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Preparation and Characterization of Slow-Release Zinc and Iron Fertilizer Encapsulated by Palm Stearin

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ABSTRACT

Using granular form application in the pisciponic system, this study investigates the effects of supplementation in the pisciponic system on plant growth performance. This study was conducted at the Aquaculture Experimental Station in Puchong, Selangor. The experiment was set up in a greenhouse with a plastic liner at the bottom. The coated fertilizers were immersed in 500 mL of distilled water in the beakers. The immersion times were analyzed for each 3, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, and 72 hours. Insoluble solids and water were then filtered using filter paper and dried in the oven, followed by the drying process to obtain a constant weight before being put in the desiccators. During the release test, the distilled water was taken at every 48-hour interval, and the concentration of nutrients was determined from the atomic absorption spectrometer. The findings indicate that the weights of release fertilizers, specifically Zn and Fe, significantly decreased over time. At the lowest concentration, the coated zinc and iron weights decreased as time increased. Referring to the curve results, the Zn fertilizer started drastically decreasing its weight at hour 24, which decreased approximately to 0.002 for every subsequent hour. Meanwhile, Fe fertilizer decreased drastically at hour 66, where the weight dropped from 0.10467 to 0.039. However, the final weights for both fertilizers at hour 72 were about the same.

INTRODUCTION

Over the past few years, Malaysian aquaculture production has grown, and its value has also increased (Mustafa et al. 2018). Aquaponics and hydroponics together are called pisciponics, where enriched nutrients are recirculated from fish tanks to grow plants (Goddek et al. 2015). Nonetheless, the world must be concerned about how future generations will be able to produce more food sustainably in the future.

The pisciponics system relies on nutrients to support plant growth and efficiently recycle nutrients (Okomoda et al. 2022). The system provides essential nutrients to the plants. The Pisciponics system is an environment-friendly and sustainable food production (Okomoda et al. 2022). Malaysia has adopted the pisciponics system to feed the ever-increasing human population and for food security (Rafiee & Saad 2008). The world is facing global population growth, and it is exceeding 7.2 billion. It is projected to be 9.7 billion by 2050, with over 85 percent living in urban areas compared with 1990, with 5 billion people only (Alexandratos & Bruinsma 2012). The world population is projected to grow exponentially (Maucieri et al. 2018). The growing number of people moving to urban areas will likely increase malnutrition, urban poverty, and hunger (United Nations Department of Economic and Social Affairs Population Division 2017).

Fertilizers are chemical substances added to soil to increase crop yield, which is crucial for plant healthy growth (Alam et al. 2013). The production and demand for food have become more dependent on various agricultural techniques (Tilman et al. 2011). The characteristics needed include increasing the productivity of fertilizers and minimizing the cost (Qureshi et al. 2018). Research is needed to develop fertilizers that maximize crop yields, enhance nutrient efficiency and reduce pollution. However, efficient production is crucial since the essential elements of nutrition or fertilization can affect the physiological processes of plants (Ahl & Mahmoud 2010). Plants need macronutrients and micronutrients, which are vital for their growth. In many cases, deficiency diseases are caused by insufficient plant micronutrient supply (Shete et al. 2015).

However, organic farming methods are not the only example of sustainable nutrient management. The leaching of nutrients can be managed by an appropriate amount of fertilizers and slow-release fertilizers in the pisciponic system to avoid leaching into the environment and causing water eutrophication (Rahman 2015). A good amount of fish combined with insufficient nutrients will result in low nutrient absorption and affect crop production in pisciponics systems. Other than that, it is also reported that pisciponic systems that rely exclusively on fish waste to provide plant nutrients have low levels of micronutrients (Ru et al. 2017). However, there is a paucity of information and a limited number of research investigations on the effects of supplementation of zinc chelate and iron chelate in granular form to absorb in water and effectively alleviate nutrient insufficient in crop plants (Roosta & Hamidpour 2013).

