasmine	9.30	Low
5	Jasmine	10.8	Low
6	Jasmine	8.80	Low
7	Jasmine	12.3	Low
8	Jasmine	9.60	Low
9	Jasmine	17.0	Low
10	Jasmine	27.0	Low
11	RC 160	12.0	Low
12	Sinandomeng	12.0	Low
13	Sinandomeng	8.10	Low
14	Sinandomeng	13.2	Low
15	Sinandomeng	11.2	Low
16	Sinandomeng	13.4	Low
17	NFA 1	ND	Low
18	NFA 2	ND	Low
Mixed (White and Red)			
19	White and Red Rice	14.2	Low
20	Sinandomeng and Red Rice	17.1	Low
Organic Rice			
21	Organic Brown	8.00	Low
22	Organic Red	10.7	Low

The IARC (2004) and the National Research Council (2001) have highlighted the significant health risks associated with exposure to low levels of arsenic, including cancer, skin lesions, diabetes, cardiovascular disease, peripheral neuropathy, and other hematologic, liver, and kidney issues. The studies of Lai et al. (2015), Liao et al. (2018) and Rettner (2013) likewise highlight the potential long-term health risks of arsenic in rice, particularly for pregnant women and infants. Younger populations, particularly adolescents, are at higher risk due to their early years of life and development. Despite rice's low concentrations, the LCR values are beyond the acceptable upper limit. The US Food and Drug Administration (2016) underscores children's greater potential for long-term exposure due to the long latency period of iAs-related cancer. Children, including adolescents, are in a critical window of development, have a high calorie per unit body weight diet, and are more exposed to contaminants unique to specific foods due to selective and less diverse dietary patterns.

3.2 Comparison of the level of arsenic according to rice varieties

For comparison, the 20 rice samples with detectable arsenic content were grouped into white rice, organic colored rice varieties, and mixed rice (white and non-organic red rice). Among the three groups presented in table 2, the lowest arsenic level was from organic rice (M = 9.30, SD = 1.91). The conventionally-grown white rice varieties showed a mean arsenic level higher than the organic rice but lower than the mix of white and colored non-organic rice. The result connotes that organic farming has reduced the amount of arsenic in rice, making the resultant rice crop healthier.

Table 2

Mean levels of arsenic in different rice varieties

	N	Mean	SD
White Rice	16	12.9	4.50
Organic Colored Rice	2	9.35	1.91
Mixed (White and Non-Organic Red Rice)	2	15.7	2.05
Total	**20**	**12.8**	**4.30**

Conventional methods of rice production use agrochemicals, which can release arsenic into the soil and water, leading to arsenic accumulation in rice grains (Interra International 2018). Organic farming uses bio-fertilizers and other organic nutrient sources to minimize exposure to harmful chemicals like arsenic. Organic rice does not involve synthetic raw materials, transgenic plants, animals, or microorganisms, maintaining the organic integrity and quality of products (National Bureau of Agricultural Commodity and Food Standards Ministry of Agriculture and Cooperatives, 2010). Organic products, like organic brown rice, are less processed than non-organic foods, containing fewer artificial colorings, sweeteners, flavorings, and preservatives, which may be harmful to health (George, 2018).

A common drawback with organic foods, given the known health benefits, is cost, as organic foods can cost considerably more than their traditional counterparts (George, 2018). The operating costs for organic and heirloom rice are more expensive than the typical rice paddy with its seasonal, lower yields, thus, driving up the price (Castro, 2019). Because of these, most Filipinos still consume white rice. Mixtures of white and colored rice sold on the market can balance health benefits and economic factors.

Table 2 further shows that the highest mean level of arsenic was from mixed rice (*M* = 15.65, SD = 2.05), potentially due to the addition of non-organic colored rice to white rice. This finding aligns with the 2013 findings of the Philippine Food and Drug Administration (FDA), which reported that instant rice had low amounts of arsenic while brown rice had higher levels. Additionally, Meharg and Zhao (2012) found that bran, the hard outer layer of the grain present in brown rice, accumulates more arsenic than white rice, as white rice production involves removing this layer, thereby reducing arsenic levels. Furthermore, Hensawang and Chanpiwat (2017) discovered that brown jasmine rice contained considerably more As than white jasmine and white glutinous rice. In terms of As exposure produced by different forms of rice consumption, brown jasmine rice intake caused around 1.7 to 2.3 times greater As exposure rates compared to other types of rice consumption. Moreover, Su et al. (2023) emphasize the greater concentration of arsenic in brown rice compared to white rice and caution against advocating for brown rice over white rice without considering the potential risks and benefits. Additionally, Yim et al. (2017) found that brown rice contained the highest amount of total arsenic compared to white rice with varying degrees of polishing.

Considering that arsenic accumulates in the bran, post-harvesting methods such as polishing raw rice grains have been found to decrease total As content in cooked rice (Kumarathilaka et al., 2019). This explains why the average values of the white rice varieties analyzed in the current study are lower than the white and colored non-organic rice mixtures. Notwithstanding the varieties of rice, white rice samples are all classified as well-milled rice by the National Food Authority of the Philippines. Most of the commercially available rice in the Philippines is sold as well-milled rice, equivalent to polished rice. The United Nations Food and Agriculture Organization (FAO) defines well-milled rice as rice grain that has had the hull, germ, outer bran layers, and the majority of the inner bran layers removed. In contrast to conventional milled rice, which permits for the existence of bran layer streaks in up to 30% of the kernels (GMA News Online, 2013).

Despite higher arsenic content in mixed rice compared to white rice and organic colored rice, the mean differences are not significant, as proven by the Kruskal Wallis Test,

χ^2 (2) = 5.22, and p=.074. The non-significant differences in arsenic levels among the rice groups imply that, from an arsenic exposure perspective, consumers may not face significantly different health risks when consuming mixed rice, white rice, or organic colored rice. This finding suggests that, in terms of arsenic content, all three types of rice may be considered relatively safe for consumption. Consumer Reports (2014) suggest that white or brown rice offers significant health benefits, outweighing arsenic trace levels. Sun et al. (2010) discovered that substituting 50 grams of white rice for brown rice resulted in a 16 percent lower risk of type 2 diabetes. For improved diets, Healthline (2019) underlines the need of selecting particular rice types.

However, the discussion on organic brown rice adds a layer of complexity. While George (2018) suggests that organic foods, including brown rice, may contain fewer agricultural pollutants than conventional crops, the health benefits of organic foods compared to conventional ones remain inconclusive. Nevertheless, it highlights that organic brown rice may offer greater health advantages compared to non-organic rice. In the broader context of risk-benefit assessment in food safety research, Assunção et al. (2019) highlight the importance of evaluating both the risks and benefits of consuming specific foods or food components. Applying this approach to rice consumption would involve assessing the potential health risks associated with arsenic exposure alongside the nutritional benefits of different rice types, ultimately guiding consumers toward informed dietary choices.

3.3 Levels of arsenic in different water samples

The cost of domestic water purifiers and bottled water has grown in recent years due to the rise in demand for cleaner water. The distribution of around 3,000 water filling stations across the Philippines has made it a reliable supply of clean, affordable drinking water for the nation. These water refilling stations offer filtered water of equal quality to bottled water at a lesser cost (Magtibay, 2018). Water refilling stations now supply clean water in 5-gallon containers right to people's homes. More and more Filipinos are purchasing their drinking water from water filling stations due to price and convenience. For example, in the locality of the current study, 41.3 percent of barangay Lucnab residents buy their drinking water from the water refilling stations.

Table 3 shows that all ten drinking water samples bought from water refilling stations had no detectable amounts of arsenic-based on AAS analysis. The results imply that the water refilling stations follow the Philippine National Standards for Drinking Water (PNSDW). The highest arsenic level allowed in drinking water is 10 μg/L (Department of Health, 2017). The Philippine National Standards for Drinking Water (PNSDW), which establishes standards and procedures for the quality of drinking water in order to safeguard the public's and consumers' health, was released by the Department of Health (DOH) in 2017. These requirements are in line with the WHO's enhanced framework for safe drinking water.

Table 3

Arsenic analysis of different water samples using Atomic Absorption Spectrophotometry

Sample No	Source	Arsenic content, μg/L	Interpretation
1	Spring Water	0.0012	Low
2	Spring Water	0.00116	Low
3	Spring Water	0.00105	Low
4	Spring Water	ND	Low
5	Spring Water	ND	Low
6	Spring Water	ND	Low
7	Spring Water	ND	Low
8	Spring Water	0.00065	Low
9	Spring Water	ND	Low
10	Spring Water	ND	Low
11	Spring Water	ND	Low
12	Spring Water	ND	Low
13	Spring Water	0.00083	Low
14	Spring Water	0.00158	Low
15	Spring Water	0.00150	Low
16	Spring Water	0.00003	Low
17	Spring Water	ND	Low
18	Spring Water	ND	Low
19	Purified Water	ND	Low
20	Purified Water	ND	Low
21	Purified Water	ND	Low
22	Purified Water	ND	Low
23	Purified Water	ND	Low
24	Purified Water	ND	Low
25	Purified Water	ND	Low
26	Purified Water	ND	Low
27	Purified Water	ND	Low
28	Purified Water	ND	Low

Notes: RdL – Required detection limit or drinking water is 0.000016 microgram/L while 0.000014 microgram/L for spring water.
ND – Not Detected

There is no health risk from exposure to arsenic, according to the findings, but there may be dangers from other types of contamination. Even though water filling stations employ effective water purification methods to provide water that is superior to the quality of traditional water systems, Magtibay (2018) has noted that the possibility of contamination is likely if the handling procedures are not carefully examined. For the residents of Barangay Lucnab, contamination may occur during the transfer or storage of the purified water at home.

Table 3 further shows that eight of the 18 (44%) spring water samples showed detectable amounts but are far below the MCL of arsenic in drinking water. Since arsenic naturally appears as a trace component in many rocks and sediments, bedrocks may be the source of the spring water's low arsenic levels. Arsenic found in the mineral deposits and rock easily dissolves in a nearby groundwater (WHO, 2014). As a result of human activities including mining and its various industrial uses, animal feeds, wood preservatives, and pesticides, arsenic can also leach into groundwater. The very low levels of arsenic may not have come from such operations because there have been no known mining activity, little vegetation, and no rice paddies in barangay Lucnab, which may imply the usage of pesticides. In a related study conducted in the Malaysian state of Perak, Rahmanian et al. (2015) claimed that the elevated As levels in the communities of Ipoh (IP) and Seri Iskandar were brought on by the usage of chemical fertilizers in the neighboring rice fields. Geographically, the IP's closeness to the Kinta small-medium industrial sector may have contributed to increased levels of As in the sample under investigation. Aside from the production of semiconductors, other sources of As include waste runoff from glass and electronics manufacturing facilities, orchard runoff, natural deposit erosion, and semiconductor manufacturing.

The low amounts of arsenic in spring water samples used by the residents posed no significant health risks associated with arsenic exposure. The finding presents a better picture than the research findings in other parts of the world and the Philippines positing that threat to public health comes from arsenic-contaminated groundwater. Inorganic arsenic is naturally present in groundwater at high concentrations in a number of nations, including Mexico, Argentina, Bangladesh, Chile, China, India, Mexico, and the United States of America. The three main sources of contamination are food prepared with contaminated water, crops irrigated with it, and drinking water (WHO, 2018). Sharp geographic, socioeconomic, and cultural divides occur between rural and urban areas as well as inside towns and cities, where residents of low-income, informal, or illegal settlements typically have less access to improved drinking-water sources than other residents (WHO, 2019).

