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Agrophysiology, biochemical, and yielding characteristics of Chinese cabbage due to formulations and concentrations of nutrient in hydroponic

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Abstract

Hydroponic solution from agricultural organic waste can be used as an alternative to chemical solutions and strongly increases the growth and yield of Chinese cabbage plants. This study was to obtain formulations, concentrations, and their interactions that have the potential to increase the agronomic, physiological, biochemical, and yielding characteristics of Chinese cabbage in hydroponic culture. This study was conducted from September to November 2022 using a randomized block design with two factors and three replications. The first factor was the formulation of organic nutrient solutions (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts; F4= AB mix as a comparison). The second factor was the concentrations (600; 900; 1,200; 1,500 ppm). Data were analyzed using ANOVA and proceeded with the Duncan at $P<0.05$. The results showed that formulations F3 and F2 significantly increased Mg and chlorophyll b levels while formulation F1 increased nitrate and flavonoids. The concentrations ranged from 1,200 to 1,500 ppm showed the highest yield and shoot fresh weight were 2.86 kg m^{-2} $year^{-1}$ and 30.70 g. The F3C4 interaction was highly recommended to increase the yield of Chinese cabbage by 2.68 kg m^{-2} $year^{-1}$ compared to the other liquid organic fertilizers and it could be used as a substitute for using liquid chemical fertilizers in hydroponic culture.

Keywords: agronomic, biomass, liquid organic fertilizers, organic wastes

Introduction

Conventional vegetable cultivation techniques have several weaknesses in producing yields such as high water usage and inefficiency, large land requirements, high use of fertilizers and pesticides, and decreased soil quality including reduction of soil organic matter and leading to erosion (Killebrew & Wolff, 2010). One approach to overcome these weaknesses and produce healthy vegetable products is the use of soil-independent or hydroponic cultivation. Savvas (2003) stated that hydroponics is a technique for growing plants using nutrient solutions that are optimized to support plant growth and development. Ohse et al. (2001); Petropoulos et al. (2016) added hydroponics as an alternative crop production technique because it was effortless to control nutrient composition, reduced soil contamination, faster plant growth, shorter plant cycles, high product quality, and was acceptable to consumers. In addition, vegetable yield in the hydroponic system was higher than conventional. Barbosa et al. (2015) reported that the yield of lettuce plants in the hydroponic culture was 41 kg m^{-2} $year^{-1}$ or 11 times greater than the conventional by 3.9 kg m^{-2} $year^{-1}$.

Nutrient solutions in hydroponic culture usually use liquid organic fertilizer (LOF). The LOF products from factories are more often used by human because it is more practical and available in agricultural shops. But the price of the liquid chemical fertilizer was quite expensive. Efforts are needed to develop LOC using agricultural organic wastes such as vegetables, fruits, and crop residues. The availability of agricultural organic waste is abundant in the field and needs to be optimized as natural LOF. In addition, Hasibuan et al. (2021) added that LOF from eggshells can benefit the farmer's economy by 50%. Agricultural organic waste can be used as liquid organic fertilizer as a hydroponic solution to support the growth

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of horticultural crops, such as waste eggshells, moringa leaves, and onion peels for Chinese cabbage (*Brassica rapa* var. *chinensis*) growth (Fatimah et al., 2021; Sari et al., 2020; Putri et al., 2021), sugarcane leaf and banana peel wastes for lettuce growth (Phibunwatthanawong & Riddech, 2019; Poliquit et al., 2021).

Several agricultural organic wastes as hydroponic solutions had macro and micronutrients and *plant growth regulators* (PGRs). Kadir et al. (2016) reported that banana peels had higher N content of 35,325-78,775 mg L^{-1} compared to the P and K nutrients were 195.83-471 mg L^{-1} and 422.3-2,046 mg L^{-1}, respectively. Moyo et al. (2011) found that the level of Mg, Mn, B, and Cu nutrients in Moringa leaves were 0.50%; 86.8; 49.93; and 8.25 mg kg^{-1}, respectively. According to Ozobia (2014) that 100 g of fresh extract of moringa leaves had Mg and Cu nutrients by 24 and 1.1 mg. Makkar et al. (2015); Wijaya & Teo (2019); Rombe & Pakasi (2020) also reported that Ca in eggshells was higher than Mg, K, P, Na, S, and Zn nutrients. Kurniati et al. (2019) revealed that banana humps and onion peels contain indole-3-acetic acid (IAA), gibberellins (GA_3), and zeatin. According to Basra & Lovatt (2016) that moringa leaves had PGRs such as IAA, zeatin, GA_3, and abscisic acid.

Based on the chemical and PGRs characteristics produced from several agricultural organic wastes such as eggshells, banana peels, moringa leaves, onion peels, bean sprouts, and banana humps. It is necessary to formulate a hydroponic solution based on the macronutrient levels such as N, P, K, and Ca. Many studies on mixing several agricultural organic wastes as LOF has been reported. For example, Enrawan (2019) that natural LOF (interaction of bay-leaf+dry rice straw+banana stems+coconut fiber+ cattle manure) at a dose of 20 ml L^{-1} could be increased plant height, number of leaves, relative growth rate, net assimilation rate, root shoot ratio, and harvest index of Chinese cabbage in the hydroponic system. However, natural LOF from mixing eggshells, banana peels, moringa leaves, onion peels, bean sprouts, and banana humps has never been reported based on the composition of macronutrients, thereby reassessment is needed to determine the useful formula for the growth of Chinese cabbage plants. This study was to obtain formulations, concentrations, and their interactions that have the potential to increase the agronomic, physiological, biochemical, and yielding characteristics of Chinese cabbage plants in the hydroponic culture.