The present work attempt to develop new slow-release zinc and iron fertilizer by palm stearin. The effects of selected micronutrient mineral composition on crop plants in the pisciponic system using granular form were investigated. Then a slow-release process using stearin as a coat for Zinc and Iron was evaluated.

MATERIALS AND METHODS

Location of Experiment

Slow-release fertilizers were processed in the Nutrition Laboratory in Block A, UPM, and the pisciponic recirculating system was conducted in a greenhouse at UPM's Aquaculture Experimental Station in Puchong, Selangor.

Synthesis of Coated Slow-Release Fertilizer

The temperature was set at 60°C in a water bath to melt seven grams of palm stearin in a beaker. After the whole palm stearin was fluxed, it was left to cool until the temperature extended to 30°C. Subsequently, 100 g of zinc chelate and iron fertilizer were added to the beaker of palm stearin and mixed using a spatula. Lastly, the zinc- and iron-coated fertilizers were kept in a desiccator for 48 hours before being dried in an air-tight container for further analysis and investigations.

Total Coating Analysis

Therefore, 10 g of coated zinc and iron micronutrients were flattened and mixed with water to increase the selected micronutrients' dissolution rate. Consequently, the solution was filtered, and the remaining insolvable solid material was dried in the oven until fully preserved. Subsequently, the zinc- and iron-coated fertilizers were dissolved in deionized water. The other steps were conducted similarly in this study. The following formula was used to calculate the coating percentage (Rahman 2016):

$$(\%)\ \text{coating} = \text{wt. of residual (g)}/10 \times 100 \qquad \ldots(1)$$

Crushing Strength Analysis

The crushing strength test is essential to ensure the product can resist physical control over the supply chain. 30 granules were randomly selected from the major part population based on the sieve with a capacity of 200 lb (100kg, 1000N). At the same time, 12.7-317.5 $mm.min^{-1}$ speed was used for computation by applying a compressive force on a single granule by using a hardness tester (capacity: 100kg, 1000 N; speed: 12.7–317.5 $mm.min^{-1}$).

Scanning Electron Microscopy Analysis

To investigate the surface morphology and thickness of the coating material, the samples of coated and uncoated zinc and iron fertilizers were cut in half using a blade. The sample cross-section was placed on the slide and coated using gold. The samples were then viewed using SEM, Model Hitachi TM3030 (Rahman 2016).

Dissolution Rate of Slow-Release Fertilizer

An Erlenmeyer flask was filled with 500 mL of distilled water and sealed before 100 g of coated fertilizers were added. Next, the Erlenmeyer flask was placed in an incubator shaker for 5 h (Zheng et al. 2010). This analysis studies the coated granules' rate of coated fertilizer release when submerged in water. The 16 samples were subjected to a dissolution test, and their dissolution rates were evaluated based on the efficiency equation (Irfan et al. 2018). A relatively long-term process (72 h) was developed to access nutrient release generated by natural-release mechanisms in a laboratory setting. The method was slightly changed in terms of fertilizer usage in the pisciponic system by sponge-soaking at a constant temperature of 27.01 through the system and a flow rate of 10 $L.min^{-1}$. Uncoated and coated fertilizers using dissolution rates. We sealed 9 samples in a beaker with 500 mL distilled water. The released coated fertilizer solution was measured using a refractometer to the known refractive index of water, and the reading was taken for 0, 3, 6, 12, 18, 24, 30, 36, 42, 48, 54, 60, 66, and 72 h (Rahman 2016).

RESULTS AND DISCUSSION

Morphology Characteristic of Coated Slow-Release Fertilizer

Based on Table 1, mass strength in g/granular was regulated before and after coating. The crushing strength will differ depending on the particle size, which is the force vital to press the particle (Ibrahim et al. 2014). In collating the crushing strength data, a comparison is essential to have

Table 1: The morphology characteristics of coated slow-release fertilizer.