In contrast, the study of Delos Reyes et al. (2017) found that groundwater samples from the Inayawan Landfill in Cebu, Philippines, showed an arsenic level of 72 μg/L, exceeding the World Health Organization's 10 μg/L limit. The majority of respondents had low exposure to arsenic-contaminated water, with a low prevalence of skin diseases. Similarly, the study of Magalona et al. (2019) showed that some of the groundwater samples from Bulacan, Batangas, and Laguna exceeded the maximum allowable limit set by EPA and WHO. The results are alarming, as people use groundwater for drinking, cooking, and personal needs. Epidemiological studies are recommended to assess the incidence of cancer, diabetes, and cardiovascular diseases.

4. Conclusion

The analysis of arsenic levels in various rice varieties available in Baguio City, Philippines highlights the importance of continued monitoring and awareness of arsenic exposure risks, particularly in staple foods like rice. While the levels detected in the studied rice samples were generally below the maximum contaminant level, the potential for long-term health effects, especially among vulnerable populations, necessitates ongoing vigilance. Organic farming practices appear to contribute to lower arsenic levels in rice, suggesting potential health benefits, although cost considerations remain a challenge. Additionally, the arsenic levels in drinking water samples indicates that water refilling stations generally provide safe drinking water, aligning with national standards. However, attention should still be paid to potential contamination risks during storage and handling.

Based on these findings, it is recommended to prioritize efforts in promoting organic farming practices for rice cultivation to minimize arsenic exposure. Government subsidies or incentives could help mitigate the cost barrier associated with organic products, making them more accessible to the general population. Furthermore, continuous monitoring and enforcement of water quality standards, especially in areas reliant on groundwater sources, are essential to ensure safe drinking water for all. Public awareness campaigns on proper water handling and storage practices can also help reduce the risk of contamination.

Additionally, further epidemiological studies are warranted to better understand the health impacts of arsenic exposure in communities with elevated levels of contamination.

References

Abbas, M., & Cheema, K. J. (2019). Correlation studies of arsenic level in drinking water and blood samples of females in district Sheikhupura, Pakistan. *Journal of Environmental Science and Management*, *22*(2), 1–5. https://doi.org/10.47125/jesam/2019_2/01

Agence France-Press (AFP) News (2013). *Largest study widens rice, arsenic link in Bangladesh.* http://ph.news.yahoo.com/largest-study-widens-rice-arsenic-bangladesh-184854774.html?.tsrc=globe

Apostol, G. L. C., Valenzuela, S., & Seposo, X. (2022). Arsenic in groundwater sources from selected communities surrounding Taal Volcano, Philippines: An exploratory study. *Earth*, *3*(1), 448–459. https://doi.org/10.3390/earth3010027

Assunção, R., Pires, S. M., & Nauta, M. (2019). Risk-Benefit assessment of foods. *EFSA Journal*, *17*. https://doi.org/10.2903/j.efsa.2019.e170917

Biswas, B., Chakraborty, A., Chatterjee, D., Pramanik, S., Bhaswati, G., Majumdar, K. K., Nriagu, J. O., Kulkarni, K. Y., Bansiwal, A., Labhasetwar, P., & Bhowmick, S. (2021). Arsenic exposure from drinking water and staple food (rice): A field scale study in rural Bengal for assessment of human health risk. *Ecotoxicology and Environmental Safety*, *228*, 113012. https://doi.org/10.1016/j.ecoenv.2021.113012

Castro, J. (2019). *These are all the different kinds of rice you can buy in the Metro*. https://www.yummy.ph/lessons/prepping/where-to-buy-heirloom-rice-a00261-20190405-lfrm

Chen, Y., Han, Y.-H., Cao, Y., Zhu, Y.-G., Rathinasabapathi, B., & Ma, L. Q. (2017). Arsenic transport in rice and biological solutions to reduce arsenic risk from rice. *Frontiers in Plant Science*, *8*. https://doi.org/10.3389/fpls.2017.00268

Chowdhury, N., Das, A., Joardar, M., De, A., Mridha, D., Das, R., Rahman, M. M., & Roychowdhury, T. (2020). Flow of arsenic between rice grain and water: Its interaction, accumulation and distribution in different fractions of cooked rice. *Science of the Total Environment*, 731, 138937. https://doi.org/10.1016/j.scitotenv.2020.138937

Ciencia, A. Jr., Mendoza, L. Cruz, G., Calde, N., Cabalfin, M. & Peñalba, M. (2015). Towards establishing water security and urban resilience in the city of Baguio. *Asian Cities Climate Resilience Working Paper Series 27.* https://pubs.iied.org/pdfs/10754IIED.pdf

Consumer Reports (2014). How much arsenic is in your rice? https://www.consumerreports.org/cro/magazine/2015/01/how-much-arsenic-is-in-your-rice/index.htm

Costa, B., Coelho, L., Araújo, C., Rezende, H., & Coelho, N. (2016). Analytical strategies for the determination of arsenic in rice. *Journal of Chemistry*, 1-11. https://doi.org/10.1155/2016/1427154

Davis, M., Signes-Pastor, A. J., Argos, M., Slaughter, F., Pendergrast, C., Punshon, T., Gossai, A., Ahsan, H., & Karagas, M. R. (2017). Assessment of human dietary exposure to arsenic through rice. *Science of the Total Environment*, 586, 1237–1244. https://doi.org/10.1016/j.scitotenv.2017.02.119

Delos Reyes, J., Flores, S. M. and Winona, M.T. (2017). *Exposure to Arsenic contaminated water and its association to skin disease prevalence in Inayawan, Cebu.* Thesis. http://www.herdin.ph/index.php/herdin-home?view=research&cid=69557

Department of Health (2017, December 22). *DOH launches Philippine National Standards for Drinking Water of 2017*. https://www.doh.gov.ph/node/12121

Department of Health (2017). *Philippine National Standards for Drinking Water.* https://www.foodshap.com/PNSDW2017.pdf

George, S. (2018.). What are the benefits of organic brown rice? https://www.leaf.tv/6764390/what-are-the-benefits-of-organic-brown-rice/

GMA News Online (2013, July 21). *NFA now selling well-milled rice.* https://www.gmanetwork.com/news/money/content/318506/nfa-now-selling-well-milled-rice/story/

Healthline (2019). *What is the healthiest type of rice*? https://www.ecowatch.com/healthiest-rice-2633703792.html

Hensawang, S. & Chanpiwat, P. (2017). Health impact assessment of arsenic and cadmium intake via rice consumption in Bangkok, Thailand. *Environmental Monitoring Assessment*, 189, 599. https://doi.org/10.1007/s10661-017-6321-8

Hoang, A. T., Prinpreecha, N., & Kim, K. (2021). Influence of mining activities on arsenic concentration in rice in Asia: a review. *Minerals*, *11*(5), 472. https://doi.org/10.3390/min11050472

International Agency for Research on Cancer (IARC) (2004). Some drinking-water disinfectants and contaminants, including arsenic. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, *84*, 1–19.

Interra International (2018). Organic rice – the healthy option. https://interrainternational.com/2018/11/organic-rice-the-healthy-option/

Israel, D. (2009). The cases of Dumaguete City and Agusan del Sur. *Philippine Institute for Development Studies Policy Notes No. 2009-01*. https://core.ac.uk/download/pdf/6506005.pdf

Jayasumana, C., Paranagama, P., Fonseka, S., Amarasinghe, M. D., Gunatilake, S., & Siribaddana, S. (2015). Presence of arsenic in Sri Lankan rice. *International Journal of Food Contamination*, *2*(1). https://doi.org/10.1186/s40550-015-0007-1

Joardar, M., Das, A., Mridha, D., De, A., Chowdhury, N., & Roychowdhury, T. (2020). Evaluation of acute and chronic arsenic exposure on school children from exposed and apparently control areas of West Bengal, India. *Exposure and Health*, *13*(1), 33–50. https://doi.org/10.1007/s12403-020-00360-x

Karagas, M. R., Punshon, T., Davis, M., Bulka, C. M., Slaughter, F., Karalis, D., Argos, M., & Ahsan, H. (2019). Rice intake and emerging concerns on arsenic in rice: a review of the human evidence and methodologic challenges. *Current Environmental Health Reports*, *6*(4), 361–372. https://doi.org/10.1007/s40572-019-00249-1

Kumarathilaka, P., SamanSeneweera, S. SikOk, Y. Meharg, A. & Bundschuh, J. (2019). Arsenic in cooked rice foods: Assessing health risks and mitigation options. *Environment International*, 127, 584-591.

Lai, P., Cottingham, K. Steinmaus, C., Karagas, M. & Miller, M. (2015). Arsenic and rice: Translating research to address health care providers' needs. *The Journal of Pediatrics*, *167*(4), 797–803. https://doi.org/10.1016/j.jpeds.2015.07.003

Layug, M. (2018, October 10). *NFA sets just 4 labels for rice.* GMA News. https://www.gmanetwork.com/news/money/economy/670805/nfa-sets-just-4-labels-for-rice/story/

Liao, N., Seto, E., Eskenazi, B., Wang, M., Li, Y., & Hua, J. (2018). A comprehensive review of arsenic exposure and risk from rice and a risk assessment among a cohort of adolescents in Kunming, China. *International Journal of Environmental Research and Public Health*, *15*(10), 2191. https://doi.org/10.3390/ijerph15102191

Magalona, M., Peralta, M., Lacsamana, M., Sabularse, V., Pelegrina, A. & de Guzman, C. (2019). Analysis of Inorganic Arsenic (As(III) and Total As) and some physicochemical parameters in groundwater samples from selected areas in Bulacan, Batangas, and Laguna, Philippines. *KIMIKA*, *30*(2), 28-38. https://doi.org/10.26534/kimika.v30i2.28-38

Magtibay, B. (2018). *Water Refilling Station: An alternative source of drinking water supply in the Philippines.* https://businessdiary.com.ph/835/water-refilling-station-study/

Majumder, S., & Banik, P. (2019). Geographical variation of arsenic distribution in paddy soil, rice and rice-based products: A meta-analytic approach and implications to human health. *Journal of Environmental Management*, *233*, 184–199. https://doi.org/10.1016/j.jenvman.2018.12.034

Meharg, A.A. and Zhao, F. (2012). *Arsenic & rice*. Springer

Mridha, D., Gorain, P. C., Joardar, M., Das, A., Majumder, S., De, A., Chowdhury, N., Lama, U., Pal, R., & Roychowdhury, T. (2022). Rice grain arsenic and nutritional content during post harvesting to cooking: A review on arsenic bioavailability and bioaccessibility in humans. *Food Research International*, 154, 111042. https://doi.org/10.1016/j.foodres.2022.111042

National Food Authority (2020). https://www.officialgazette.gov.ph/section/briefing-room/department-of-agriculture/national-food-authority-department-of-agriculture/

National Research Council (2001). *Arsenic in drinking water: 2001 update.* National Academy Press.

National Bureau of Agricultural Commodity and Food Standards Ministry of Agriculture and Cooperatives (2010). Thai agricultural standard 9000 part 4 – 2010, Organic agriculture part 4: Organic rice. https://www.acfs.go.th/standard/download/eng/ORGANIC_RICE_part4.pdf

Nguyen, H. P. A., Cu, Y. H., Watchalayann, P., & Soonthornchaikul, N. (2020). Assessing inorganic arsenic in rice and its health risk to consumers in Ho Chi Minh City, Vietnam. *Journal of Health Research*, *35*(5), 402–414. https://doi.org/10.1108/jhr-09-2019-0221

Nuvolone, D., Stoppa, G., Petri, D., & Voller, F. (2023). Long-term exposure to low-level arsenic in drinking water is associated with cause-specific mortality and hospitalization in the Mt. Amiata area (Tuscany, Italy). *BMC Public Health*, *23*(1). https://doi.org/10.1186/s12889-022-14818-x

Nunes, L. S., Li, G., Chen, W., Meharg, A. A., O'Connor, P. J., & Zhu, Y. (2022). Embedded Health Risk from Arsenic in Globally Traded Rice. *Environmental Science & Technology*, *56*(10), 6415–6425. https://doi.org/10.1021/acs.est.1c08238

Rahmanian, N. Ali, S.H., Homayoonfard, M., Ali, N., Rehan, M., Sadef, Y., & Nizami, A. (2015). Analysis of physiochemical parameters to evaluate the drinking water quality in the state of Perak, Malaysia. *Journal of Chemistry*. https://doi.org/10.1155/2015/716125

Ramly, N., Mahir, H. M. A., Azmi, W. N. F. W., Hashim, Z., Hashim, J. H., & Shaharudin, R. (2023). Arsenic in drinking water, hair, and prevalence of arsenicosis in Perak, Malaysia. *Frontiers in Public Health*, *11*. https://doi.org/10.3389/fpubh.2023.998511

Rettner, R. (2013). *Arsenic in rice not a risk over short term, FDA Finds*. http://www.livescience.com/39474-arsenic-rice-fda.html

Rokonuzzaman, M., Li, W. C., Man, Y. B., Tsang, Y. F., & Ye, Z. (2022). Arsenic accumulation in rice: sources, human health impact and probable mitigation approaches. *Rice Science/Rice Science*, *29*(4), 309–327. https://doi.org/10.1016/j.rsci.2022.02.002

See, D. (2020). *NFA assures sufficient rice supply for Baguio, Benguet*. http://www.baguio.gov.ph/content/nfa-assures-sufficient-rice-supply-baguio-benguet

Sharma, A.K., Tjell, J.C., Sloth, J.J. & Holm, P.E. (2014). Review of arsenic contamination, exposure through water and food and low cost mitigation options for rural areas. *Applied Geochemistry*, *41*, 11-33. https://doi.org/10.1016/j.apgeochem.2013.11.012

Shraim, A. (2017). Rice is a potential dietary source of not only arsenic but also other toxic elements like lead and chromium. *Arabian Journal of Chemistry*, *10*, S3434–S3443. https://doi.org/10.1016/j.arabjc.2014.02.004

Signes-Pastor, A. J., Carey, M., & Meharg, A. A. (2016). Inorganic arsenic in rice-based products for infants and young children. *Food Chemistry*, *191*, 128–134. https://doi.org/10.1016/j.foodchem.2014.11.078

Sobel, M. H., Sanchez, T. R., Jones, M. R., Kaufman, J. D., Francesconi, K. A., Blaha, M. J., Vaidya, D., Shimbo, D., Gossler, W., Gamble, M. V., Genkinger, J. M., & Navas-Acien, A. (2020). Rice Intake, Arsenic Exposure, and Subclinical Cardiovascular Disease Among US Adults in MESA. *Journal of the American Heart Association*, *9*(4). https://doi.org/10.1161/jaha.119.015658

Soe, A. M. M., Mu, A. A., & Toyoda, K. (2023). Arsenic and heavy metal contents in white rice samples from rainfed paddy fields in Yangon division, Myanmar—Natural background levels? *PloS One*, *18*(3), e0283420. https://doi.org/10.1371/journal.pone.0283420

States, J.C., Barchowsky, A., Cartwright, I.L., Reichard, J.F., Futscher, B.W. & Lantz, R.C. (2011). Arsenic toxicology: Translating between experimental models and human pathology. *Environmental Health Perspective*. https://doi.org/10.1289/ehp.1103441

Su, L. J., Chiang, T., & O'Connor, S. N. (2023). Arsenic in brown rice: do the benefits outweigh the risks? *Frontiers in Nutrition*, *10*. https://doi.org/10.3389/fnut.2023.1209574

United Nations Food and Agricultural Organization/World Health Organization (UN FAO/WHO) (2011). *Safety evaluation of certain contaminants in food*. Prepared by the sixty-fourth meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). FAO Food and Nutrition Paper.

Uppal, J. S., Zheng, Q., & Le, X. C. (2019). Arsenic in drinking water—recent examples and updates from Southeast Asia. *Current Opinion in Environmental Science & Health*, *7*, 126–135. https://doi.org/10.1016/j.coesh.2019.01.004

US Food and Drug Administration (2016). *Arsenic in rice and rice products risk assessment report*. https://www.fda.gov/files/food/published/Arsenic-in-Rice-and-Rice-Products-Risk-Assessment-Report-PDF.pdf

US Food and Drug Administration (FDA) (2014). *Arsenic in rice and rice products*. http://www.fda.gov/food/foodborneillnesscontaminants/metals/ucm319870.htm

Watson, C., & Gustave, W. (2022). Prevalence of arsenic contamination in rice and the potential health risks to the Bahamian population—A preliminary study. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.1011785

World Health Organization International Agency for Research on Cancer (IARC) (2004). Some drinking-water disinfectants and contaminants, including arsenic. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, *84*, 1–19.

World Health Organization (WHO) (2019). *Drinking water*. https://www.who.int/news-room/fact-sheets/detail/drinking-water

World Health Organization (WHO) (2018). *Arsenic.* https://www.who.int/news-room/fact-sheets/detail/arsenic

WHO (2014). *Environmental health criteria, No. 224: Arsenic and arsenic compounds.* http://www.who.int/ipcs/publications/ehc/ehc_224/en/

Yim, S. R., Park, G. Y., Lee, K. W., Chung, M. S., & Shim, S. M. (2017). Determination of total arsenic content and arsenic speciation in different types of rice. *Food Science and Biotechnology/Food Science and Biotechnology*, *26*(1), 293–298. https://doi.org/10.1007/s10068-017-0039-9

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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

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Leafina: Potency of *Kakawate* leaves, fishbone meal and *saba* banana peel compost soil amendment to the water holding capacity of loam soil

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Abstract

In tropical regions like the Philippines, drought susceptibility is caused by high evaporation rates and poor soil water retention. To deal with this, soil amendments are crucial, enhancing soil properties to aid plant growth. In this study, LeaFiNa, a compost soil amendment composed of Kakawate leaves (KL), fishbone meal (FB), and Saba banana peels (BP) was introduced, aiming to boost soil water holding capacity (SWHC) of loam. Different LeaFiNa ratios were tested, including 3KL:1FB:2BP, 6KL:4FB:1BP, and 3KL:8FB:1BP, alongside vermicast and commercial soil amendment (neem cake) as positive controls, and plain loam soil as the negative control. Percolation method and pressure plate extraction was performed. One-way ANOVA showed a significant difference among the experimental treatments (α=0.05) in which 6KL:4FB:1BP ratio emerged with the highest SWHC of 49.60%. Meanwhile, Tukey's HSD test revealed no significant difference between 6KL:4FB:1BP and vermicast, yet a significant difference with the negative control. Moreover, the experimental treatments, particulalry the 6KL:4FB:1BP, also exhibited ideal results on other SWHC parameters such as the soil moisture content at saturation and wilting points, and in terms of gravitational water and plant available water. These findings suggest the LeaFiNa's potential in alleviating drought stress in tropical soils by enhancing water retention, offering promising outcomes for sustaining agricultural productivity in water-scarce regions.

Keywords: *soil water holding capacity, loam soil, compost soil amendment, Kakawate leaves, fishbone meal, Saba banana peels*

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1. Introduction

Areas with tropical temperatures are prone to drought stresses due to the loss of water evaporated into the atmosphere or through gravitational forces pulling the water below the soil surface (Atkinson, 2018; Stocker et al., 2023). In the Philippines, approximately 70% of its land area experiences severe cases of drought due to the incidence of extreme warm events such as El Niño (Delina et al., 2023). Globally, numerous regions also experience frequent and increased drought conditions whose cause is characterized by varying degrees of precipitation and immense water drainage. Plants receive adverse effects brought by the rapid change of climate due to weak water holding capacities of the soil (Li et al., 2021). The assessment of the levels of soil water holding capacity in soil may be a factor towards addressing drought concerns nationwide.

Soil water holding capacity (SWHC) is a key indicator of soil quality, representing the amount of water retained against gravitational forces (Olorunfemi et al., 2016). Soil properties, including SWHC, play a crucial role in regulating nutrient availability to plants, thus impacting agricultural productivity (Suleiman et al., 2017). It is particularly vital during drought conditions, where water scarcity can significantly impact crop yield (Fahad et al., 2017). Soil organic matter, considered a soil amendment, contributes to enhancing SWHC (Libohova et al., 2018). However, widespread use of chemical fertilizers in modern agriculture poses significant environmental and health hazards, affecting soil microbial activity, fertility, pH balance, pest control, and water contamination (Labajo & Pabiona, 2022; Wu, 2020). Despite their convenience, chemical fertilizers have detrimental effects on both human health and environmental pollution.

Thus, this study aimed to evaluate potency of a compost soil amendment made from Kakawate (*Gliricidia sepium*) leaves, fishbone meal, and Saba banana (*Musa paradisiaca*) peels compost to enhance the water holding capacity of loam soil. Each component of the soil amendment addresses specific nutrient requirements; Kakawate leaves balance carbon-nitrogen ratios, fishbones supplement phosphorus levels, and banana peels enrich potassium content. Moreover, these three are commonly found in households, making it accessible and easily utilized.

The research involved testing varying ratios of organic components using laboratory methods such as the 24-hour percolation and pressure plate extraction. Limitations included the availability and selection of specific organic materials rich in macronutrients and the pre-preparation of experimental setups for soil nutrient analysis. The study employed statistical tests, including one-way ANOVA and Tukey's HSD, to analyze water holding capacity.

The proposed soil amendment's efficiency was evaluated by varying NPK ratios, using readily available food and garden wastes as sustainable alternatives to chemical fertilizers. This approach aligns with RA 9003 and sustainable development goal number 11, promoting proper waste disposal and environmental practices. Additionally, the amendment meets the macronutrient requirements for soil quality and fertility, offering a cost-effective and resource-friendly option compared to commercial amendments. By increasing soil water holding capacity, the amendment aims to enhance plant growth, reduce crop loss in humid conditions, and mitigate adverse effects of water shortage, supporting goals outlined in the Harmonized National Research and Development Agenda for optimizing nutrient and water management and promoting innovative farming approaches resilient to changing climates.

2. Literature Review

2.1. Importance of soil water holding capacity

Water from the soil acts as a solvent and nutrient carrier for plants. It is one of the essential elements a plant requires to survive. This also dictates plant distribution, carbon allocation, the rate of photosynthesis, and cycles its nutrients (Cianfrani et al., 2019). Water content is an inherent trait of soil and is a concept used in many scientific and technological fields. A soil’s moisture plays a vital role as a hydrological attribute and helps in infiltration, evapotranspiration, and solute transport (Lee & Kim, 2019). The soil's water holding capacity (SWHC) provides perception into the maximum amount of water a soil can retain, it shows its capacity to supply water which is essential for plant growth support (Zhang et al., 2021). An organic matter increase is one of the ways you can increase soil water holding capacity, porosity also plays a role in improving SWHC (Pitch, 2020).