Treatment	Coating [%]	Thickness [mm]	Diameter [mm]	Crushing strength [N]
Zinc-coated	7.67	$2.77^{a}\pm0.1$	$3.72^{a}\pm0.1$	$56.81^{a}\pm0.2$
Iron-coated	7.67	$2.95^{a}\pm0.1$	$4.20^{a}\pm0.1$	$60.13^{a}\pm0.2$
Uncoated Zinc	0.0	$2.92^{a}\pm0.2$	$3.45^{a}\pm0.1$	$20.12^{b}\pm0.1$
Uncoated Iron	0.0	$2.83^{b}\pm0.1$	$3.40^{a}\pm0.1$	$25.73^{b}\pm0.1$

Table 2: The weights of coated zinc and iron using stearin of micronutrients with substrate dissolution rates.

Weight of fertil-izer (g)	Time (h)												
	3	6	12	18	24	30	36	42	48	54	60	66	72
Zinc	0.3±0.2	0.28±0.1	0.27±0.1	0.25±0.1	0.22±0.1	0.17±0.1	0.13±0.1	0.11±0.2	0.09±0.2	0.08±0.1	0.07±0.2	0.06±0.1	0.03±0.1
Iron	0.3±0.1	0.28±0.2	0.28±0.1	0.26±0.1	0.24±0.1	0.24±0.1	0.21±0.2	0.18±0.1	0.17±0.2	0.16±0.1	0.13±0.2	0.10±0.1	0.03±0.2
Uncoated Zinc	0.3±0.1	0.2±0.1	0.1±0.2	0	0	0	0	0	0	0	0	0	0
Uncoated Iron	0.3±0.1	0	0	0	0	0	0	0	0	0	0	0	0

abundant mechanical strengths in coated zinc and iron to compare standardized granules because the crushing strength rises significantly with the rise in coated fertilizers to have the mechanical strength to resist the normal handling and storage without rupture. Besides, mechanical strength could influence the granule's porosity, shape, surface crystal, and moisture content. This is in line with the findings of Affendi et al. (2020), in which the coated urea with palm stearin enhances the stability of urea.

Scanning Electron Microscopy Analysis

Fig. 1: SEM of nano-sub nanocomposites: a) present the iron surface coated with stearin; b) without stearin; c) present the zinc surface coated with stearin, and d) without coated with stearin

Dissolution Rate of Slow-Release Fertilizer

Fig. 1 shows the Scanning Electron Microscopy Analysis (SEM) on the fertilizers for coated and non-coated using

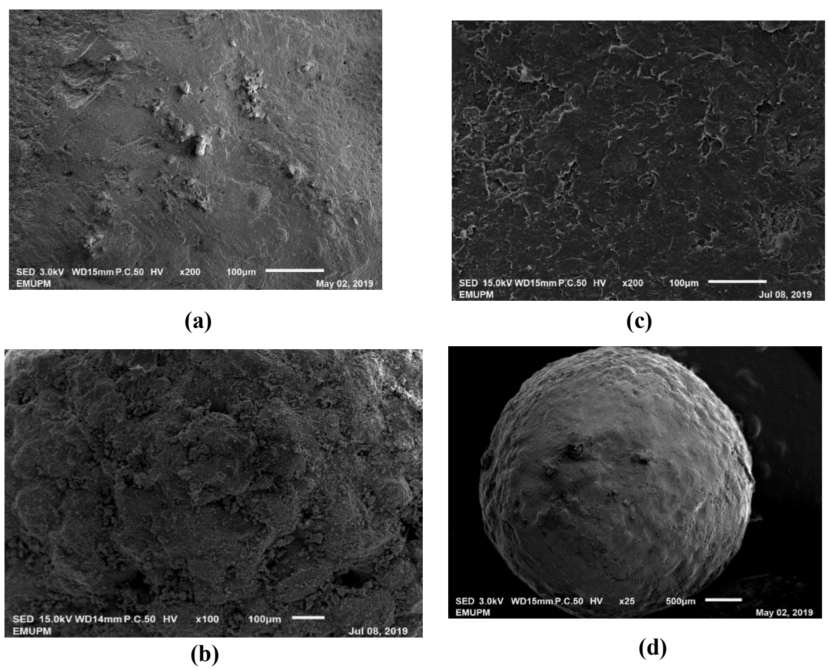


Fig. 1: SEM of nano-sub nanocomposites: a) present the iron surface coated with stearin; b) without stearin; c) present the zinc surface coated with stearin, and d) without coated with stearin.