2.2. Loam soil

An average loam soil consists of approximately equal parts of soil solids, which comprise a combination of sand, silt, and clay, and pore spaces filled with water. The dimensions and arrangement of these pore spaces are influenced by the characteristics of mineral particles, including their size and shape, as well as the actions of microorganisms (Vittum, 2009). The utilization of loam soil in agricultural practices presents notable benefits stemming from its exceptional capacity to retain water and essential nutrients. These inherent attributes contribute to the establishment of a stable growth environment for plants, characterized by prolonged moisture retention and facilitated nutrient storage. Furthermore, the heightened surface area of loam soil particles amplifies nutrient absorption and retention, resulting in healthier and more productive crops (Haruna & Nkongolo, 2013).

2.3. Kakawate (Gliricidia sepium) leaves

In the Philippines, Kakawate, or Madre de Cacao, is widely cultivated due to its adaptability to various soil conditions (Villegas-Pangga & Cedillo, 2021). The Cavite agroforestry system has demonstrated the effectiveness of Kakawate leaves in soil improvement, alongside crops like coconut and coffee, reducing erosion and enhancing water retention (Parreño-de Guzman et al., 2015). Incorporating Kakawate into soil promotes faster water infiltration, decreases surface runoff, and enhances soil characteristics such as organic carbon content, microbial biomass, aggregation, water retention, and cation exchange capacity (Srinivasarao, 2011). Kakawate leaves decompose quickly, enriching the soil with nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium (Baloch et al., 2015). Applying Kakawate leaves at a rate of one ton per hectare can provide significant quantities of essential nutrients, making it a valuable component of organic fertilizers. Moreover, Kakawate enhances soil productivity and crop yield in rain fed agriculture (Villegas-Pangga & Cedillo, 2021).

2.4. Fishbone

Fishbone is rich in calcium and phosphorus, with roughly 2% of the total fish weight composed of these nutrients (Ramadhani et al., 2018). Studies have demonstrated that the presence of fishbone significantly enhances soil water availability, as increased phosphorus content in soil amendments correlates with improved soil porosity and water retention (Fu et al., 2023). In soil improvement studies, compost manure containing fishbone exhibited the highest water absorption capacity among various setups, indicating favorable results (Oni et al., 2022). Additionally, fishbone have been found to have the highest moisture content among non-edible food wastes, facilitating biomass degradation and nutrient release (Islam et al., 2023).

2.5. Saba banana (Musa paradisiaca) peels

Saba bananas, a significant global food crop, are rich in fiber, potassium, and various vitamins and antioxidants (Ohagan et al., 2023). When added to compost, banana peels enhance water retention and soil structure due to their rapid decomposition, releasing nutrients quickly (Zaini et al., 2020). Given their high potassium content, banana peels serve as a valuable source of potassium for agricultural purposes, contributing to efficient waste management practices (Islam, 2019). Studies evaluating bamboo biochar production revealed a correlation between potassium content and water holding capacity, underscoring potassium's role in soil water retention (Hien et al., 2021). Despite lower usage in NPK ratios, potassium remains vital for plant physiology, emphasizing its significance in soil nutrient balance (Leigh & Wyn Jones, 1984).

2.6. The percolation method in determining soil water holding capacity

Many attempts have been made to get quantitative measures of soil water holding capacity, however, due to the intricacy and nature of soil permeability, there have been minor issues in obtaining the data. Following a few observations, it is discovered that the idea of percolation is applicable, inexpensive and a functional basis for measuring soil water holding capacity (Govindasamy et al., 2022).

The process of percolation. Based on the traditional way of implementing the percolation method, the medicinal material powder is placed in a percolation tank. Next to that, the percolation extract is acquired, and the extraction solvent is constantly added simultaneously. In terms of soil water holding capacity, filter paper is placed in a funnel then the soil sample will be measured at 100g which will then settle in the funnel. The measured 100mL of water will be gradually added to the soil sample. After that, the funnel clamp will be released and the excess water will percolate onto the graduated cylinder, while the collected water will be recorded (Estefan et al., 2013). The difference between the added water and drained water will be calculated, and the resulting soil water holding capacity will be calculated using the equation:

$$SWHC = \frac{Volume\ of\ water\ retained\ by\ soil\ (V1 - V2)}{Weight\ of\ sample\ (W)} \times 100$$

SWHC - Soil water holding capacity

V1 - Initial volume of the water

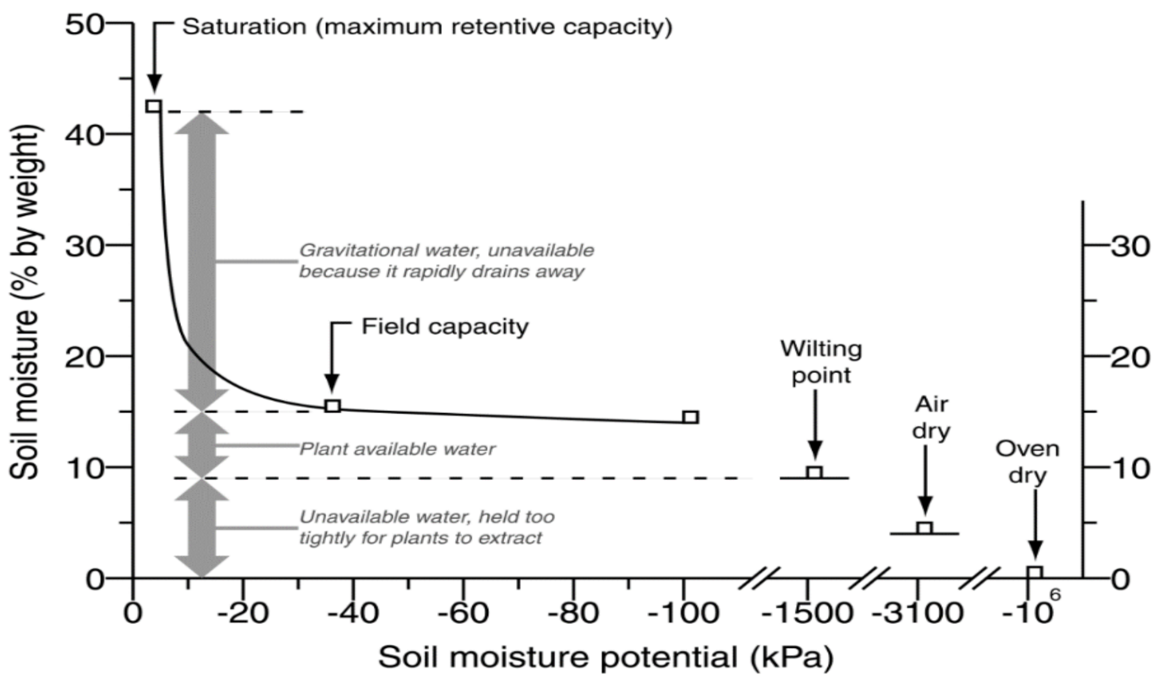
V2 - Volume of the water after the process of percolation

2.7. Phases of soil water holding capacity

Soil Water Holding Capacity (SWHC), as the capacity of the soil to retain moisture in soil macro and micropores, is correlated with pressure and gravity due to force acting on the soil. Several controlled laboratories research have used different methods, such as; Column Method (CM) where plastic columns are used to calculate the retained water, and Keen Raczkowski box Method (KM) where they used a box to saturate soil samples (Govindasamy et al., 2022). Although the results showed with studies who have used these kinds of methods were comparable for total population of soil, there is an occurrence of overestimation of water content. A prominent reason for this is that these methods do not apply any additional pressure when measuring soil’s water content. Application of pressure is essential in searching for the water content of soil types because soil has different phases according to the pressure applied (measured at kPa or Kilopascal) by gravitational force which are Saturation (SAT), Field Capacity (FC), and Wilting Point (WP). In most studies, SAT is determined to be the same as total porosity, so it is measured at 0 kPa. While Field Capacity and Wilting Point are measured at -33 kPa and -1500 kPa, respectively (Minasny & McBratney, 2017).

Figure 1

Soil moisture classes and important points on the soil moisture relationship curve



3. Methodology

3.1. Composting process for LeaFiNa components

Kakawate leaves, Saba banana peels, and fish bone meal were crushed into smaller fragments using tools like a blender and scissors to ensure consistency. During composting, each component was placed in its designated bins. The vertical composting method was employed, enclosing materials in bins with holes to oxygenate them and insulate temperature, preventing disruption from pests and odors. Varying amounts of soil were added to each bin to expedite decomposition and enhance microbial activity, maintaining a consistent ratio of 2 parts LeaFiNa to 8 parts soil. Foil was used to cover all setups for insulation.

3.2. Nutrient analysis of LeaFiNa components

Compost samples of Kakawate leaves, fishbone, and Saba banana peels underwent analysis at the Analytical Services Laboratory of the University of the Philippines, Los Baños Campus, within the Soil Physics Department. The Soil Test Kit method was employed, wherein solutions were introduced to small soil samples in test tubes for nitrogen, phosphorus, and potassium analysis. Upon reaction, which typically occurs within a few minutes, the resulting color indicates the relative acidity, salinity, or nutrient levels in the sample. Results showed that Kakawate leaves exhibited a nitrogen content of 0.20% per 1.0g of sample, while fish bone meal compost displayed a phosphorus content of 0.27% per 2.85g and Saba banana peels compost manifested a potassium content of 0.01% per 2.5g. These findings determined the suitable ratios to create LeaFiNa soil amendment across various compositions.

3.3. Preparation of experimental setups

Different proportions of LeaFiNa were determined based on the NPK content of organic components, coming up with the ratios such as 3KL:1FM:2BP, 6KL:4FM:1BP, and 3KL:8FM:1BP. Each component was carefully measured to maximize its presence in the experimental treatments, resulting in the following calculations as shown below. Significant amounts per ratio were made as these key components were used. Additionally, the soil amendments including the vermicast and neem cake were prepared in designated bins, blending them with soil at a ratio of 20 parts soil amendment to 80 parts soil.

Table 1

Weight of each nutrient per component of NPK

Sample	Mass of nitrogen per 1.0 g	Mass of phosphorus per 2.85 g	Mass of potassium per 2.5 g
Kakawate leaves	0.002g	-	-
Fishbone meal	-	0.007695g	-
Saba banana peels	-	-	0.00025g

The formula used to calculate the total weight of each component in their respective ratios:

$$Total\ Weight\ of\ Component\ (g) = \frac{(weight\ of\ soil\ sample)\ \ (weight\ of\ nutrient\ component\ in\ ratio)}{total\ weight\ of\ nutrient}$$

Therefore, the following calculations were utilized to come up with the LeaFina ratios. For the 6KL:4L:FB:1BP, 30g of Kakawate leaves was used for 0.06g of nitrogen, 14.814g of fishbone meal for 0.04g of phosphorus, and 100g of Saba banana peels for 0.01g of potassium; for the 3KL:8:FB:1BP, 15g of Kakawate leaves for 0.03g of nitrogen, 29.629g of fishbone mean for 0.08g of phosphorus, and 100g of Saba banana peels for 0.01g of potassium; and for 3KL:1FB:2BP, 15g of Kakawate leaves for 0.03g of nitrogen, 3.703g for 0.01g of phosphorus, and 200g of Saba banana peels for 0.02g of potassium.

3.4. Testing procedure

Various soil water retention parameters were measured through percolation method and pressure plate extraction to determine the saturation point, field capacity, wilting point, gravitational water, plant available water, and unavailable water.

Preparation of setups. The experiment consisted of two groups: the experimental group, comprising three LeaFiNa ratios, and the control group, including vermicast and commercial soil amendment as positive controls, and pure loam soil as the negative control. A total of 30 setups were prepared for soil water holding capacity testing using the percolation method, with 5 replicates and 1 trial. Each setup contained 50g of the mixture in a small container poured into percolation tubes. The completely randomized design ensured equal treatment probability across the 5 replicates of each treatment.

Percolation method. The cheesecloth was attached to one end of the percolation tube as a filter. The setup was arranged on a stand, with each tube labeled accordingly. Then, the soil-fertilizer mixtures were poured into the tubes, followed by the simultaneous addition of 50mL of water into each tube, with beakers placed beneath to catch any excess water. Foil was utilized to cover the top of the tubes and beakers to prevent evaporation. After 24 hours, the amount of water retained by each setup was measured to calculate its soil water holding capacity using the prescribed formula;

$$SWHC = \frac{Volume\ of\ water\ retained\ by\ soil\ (V1 - V2)}{Weight\ of\ sample\ (W)} \times 100$$

SWHC - Soil water holding capacity

V1 - Initial volume of the water

V2 - Volume of the water after the process of percolation

Phases of soil water holding capacity. Soil samples were put inside the crucibles with different variables: LeaFiNa ratios, vermicast, commercialized soil amendment, and loam soil only, filling it up to three-fourths of their capacity, packed and compressed properly. Subsequently, tap water was added to a depth of approximately 3 cm, and the setups were left undisturbed for 24 hours. The weight of the crucible plus the soil sample was recorded as the moisture retained at saturation, equating to 0-bar pressure. Using a pressure plate extractor, moisture retention was measured at field capacity (⅓ bar) and wilting point (15 bar). After drying the samples in an oven at 105°C for 24 hours, the difference in moisture retention at different pressures was calculated to determine the gravitational water, plant available water (PAW), and unavailable water, using the following formulas.

$$Soil\ moisture\ content\ (\%) = \frac{weight\ of\ wet\ soil\ (g)\ -\ weight\ of\ dry\ soil\ (g)}{weight\ of\ dry\ soil\ (g)}\ x100$$

$$Gravitational\ Water\ (\%)\ =\ Saturation\ (\%)\ -\ Field\ Capacity\ (\%)$$

$$Plant\ Available\ Water\ (\%)\ =\ Field\ Capacity\ (\%)\ -\ Wilting\ Point\ (\%)$$

$$Unavailable\ Water\ (\%)\ =\ Wilting\ Point\ (\%)$$

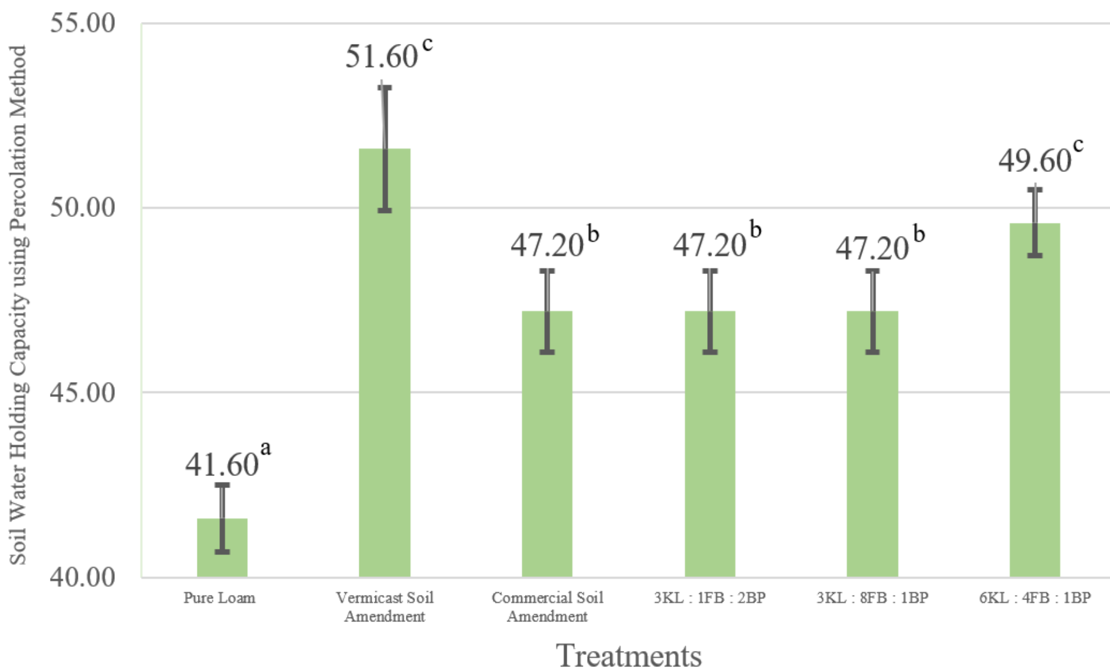
4. Findings and Discussion

Figure 2 shows the mean soil water holding capacity in terms of the water retained and lost by each treatment in the percolation method. Results showing a lower amount of water loss and a higher amount of water retained indicate a higher percentage of SWHC. This reveals that the treatment of 6KL:4FB:1BP acclaimed the highest mean percentage of SWHC among all experimental set-ups (49.6%).

Soil water retention relies on various factors such as pore structure, size distribution, shape, and continuity to mention some (Møldrup et al., 2013). Among these factors, the organic matter content plays a significant role in determining the quality of pore structure. This aspect is influenced not only by soil texture, determined by the proportions of clay, sand, and silt particles, but also by the ratio of organic matter containing essential nutrients (Munkholm et al., 2012). These nutrients contribute to sustaining healthier pores in the soil, thereby impacting its water retention capabilities. In all experimental setups, pure organic matter was used. However, from the references cited, it can be deduced that the ratio of 6KL:4FB:1BP in NPK content contained sufficient organic matter to influence the pore structure of the soil. The pore size of soil is a crucial factor affecting its water-holding capacity. Sandy soils, which are characterized by larger pores, typically exhibit low water retention capabilities. Conversely, vermicast-amended soil, along with the proposed soil amendment using the 6KL:4FB:1BP ratio, contains smaller pores, which enhance its water retention ability it creates a larger surface area for water adhesion (Josa et al., 2013).

Figure 2

Mean soil water holding capacity of different soil amendments using percolation method



Tukey's HSD determined that treatments 3KL:1FB:2BP, commercial soil amendment, and 3KL:8FB:1BP, exhibit no significant difference from each other. Meanwhile, experimental setup 6KL:4FB:1BP and the vermicast soil amendments also show no significant difference between each other. However, compared to all other set-ups, experimental setup 6KL:4FB:1BP and the vermicast soil amendment demonstrate significant difference when compared to the negative control, which is the pure loam. This highlights that experimental setup 6KL:4FB:1BP and the vermicast soil amendment possess the highest soil water holding capacity among all set-ups. Furthermore, statistical results exhibited an F-value of 42.18 with a p-value of 0.000, which is less than 5% level of significance, indicating significant differences among each other. Thus, 6KL:4FB:1BP emerges as the experimental setup with the highest soil water holding capacity.

Figure 3

Mean soil moisture content during saturation phase of different soil amendments

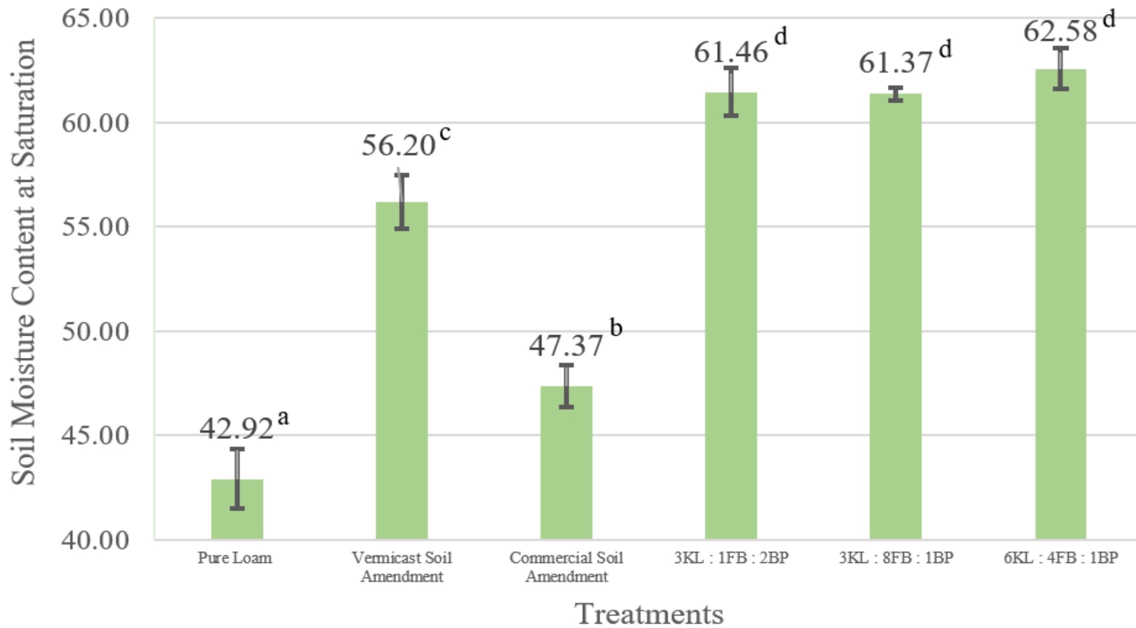
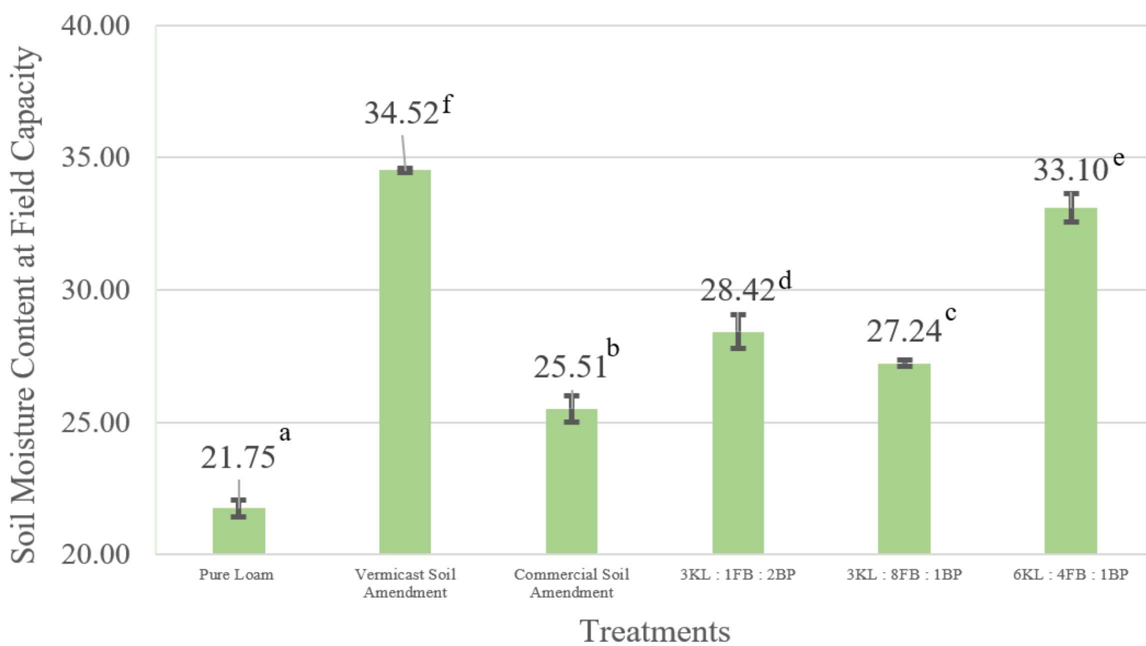


Figure 3 presents the soil content during the saturation phase of soil water holding capacity wherein 0-bar of pressure was exerted to treatments. The results indicate that the three experimental setups (6KL:4FB:1BP, 3KL:1FB:2BP, and 3KL:8FB:1BP) exhibited the highest moisture content, followed by the vermicast soil amendment, commercial soil amendment, and plain loam soil, in descending order. Statistical analysis revealed a significant difference between the groups, with an F-value of 295.572 and a p-value of 0.000, which is below the significant level of 5%. Post-hoc analysis using Tukey's HSD test indicated that the three experimental groups showed comparable effectiveness, as they belong to the same subgroup. Conversely, plain loam soil, vermicast soil amendment, and commercial soil amendment were categorized into three distinct subgroups, respectively.