Table 3: The nutrient concentrations of coated zinc and iron using stearin of micronutrients with time.

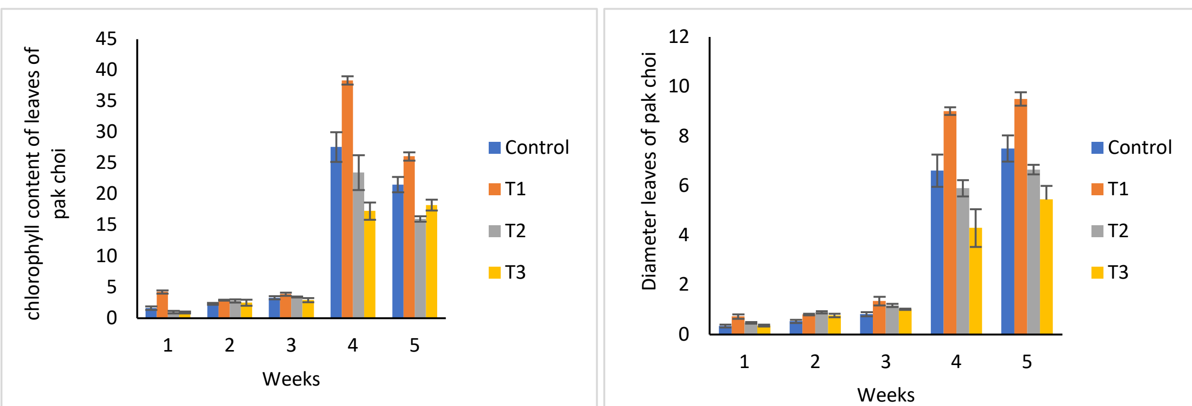
Concentration (g)	Time (h)												
	3	6	12	18	24	30	36	42	48	54	60	66	72
Zinc	0.3±0.1	0.28±0.2	0.27±0.2	0.25±0.1	0.22±0.1	0.17±0.2	0.13±0.1	0.11±0.1	0.09±0.2	0.08±0.1	0.07±0.1	0.06±0.2	0.03±0.1
Iron	0.3±0.1	0.28±0.1	0.28±0.2	0.26±0.1	0.24±0.1	0.24±0.1	0.21±0.2	0.18±0.1	0.17±0.2	0.16±0.1	0.13±0.1	0.10±0.2	0.03±0.1

the stearin. There are significant differences between coated fertilizers and uncoated fertilizers. The concentrations of coated and uncoated fertilizers were measured using the dissolution rates in water. According to Meng et al. (2019), palm stearin is a moisture barrier containing saturated fatty acids. The palm stearin material also led to high hydrophobicity (Aliyu 2017).

Coated zinc, iron, and uncoated fertilizers released nutrients at hour 3. However, Table 2 and 3 shows that iron releases a higher concentration of nutrients than coated zinc. Meanwhile, the uncoated fertilizers were uniformly dissolved in the water until 24 h. In addition, there was a significant difference between coated fertilizers and those not coated. However, these results align with the finding reported by Bley et al. (2017) in nutrient release and potassium leaching from polymer-coated fertilizers. Other results were also in line with studies on the release characteristics of a new controlled-release fertilizer showing the same patterns (Zheng et al. 2010).