These findings conclude the role of soil moisture dynamics during the saturation phase of water holding capacity. Soil water retention varies depending on the texture and structure of the soil. Following rainfall or irrigation, when the soil becomes saturated, there is a consistent and swift downward flow of water, known as drainage, caused by gravitational force (Zotarelli et al., 2019). Figure 3 illustrates that during the saturation phase, where soil moisture decreases rapidly and continuously, the experimental group demonstrated notable values of soil water retention. The observed variations in water content among setups highlight the effectiveness of compost pure organic matter in the saturation phase. Consistent with the findings of Minasny and McBratney (2018), the presence of organic matter significantly influences soil saturation dynamics, affecting water storage and redistribution mechanisms. These insights underscore the relevance of incorporating organic amendments into soil management strategies to optimize water retention and distribution for sustainable agricultural practices.

Figure 4

Mean soil moisture content at field capacity of different soil amendments



In figure 4, the analysis of the means of water content retained at a pressure of ⅓ bar using the plate extractor revealed significant results. Specifically, among the experimental setups, the 6KL:4FB:1BP exhibited the highest values, indicating higher water retention abilities during the field capacity phase of soil water holding capacity, same with the positive control vermicast. This was followed by the 3KL:1FB:2BP, 3KL:8FB:1BP, commercial soil amendment, and plain loam soil, in descending order.

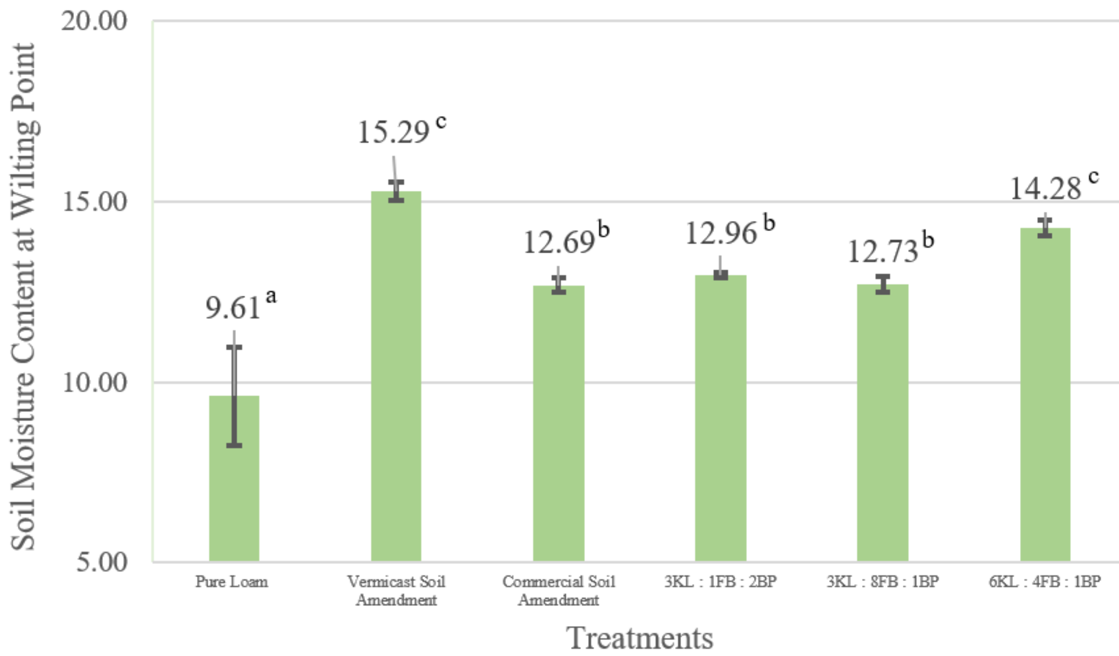
The indicated increase in field capacity in specific setups indicates their capacity to retain more water during the water absorption process, potentially leading to improved plant growth and yield. Following rapid drainage during the saturation phase, field capacity defines the maximum water retention capability of soil (Gardiner & Miller, 1998). The ideal water content for plant growth is maintained through the drainage of water from larger pores, while smaller pores retain the necessary amount of water. This process occurs because smaller pores tend to retain water after larger pores, known as macropores, have drained due to gravitational forces (Elkheir et al., 2016). Consequently, experimental setup 6KL:4FB:1BP yielded the highest soil moisture retention rate among experimental set-ups together with the positive control vermicast soil amendment demonstrating a better capacity for water retention, potentially ensuring plants with a more consistent and sustained water supply. It can be deduced that during the field capacity phase of these soil samples, their smaller soil pores, which possess the ability to withstand gravitational forces, effectively retain water through capillary action (Elkheir et al., 2016).

Additionally, the results of the Tukey's HSD test unveiled clear distinctions among all experimental setups, as each mean was assigned to distinct subgroups for this phase of soil water holding capacity. This underscores the considerable variability in water retention capabilities among the various soil treatments. Moreover, statistical results showed a F-value of 643.66 alongside a p-value of 0.000, which falls below the 5% level of significance. This indicates statistically significant differences among the experimental set-ups, further emphasizing the substantial variations in their water retention capacities.

Figure 5 presents the mean outcomes of samples subjected to a pressure of 15 bar using the pressure plate extractor. Higher values indicate greater water retention after the application of pressure. Among the experimental setups, the 6KL:4FB:1BP ratio demonstrated higher water retention abilities as well as positive control vermicast soil amendment compared to other set-ups. The statistical results yielded an F-value of 53.28 with a p-value of 0.000, which falls below the 5% significance level. This indicates significant differences among the set-ups in terms of their water retention capabilities during the phase.

Figure 5

Mean soil moisture content at wilting point of different soil amendments



The permanent wilting point marks a crucial stage in plant growth, indicating the point at which no water is accessible to the plant. Even though some water may still be present in the soil, it becomes unreachable for root absorption. At this critical juncture, plants struggle to extract water quickly enough to fulfill their water needs. Thus, higher levels of retained water at this phase signify greater soil moisture retained even at the last phase of water holding capacity (Zotarelli et al., 2019). In line with that, the 6KL:4FB:1BP ratio still demonstrated higher water retention abilities among experimental set-ups. Even though plants reach the wilting point stage, where they begin to wilt and may not recover their turgor, it can be deduced that among the different set-ups, the 6KL:4FB:1BP ratio and vermicast soil amendment retains the most significant amount of water in the soil at this stage. However, this water is typically unavailable for plants as the wilting point represents the culmination of water holding capacity. In general, water is retained in the soil's micropores at this stage, held with a tension that exceeds the plant's capacity to extract the water, making the wilting point equivalent to unavailable water (Schoonover & Crim, 2015).

The findings from Tukey's HSD test revealed distinct groupings among the experimental setups. Specifically, plain loam soil exhibited the lowest mean and stood alone in its subgroup. The commercial soil amendment, along with set-ups 3KL:1FB:2BP and 3KL:8FB:1BP, formed another subgroup with their means being second to the highest. Meanwhile, set-ups 6KL:4FB:1BP and vermicast soil amendment were grouped together in a separate subgroup, both having the highest means among all set-ups. This indicates that they possess comparable efficacy and demonstrate the most notable distinction from the negative control, in a positive way.

Figure 6

Means of gravitational water of soil amendments

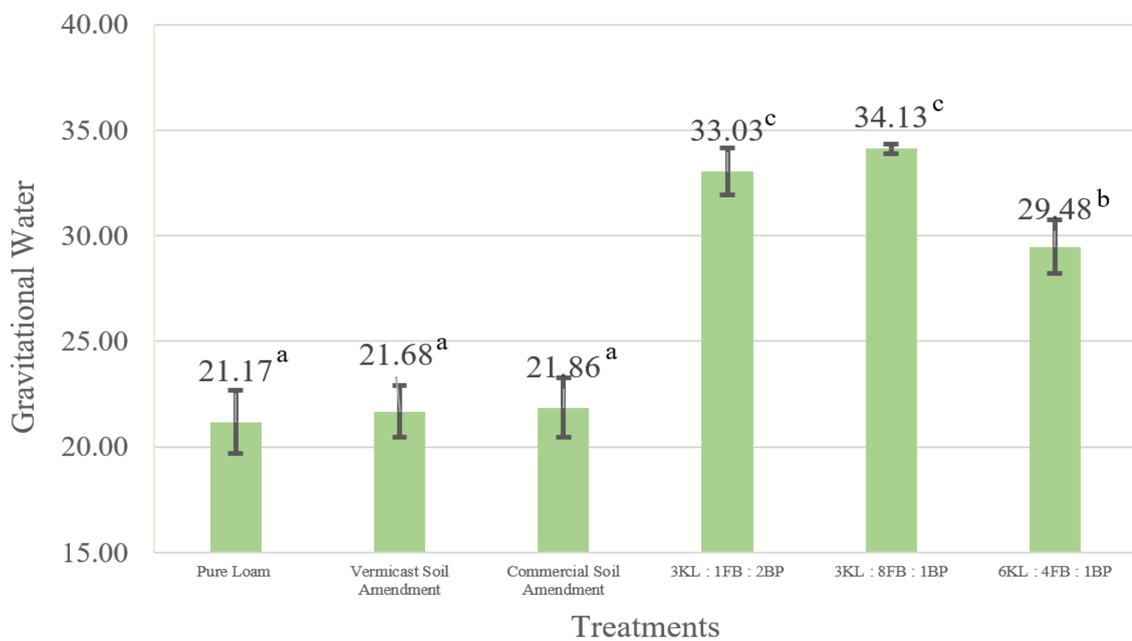


Figure 6 presents the gravitational water content of the soil samples, showcasing the water absorbed by macropores. Among all setups, experimental set-ups 3KL:1FB:2BP and 3KL:8FB:1BP exhibited the highest results, followed by setup 6KL:4FB:1BP. Conversely, plain loam soil, vermicast soil amendment, and commercial soil amendment showed minimal differences, with distinctions mainly observed in decimal points. Tukey's HSD test indicated that plain loam soil, vermicast soil amendment, and commercial soil amendment belong to the same subgroup, showing statistically similar results. In contrast, setup 6KL:4FB:1BP is isolated in a subgroup with higher values compared to the aforementioned, while both setups 3KL:1FB:2BP and 3KL:8FB:1BP are grouped together in a separate subgroup. Furthermore, the one-way ANOVA test revealed a significant difference between groups, with an F-value of 126.66 and a p-value of 0.000, falling below the predetermined significance level of 5%.

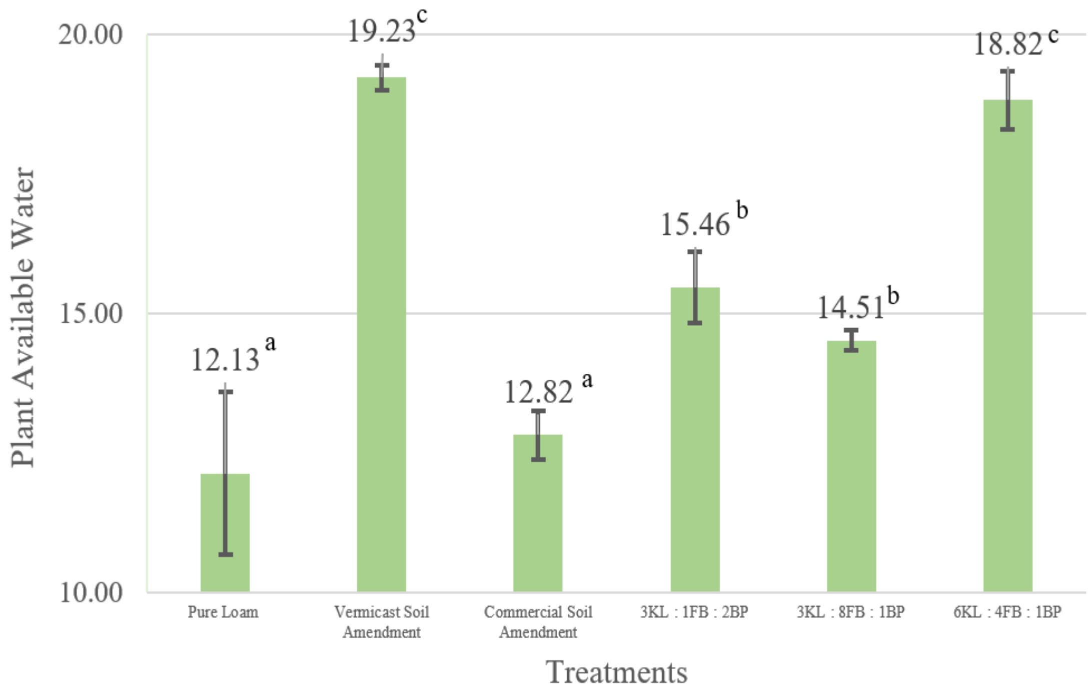
When soil demonstrates a high capacity to retain gravitational water, it signifies its ability to preserve moisture even after excess water has drained away. This attribute holds significant importance for plant growth, as it guarantees a steady and sufficient water supply to plant roots, particularly during drought periods or intervals between watering (Schoonover & Crim, 2015). The experimental setups with ratios of 3KL:1FB:2BP and 3KL:8FB:1BP, which yielded the most favorable outcomes, exhibit increased gravitational water content in soil water holding capacity (SWHC). This is advantageous for soils, as it enhances moisture retention and availability for plant roots, thereby promoting healthier plant growth (Gavrilescu, 2021). The amount of gravitational water is determined by subtracting the water content at saturation from the water held at field capacity. From the observation that experimental set-ups 3KL:1FB:2BP and 3KL:8FB:1BP showed higher averages at saturation but lower averages at field capacity, it can be deduced that their gravitational water content was higher compared to that of 6KL:4FB:1BP, as the latter yielded higher results at field capacity.

Some soils, particularly those rich in sand, may exhibit a phenomenon of having higher gravitational water but lower field capacity. This is due to the larger pore spaces between sand particles, which facilitate rapid drainage of water under the influence of gravity. Consequently, while these soils may have ample gravitational water—allowing water to move freely downwards—their ability to retain water against gravity (known as field capacity) might be compromised as the water drains away quickly, leaving the soil relatively dry. This situation commonly arises in soils characterized by poor compaction and structure (Gavrilescu, 2021). Based on this understanding, it can be inferred why set-ups 3KL:1FB:2BP and 3KL:8FB:1BP exhibited higher average water content levels at saturation but lower averages at field capacity.

Figure 7 illustrates the average soil water moisture content that is readily accessible for plant uptake, also known as Plant Available Water (PAW). It presents the disparity between soil water content at Field Capacity and Permanent Wilting Point. The findings indicate that the 6KL:4FB:1BP treatment exhibited the highest mean percentage of PAW among all experimental set-ups, reaching 18.82%.

Figure 7

Means of plant available water of different soil amendments



Commonly known as Readily Available Water (RAW), Total Available Water (TAW), or Plant Available Water (PAW), this stage denotes the point where water is exclusively accessible for plant utilization. This phase bears great significance in comprehending water holding capacity, as the water retained in micropores predominantly determines the accessibility of water for plants within the soil (Wu et al., 2018). Hence, results in figure 7 showed that the 6KL:4FB:1BP treatment demonstrated the highest average percentage of PAW, similar to the positive control vermicast, indicating its efficacy in providing sufficient water for essential metabolic processes in plants. These processes include photosynthesis, transpiration, and nutrient transport, all of which are crucial for plant health and growth. PAW directly affects plant hydration, nutrient absorption, and overall well-being. Inadequate PAW levels can result in water stress, wilting, diminished growth, and potentially plant demise (Ahluwalia et al., 2021).

The one-way ANOVA test revealed a significant difference between groups, with an F-value of 86.971 and a p-value of 0.000, which is below the predetermined significance level of 5%. Furthermore, Tukey's HSD test indicated that the commercial soil amendment and plain loam soil fall within the same subgroup, while set-ups 3KL: 1FB: 2BP and 3KL: 8FB: 1BP are grouped together in another subgroup. Interestingly, both the vermicast soil amendment and the 6KL: 4FB: 1BP setup demonstrated statistically similar results by being categorized within the same subgroup.

Upon comparing the experimental set-ups, they differ among their nitrogen content, with 6KL:4FB:1BP having the highest quantity of N. This factor may pertain to a conclusion from a similar study showing a systematic increase of yield quality for wheat with the increase of nitrogen treatment during cold-arid seasons (Wang et al., 2015). In metabolic processes, vegetative and reproductive growth and yield significantly increase upon the adequate supply of nitrogen (Chaves et al., 2014). The nitrogen content of soil is found to aid in the rate of saturation as it primarily spreads within water-filled pores, a factor influenced by the level of porosity. This is an indication of a higher water retention in soils (Indoria et al., 2017). Thus, the higher content of N in a treatment has a direct relationship on SWHC.

However, excessive nitrogen application could lead to soil acidification as well as worsen the soil environment which ultimately has a negative impact on crop growth and yield (Sun et al., 2016). According to a study by Sun et al. (2020), the optimal N application rates were based on optimal P and K application rates. Therefore, building the right equilibrium for phosphorus (P) and potassium (K) application rates in plant production, will encompass greater impacts to soil properties, leaf physiology, and crop yield in plants across different N application rates, guided by the optimal P and K application rates. (Giacometti et al., 2013). Among the three NPK application rates from a study by (Gul et al., 2015), a ratio with 75:50:30 showed the most optimal performance in terms of crop growth, yield, and yield attributes. Similar to this treatment, the ratio 6:4:1 utilizes decreasing levels within each individual NPK content.

5. Conclusion

This study concludes that treatments 6KL:4FB:1BP and the vermicast soil amendment exhibited the highest SWHC and comparable results in terms of the percolation method after 24 hours. This indicates that within the experimental set-ups, treatment 6KL:4FB:1BP shows the most favorable result. Among the six setups of soil amendments, the application of treatment 6KL:4FB:1BP yielded the highest water content in the assessment of saturation at 0 bar using the percolation process after 14 days. In addition, this was attained equally significant by 3KL:1FB:2BP and 3KL:8FB:1BP. Therefore, the amount of water at the saturation stage is the highest for these treatments. As for PAW, treatments 6KL:4FB:1B and vermicast soil amendment yielded the highest amount of water accessible for plant use, thereby exhibiting also statistically similar results.

LeaFina, particularly the treatment 6KL:4FB:1B, can be a potential candidate as a soil amendment to enhance soil water holding capacity. It serves as an efficient alternative for chemical and costly soil amendments that cause multiple environmental risk factors such as soil degradation and soil biodiversity destruction (Palansooriya et al., 2020). Along with health risks posed by synthetic fertilizers like a nitrogenous based fertilizer which when consumed in crops in excess, can cause various conditions like diabetes, and neural tube defects (Ahmed et al., 2017). This study sets the foundation for the evaluation into alternative materials for fertilizer manufacturing, with the goal of alleviating the harmful impacts linked to chemical fertilizers on human health and the environment.

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References

Ahluwalia, O., Singh, P., & Bhatia, R. (2021). A review on drought stress in plants: Implications, mitigation and the role of plant growth promoting rhizobacteria.

Resources, Environment and Sustainability, *5*, 100032. https://doi.org/10.1016/j.resenv.2021.100032

Atkinson, C. (2018). How good is the evidence that soil-applied biochar improves water-holding capacity? *Soil Use and Management, 34*(2), 177–186. https://doi.org/10.1111/sum.12413

Baloch, P. A., Abro, B. A., Chandio, A. S., Depar, N., & Ansari, M. A. (2015). Growth and yield response of maize to integrated use of *Gliricidia sepium*, farm manure and NPK fertilizers. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences, 31*(1), 14–23. https://pjaaevs.sau.edu.pk/index.php/ojs/article/view/129

Chaves, L. H. G., Guerra, H. O. C., Campos, V. B., Pereira, W. E., & Ribeiro, P. H. P. (2014). Biometry and water consumption of sunflower as affected by NPK fertilizer and available soil water content under Semiarid Brazilian conditions. *Agricultural Sciences*, *05*(08), 668–676. https://doi.org/10.4236/as.2014.58070

Cianfrani, C., Buri, A., Vittoz, P., Grand, S., Zingg, B., Verrecchia, É. P., & Guisan, A. (2019). Spatial modelling of soil water holding capacity improves models of plant distributions in mountain landscapes. *Plant and Soil*, *438*(1–2), 57–70. https://doi.org/10.1007/s11104-019-04016-x

Delina, L. L., Ludovice, N. P. P., Gaviola, J., & Cagoco-Guiam, R. (2023). Living with climate and state fragility in a “chaotic paradise:” securitizing livelihoods in the Philippines’ Cotabato River Basin. *Climate Risk Management*, *42*, 100558. https://doi.org/10.1016/j.crm.2023.100558

Elkheir, H. A., Yunus, M., & Muslimin, M. (2016). Duration of soil water content between field capacity and wilting point and its effect on growth of some aerobic rice cultivars (*Oryza sativa L.). International Journal of Agriculture System*, *4*(1), 36-45.

Estefan, G., Sommer, R. and Ryan, J. (2013). *Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region, Third Edition*. International Center for Agricultural Research in the Dry Areas (ICARDA).