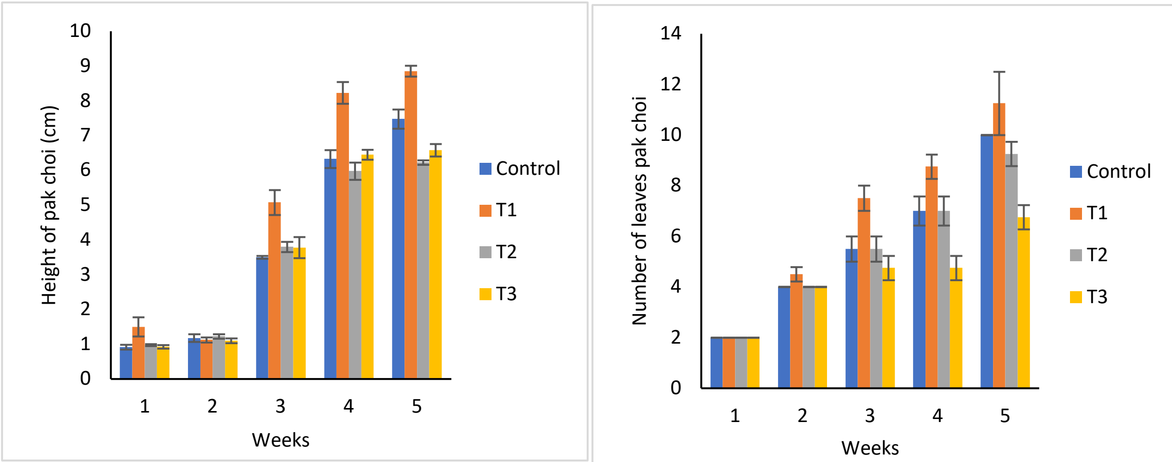
In this study, significant differences in the diameters and lengths of pak choi showed the lowest in the graph regarding the highest treatment. The leaf chlorophyll contents in pak choi were higher in Treatment 1 compared to other treatments, and the leaf chlorophyll contents significantly ($p<0.05$) correlated with Fe concentration (Fig. 2 a,b). This result is in line with a past study by Kaya et al. (2001) on Fe application and tomato leaf chlorophyll contents in which Fe deficiencies can be corrected with Fe fertilizers, chelating agents or decreased pH in growth media. Adding Fe in Treatment 1 for plant growth significantly increased the leaf chlorophyll contents, lengths, diameters, and heights in the plants (Fig. 2b). As for the production pak choi, the averaged crop cycle, the Soil Plant Analysis Development (SPAD), and plant height showed average values between 15 and 40 (Fig. 3a). However, Treatment 1 showed higher values than other treatments due to the additional iron-coated application. Besides, based on Fig. 3a, the plant height in Treatment 1 for both crops was also increased. Fe deficiency is a major nutritional disorder that causes a decrease in vegetative growth, marked yield, and quality losses. The results showed that Fe deficiency (0 mg Fe-1) and Fe excess could also stunt plant growth and reduce radicle development.

Furthermore, excess Fe can cause plants to lose weight and defoliate earlier (Hembrom & Singh 2015; Sultana et al. 2018). The highest growth and yield observed in Treatment 1 might be due to the addition of iron fertilizers to the system. The results of this study are similar to those found by Rakshit et al. (2016) for pisciponic plants in terms of growth, yield, quality, and nutrition.



(a) **(b)**

Fig. 2: Chlorophyll and diameter of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system (a) Chlorophyll content of leaves of pak choi; (b) diameter of leaves of pak choi.