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Saud, S., Ihsan, M. Z., Alharby, H., Wu, C., Wang, D., & Huang, J. (2017). Crop production under drought and heat stress: Plant responses and management options. *Frontiers in Plant Science, Plant Abiotic Stress*. https://doi.org/10.3389/fpls.2017.01147

Fu, H., An, S., Liu, L., Li, M., Wang, Y., & Yang, L. (2023). Simultaneous enhancement of soil properties along with water-holding and restriction of Pb–Cd mobility in a soil-plant system by the addition of a phosphorus-modified biochar to the soil. *Journal of Environmental Management*, *345*, 118827. https://doi.org/10.1016/j.jenvman.2023.118827

Gavrilescu, M. (2021). Water, soil, and plants interactions in a threatened environment. *Water*, 13(19), 2746.

Giacometti, C., Demyan, M. S., Cavani, L., Marzadori, C., Ciavatta, C., & Kandeler, E. (2013). Chemical and microbiological soil quality indicators and their potential to differentiate fertilization regimes in temperate agroecosystems. *Applied Soil Ecology*, *64*, 32–48. https://doi.org/10.1016/j.apsoil.2012.10.002

Govindasamy, P., Mahawer, S. K., Mowrer, J., Bagavathiannan, M., Prasad, M., Ramakrishnan, S., Halli, H. M., Kumar, S., & Chandra, A. (2022). Comparison of low-cost methods for soil water holding capacity. *Communications in Soil Science and Plant Analysis*, *54*(2), 287–296. https://doi.org/10.1080/00103624.2022.2112216

Haruna, S. I., & Nkongolo, N. V. (2013). Variability of soil physical properties in a clay-loam soil and its implication on soil management practices. *ISRN Soil Science (Online)*, *2013*, 1–8. https://doi.org/10.1155/2013/418586

Hiền, T. T. T., Tsubota, T., Taniguchi, T., & Shinogi, Y. (2020). Enhancing soil water holding capacity and provision of a potassium source via optimization of the pyrolysis of bamboo biochar. *Biochar (Online)*, *3*(1), 51–61. https://doi.org/10.1007/s42773-020-00071-1

Indoria, A., Sharma, K. L., & Reddy, K. S. (2020). Hydraulic properties of soil under warming climate. In *Elsevier eBooks* (pp. 473–508). https://doi.org/10.1016/b978-0-12-818032-7.00018-7

Islam, M., Halder, M., Siddique, M. A., Razir, S. A. A., Sikder, S., & Joardar, J. C. (2019). Banana peel biochar as an alternative source of potassium for plant productivity and sustainable agriculture. *International Journal of Recycling of Organic Waste in Agriculture, 8*, 407-413.

Islam, M. R., Wang, Q., Guo, Y., Wang, W., Sharmin, S., & Ebere Enyoh, C. (2023). Physico-Chemical characterization of food wastes for potential soil application. *Processes, 11*(1), 250.

Josa, R., Gorchs, G., Gisbert, M. G., & Solé-Benet, A. (2013). Influence of tillage on soil macropore size, shape of top layer and crop development in a sub-humid environment. *Biologia, 68(*6), 1099–1103. https://doi.org/10.2478/s11756-013-0250-y

Labajo, J. R. N., & Pabiona, M. G. (2022). Physical and chemical properties of soil on selected sugarcane farms in Mt. Nebo, Valencia City, Bukidnon, Philippines. *Asian Journal of Agriculture, 6*(2). https://doi.org/10.13057/asianjagric/g060204

Lee, E., & Kim, S. (2019). Seasonal and spatial characterization of soil moisture and soil water tension in a steep hillslope. *Journal of Hydrology*, *568*, 676–685. https://doi.org/10.1016/j.jhydrol.2018.11.027

Leigh, R. A., & Jones, R. G. W. (1984). A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell. *New Phytologist (Print)*, *97*(1), 1–13. https://doi.org/10.1111/j.1469-8137.1984.tb04103.x

Li, L., Zhang, Y.-J., Novak, A., Yang, Y., & Wang, J. (2021). Role of biochar in improving sandy soil water retention and resilience to drought. *Water*, *13*(4), 407. https://doi.org/10.3390/w13040407

Libohova, Z., Seybold, C., Wysocki, D., Wills, S., Schoeneberger, P., Williams, C., Lindbo, D., Stott, D., & Owens, P. R. (2018). Reevaluating the effects of soil organic matter and other properties on available water-holding capacity using the National Cooperative Soil Survey Characterization Database. *Journal of Soil and Water Conservation, 73*(4), 411–421. https://doi.org/10.2489/jswc.73.4.411

Liu, C., Wang, H., Tang, X., Guan, Z., Reid, B. J., Rajapaksha, A. U., Ok, Y. S., & Sun, H. (2015). Biochar increased water holding capacity but accelerated organic carbon leaching from a sloping farmland soil in China. *Environmental Science and Pollution Research, 23*(2), 995–1006. https://doi.org/10.1007/s11356-015-4885-9

Miller, R.W. & Gardiner, D.T. (1998). *Soils in our environment.* Prentice Hall. 8th edition. ISBN 0136108822.

Minasny, B., & McBratney, A. B. (2017). Limited effect of organic matter on soil available water capacity. *European Journal of Soil Science, 69*(1), 39–47. https://doi.org/10.1111/ejss.12475

Munkholm, L. J., Heck, R. J., & Deen, B. (2012). Soil pore characteristics assessed from X-ray micro-CT derived images and correlations to soil friability. *Geoderma (Amsterdam), 181–182*, 22–29. https://doi.org/10.1016/j.geoderma.2012.02.024

Møldrup, P., Deepagoda, T. C., Hamamoto, S., Komatsu, T., Kawamoto, K., Rolston, D. E., & De Jonge, L. W. (2013). Structure-dependent water-induced linear reduction model for predicting gas diffusivity and tortuosity in repacked and intact soil. *Vadose Zone Journal*, *12*(3), 1–11. https://doi.org/10.2136/vzj2013.01.0026

Ohagan, J., Harnaiz, L. L., Nagal, C. J., Taylaran, R., & Gonzaga, A., Jr. (2023). Productivity of 'Saba' banana (*Musa acuminata x balbisiana*) as influenced by different levels of NPK fertilizer under Jasaan Soil Series. *In Mindanao Journal of Science and Technology*, *21*(1). https://mjst.ustp.edu.ph/index.php/mjst/article/view/1516

Olorunfemi, I., Fasinmirin, J., & Ojo, A. (2016). Modeling cation exchange capacity and soil water holding capacity from basic soil properties. *Eurasian Journal of Soil Science, 5*(4), 266. https://doi.org/10.18393/ejss.2016.4.266-274\

Oni, T. O., Edward, D. C., Iloh, O. V., & Dokubo, C. (2022). determination of microbial and physicochemical properties of compost manure made from plant and animal materials in Ogwashi-Uku. *IPS Interdisciplinary Journal of Biological Sciences*, *1*(2), 22–24. https://doi.org/10.54117/iijbs.v1i2.6

Palansooriya, K. N., Shaheen, S. M., Chen, S. S., Tsang, D. C., Hashimoto, Y., Hou, D., Bolan, N., Rinklebe, J., & Ok, Y. S. (2020). Soil amendments for immobilization of potentially toxic elements in contaminated soils: A critical review. *Environment International*, *134*, 105046. https://doi.org/10.1016/j.envint.2019.105046

Parreño-de Guzman, L. E., Zamora, O. B., & Bernardo, D. F. H. (2015). Diversified and integrated farming systems (DIFS): Philippine experiences for improved livelihood and nutrition. *Journal of Developments in Sustainable Agriculture*, *10*(1), 19-33.

Pitch, B. N. P. (2020). *Adding biochar to the composting process: effect of the resulting amendment in agricultural soils*. http://hdl.handle.net/2445/179114

Ramadhani, S. F., Iswanto, B., & Purwaningrum, P. (2018). Waste utilization of red snapper (Lutjanus sp.) fish bone to improve phosphorus contents in compost. *IOP Conference Series*, *106*, 012091. https://doi.org/10.1088/1755-1315/106/1/012091

Schoonover, J. E., & Crim, J. F. (2015). An introduction to soil concepts and the role of soils in watershed management. *Journal of Contemporary Water Research & Education*, *154*(1), 21–47. https://doi.org/10.1111/j.1936-704x.2015.03186.x

Srinivasa Rao, Ch., Venkateswarlu, B., Dinesh Babu, M., Wani, S.P, Dixit, S, Sahrawat, K.L. and Sumanta Kundu (2011). *Soil health improvement with Gliricidia green leaf manuring in rainfed agriculture, on farm experiences*. Central Research Institute for Dryland Agriculture.

Stocker, B.D., Tumber-Dávila, S.J., Konings, A.G. et al. Global patterns of water storage in the rooting zones of vegetation. *Nat. Geosci. 16*, 250–256 (2023). https://doi.org/10.1038/s41561-023-01125-2

Suleiman, R., Jimoh, I.A., & Aliyu, J. (2017). Assessment of soil physical and chemical properties under vegetable cultivation in Abuja Metropolitan Area, Nigeria. *Zaria Geogr.*, *24* (1), 89-99.

Sun, J., Li, W., Li, C., Chang, W., Zhang, S., Zeng, Y., Zeng, C., & Peng, M. (2020). Effect of different rates of nitrogen fertilization on crop yield, soil properties and leaf physiological attributes in banana under subtropical regions of China. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.613760

Villegas-Pangga, G., & Cedillo, N. O. (2021). Fertilizer value of compost and densified fertilizers made from swine and poultry manures on crops and chemical properties of clay soil. *Journal Article*. 938. https://www.ukdr.uplb.edu.ph/journal-articles/938

Vittum, P. J. (2009). Soil Habitats. *In Encyclopedia of Insects* (2nd ed., pp. 935–939). https://doi.org/10.1016/b978-0-12-374144-8.00247-2

Wang, T., Liu, Y., Han, Y., & Xu, L. (2015). An experimental study on the mechanical properties of silty soils under repeated freeze–thaw cycles. *Cold Regions Science and Technology*, *112*, 51–65. https://doi.org/10.1016/j.coldregions.2015.01.004

Wu, L., Jiang, Y., Zhao, F., He, X., Liu, H., & Yu, K. (2020). Increased organic fertilizer application and reduced chemical fertilizer application affect the soil properties and bacterial communities of grape rhizosphere soil. *Scientific Reports*, *10*(1), 9568. https://doi.org/10.1038/s41598-020-66648-9

Zaini, H. B. M., Sintang, M. D. B., & Pindi, W. (2020). The roles of banana peel powders to alter technological functionality, sensory and nutritional quality of chicken sausage. *Food Science and Nutrition, 8*(10), 5497–5507. https://doi.org/10.1002/fsn3.1847

Zhang, Y., Wang, K., Wang, J., Liu, C., & Shangguan, Z. (2021). Changes in soil water holding capacity and water availability following vegetation restoration on the Chinese Loess Plateau. *Scientific Reports (Nature Publishing Group)*, *11*(1). https://doi.org/10.1038/s41598-021-88914-0

Zotarelli, L., Dukes, M. D., & Morgan, K. T. (2010). Interpretation of soil moisture content to determine soil field capacity and avoid over-irrigating sandy soils using soil moisture sensors. *EDIS*, *2010*(2). https://doi.org/10.32473/edis-ae460-2010