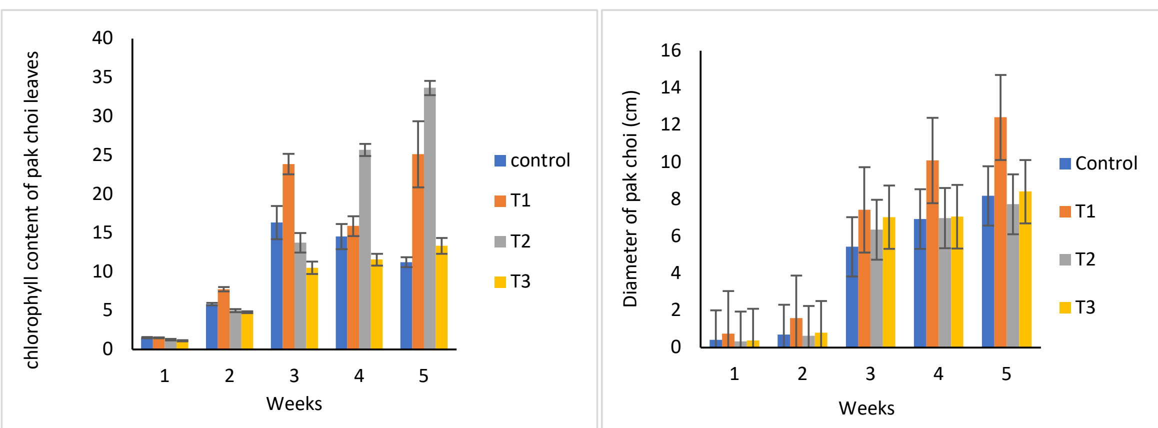


(a) **(b)**

Fig. 3: Height and number of leaves of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system (a) height of pak choi (cm); (b) the number of leaves of pak choi.

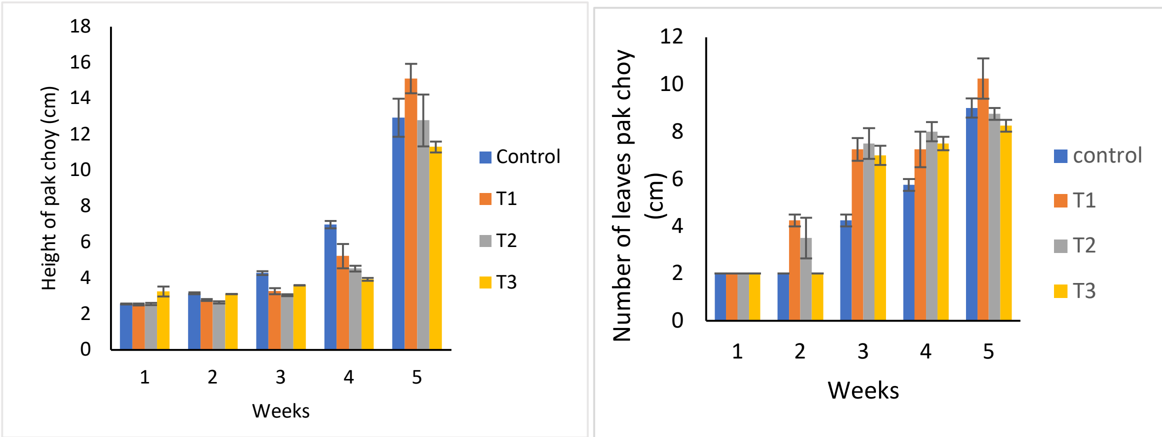
In this study, higher chlorophyll contents were recorded in Treatment 2 for pak choi; however, they recorded the lowest mean value in the control treatment. Based on the literature, a few species' depletion of leaf area leads to increased zinc contents that can affect photosynthesis activity. Treatments with a higher amount of zinc and without zinc could record the lowest mean values in length and height. As previously described, Kasozi et al. (2019) found that higher zinc concentrations reduced barley stems and leaves.

Fig. 5 shows the number and height of leaves of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system. In terms of the heights of pak choi in this study, significant differences were observed in the treatments. The highest mean value was recorded in T0 and followed by T1. However, Treatment 3 recorded the lowest height for pak choi. This indicates that a high zinc concentration does not promote plant growth. This finding aligns with Saeid et al. (2013), who found that gladiolus height was significantly positively correlated with growth. Hembrom & Singh (2015) also made a similar observation when they carried out an experiment on gladiolus pertaining to the foliar application of Zn at a 0.4% dose with the improved length and width of the longest leaf. The number of leaves in Fig. 4 shows the effects of zinc-coated



(a) **(b)**

Fig. 4: Chlorophyll and diameter of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system (a) chlorophyll content of pak choi leaves; (b) diameter of pak choi (cm).

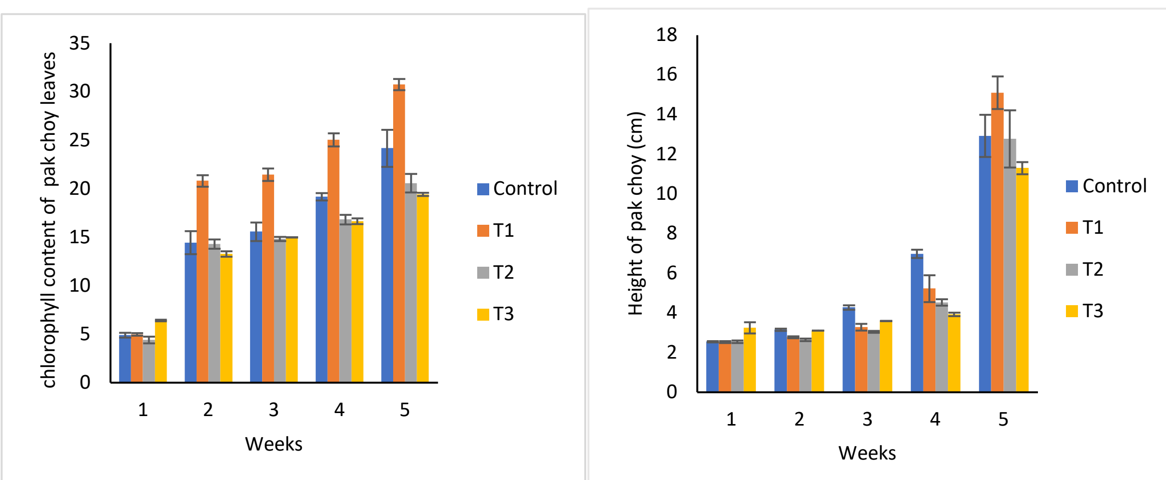


(a) (b)

Fig. 5: Number and height of leaves of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system.

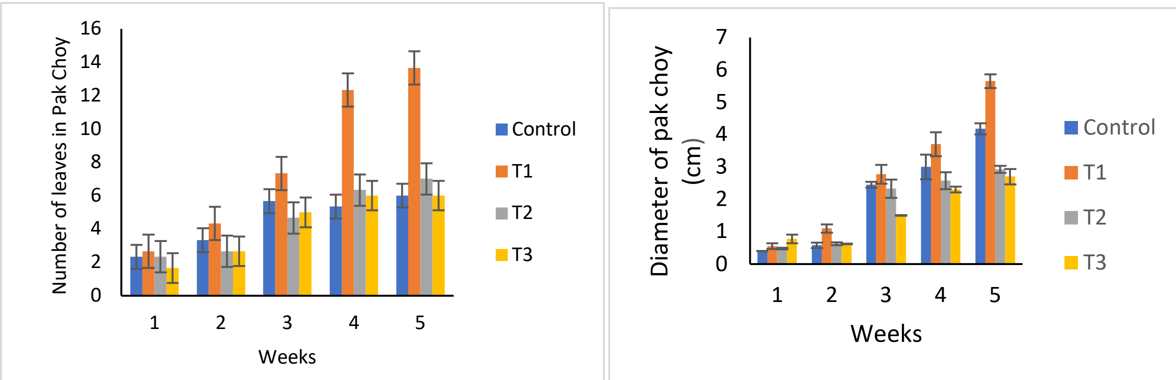
fertilizers with significant differences in the number of leaves. The highest mean value was recorded in Treatment 1. According to Monnet et al. (2001), a higher concentration of Zn at 3 ppm can reduce the photosynthesis activity, while 1.5 ppm or less shows a good result in increasing the photosynthesis rate.

Higher chlorophyll contents of pak choi were observed in Treatment 2, with the highest value (Fig. 6a). These results align with the findings of Roosta and Hamidpour (2013), which stated that the application of fertilizers had positively affected the leaf concentrations. Besides, the results also showed a significant gain in terms of plants' length, weight, and chlorophyll contents. These results agree with the findings reported by Yang & Kim (2019) that the combination of zinc yielded a better result than the application of zinc alone. In addition, in Treatment 1, the combination of zinc and iron showed the highest yield. According to Mousavi et al. (2012), the lack of zinc can lead to iron (Fe) deficiency and cause Fe failure from the shoot to root due to zinc shortage. Besides, zinc utilization has a negative effect on Fe concentration in plant tissues if the amount is too much or too little, which may be due to the physiological factors of plants. Overall, on average,



(a) (b)

Fig. 6: Chlorophyll and height of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system (a) chlorophyll content of pak choi; (b) height of pak choi (cm).



(a) **(b)**

Fig. 7: Number and diameter of leaves of pak choi in the rearing tank trough outlet in which lemon fin barb hybrids were cultured in the pisciponic system (a) number of leaves in pak choi; (b) diameter of pak choi.

the highest height in pak choi was recorded in Treatment 1 at 16 cm (Fig. 6b). Additionally, the plants treated with a mixture of zinc and iron fertilizers in Treatment 1 showed good results.

The number and diameter of leaves of pak choi were observed for the growth performance (Fig 7). Coated zinc and iron and its combination showed significant zinc and iron accumulation in pak choi leaves. The diameters of pak choi showed the highest mean value recorded in T1 (5.07 cm), followed by T0 and T2. The coated zinc and iron did not affect the diameter of the leaves, as the control treatment recorded the highest mean value. In contrast, Treatment 1 affected the diameters of pak choi with a highly significant difference in all treatments, despite the possibility that this was due to the slow release of coated zinc and iron fertilizers over a long exposure. This finding is in line with Sheykhbaglou et al. (2010) study in which nano iron oxide at the concentration of $0.75g^{-1}$ increased the leaf and pod dry weight, as well as Rono et al. (2018) study using 30 Fe kg^{-1} treatment where the iron amino acid chelate supplementation reported better growth in terms of height, the number of leaves, diameter, and dry weight compared to the use of too much and too little fertilizers. In the current study, both treatments recorded the highest number of leaves, while Treatment 3 recorded the lowest number.

The analysis of variance (ANOVA) results showed that the application of coated iron and zinc fertilizers had a significant ($P \leq 0.05$) effect on these parameters. The effects of different iron- and zinc-coated treatments on leaf chlorophyll were significant in pak choi for all treatments. The highest mean value was recorded in Treatment 2 (33.65), and the lowest was in the control treatment (11.22). As for the diameters of pak choi, a significant difference was observed in all treatments. The highest mean value was recorded in Treatment 3 (28.40), whereas the lowest was recorded in Treatment 2 (7.73). Regarding the heights of pak choi, significant differences were observed in the treatments. The highest mean value was recorded in the control treatment (10.90), and the lowest was in Treatment 3 (5.90). As for the number of pak choi leaves, there were significant differences in the control treatment, Treatment 2, and Treatment 3. Treatment 1 (10.25) recorded the highest mean value, and Treatment 3 (8.25) recorded the lowest.

CONCLUSION

The application of Zn and Fe fertilizers is essential for plant growth performance. It has been observed that coated and uncoated fertilizers behave differently in terms of the release of nutrients at different time intervals. The analysis of variance for plant height revealed highly significant results for treatment 1, combining zinc and iron. Applying micronutrient coated increases the diameters of pak choi showed the highest mean value recorded in T1, followed by T0 and T2, respectively. It is indicated that all treatment levels were significantly different from each other. Besides that, it increases the number of leaves per plant compared to control. Statistical analysis for length per plant has reflected highly significant results. Therefore, plants that received no fertilization of micronutrients show less length of branches per plant. There is a need for further research on the impact of palm stearin-coated fertilizers and their impact on plant growth performance and the rate of nutrient release.

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