Material and Methods

Fermentation process and formulation determination

The organic wastes in this study included banana peels, moringa leaves, onion peels, bean sprouts, banana humps, and eggshells. The banana peels, onion peels, bean sprouts, and eggshells were obtained from the traditional marketplace in Medan City, while banana humps and moringa leaves were taken from farmers' gardens in Medan City. All organic waste except eggshells were washed, dried, and homogenized into smaller sizes, then weighed 0.5 kg each and blended. Eggshells are washed, dried, and ground into powder. For each organic waste, 50 mL of molasses and water were added until the solution reached a volume of 4 L. All materials were stirred until homogeneous then closed and stored at room temperature with anaerobic fermentation for 10 d. The fermented liquid was filtered and put into a plastic bottle with a volume of 250 mL and analyzed for chemical characteristics in the laboratory. Determination of natural nutrient solution formulation based on the highest N, P, K, and Ca nutrients from each organic waste (**Table 1**). 100 mL of each organic waste was collected, homogenized, and analyzed for chemical characteristics (**Table 2**).

Study area and methodology

This study was conducted at Glugur Darat I, Medan Timur Subdistrict, Medan City, Indonesia from September to November 2022. This study used a Randomized Block Design with two factors and three replications. The first factor was the formulas of LOF (F1, F2, F3) and liquid chemical fertilizer as a control (F4= AB mix). The second factor was concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm). The concentration of 600 ppm was used as a benchmark because the fresh weight of Chinese cabbage plants was insignificantly different from the concentration of 1,000 ppm in the hydroponic system (Ramaidani et al., 2022). Analysis of the chemical characteristics of organic waste and solution formulation in the laboratory of Socfin Indonesia, Inc., Medan. The hydroponic system used a deep flow technique. The hydroponic installation had a length of 1.8 m and a 12 cm width. Twelve holes of the pipe were punched at a distance of 15 cm as the planting holes. At the bottom of the pipe, perforated 2 cm according to the diameter of the nutrient pipe.

Seedlings preparation and plant growing

Chinese cabbage seeds are sown on rockwool media size 2.5×2.5×2.5 cm^3. Rockwool soaked in water then drained and placed on a plastic tray. A planting hole was made at the top of the rockwool. One seed is inserted into the planting hole on rockwool, then the plastic tray was covered with black plastic and placed in the shade. After 2 d, transferred to unshade condition.

Table 1. Determination of natural solution formulations based on the highest N, P, K, and Ca nutrients from each organic waste

Nutrients	Highest sequence	Organic wastes	Solution formulations (N+P+K+Ca)
N (%)	4.070	Banana peels	F1= banana peels+bean sprouts+eggshells. F2= banana humps+onion peels+bean sprouts+moringa leaves. F3= moringa leaves+onion peels+bean sprouts.
	3.970	Banana humps	
	3.930	Moringa leaves	
P_2O_5 (%)	0.011	Bean sprouts	
	0.010	Onion peels	
	0.008	Moringa leaves	
K_2O (%)	0.141	Banana peels	
	0.107	Bean sprouts	
	0.104	Onion peels	
Ca (%)	0.149	Eggshells	
	0.044	Moringa leaves	
	0.029	Bean sprouts	

Table 2. Chemical characteristics of each solution formulation

Chemical characteristics	Methods	Solution formulation		
		F1	F2	F3
Organik-C (%)	Walkley and Black	0.48	0.56	0.60
pH	Colorimetric	5.51	4.05	3.98
N (ppm)	Kjeldahl	40.00	337.00	408.00
P (ppm)	Dry ashing-HNO	40.00	68.00	88.00
K (ppm)	Dry ashing-HCl	870.00	910.00	1040.00
Mg (ppm)	Dry ashing-HCl	70.00	80.00	90.00
Ca (ppm)	Dry ashing-HCl	620.00	250.00	470.00
B (ppm)	Dry ashing-HNO_3	8.31	7.64	5.12
Fe (ppm)	Dry ashing-HCl	9.34	12.91	7.64
Cu (ppm)	Dry ashing-HCl	0.08	0.08	0.22
Mn (ppm)	Dry ashing-HCl	0.39	0.85	0.97
Zn (ppm)	Dry ashing-HCl	0.58	1.19	1.04

The transplanting of Chinese cabbage seedlings was conducted at 14 days after sowing (DAS) which is marked by 3-4 leaves. The transplanting was conducted with the media rockwool based on the seeding process and inserted into the pipe in a greenhouse.

Solutions of natural and inorganic nutrients are dissolved with water according to treatments. The water used as a solvent has first measured the pH using a pH meter and the concentration of the water was measured with a Total Dissolved Solids (TDS) meter. Likewise, the hydroponic nutrient solution. The nutrient solution was inserted into a holding container of 4 L and delivered via a pump. The solution pH was checked for three days and added 2 liters of nutrient solution for 10 d according to treatments. Chinese cabbage plants are harvested with the criteria for green leaves, large size, healthy, and freshness.

Parameters and data analysis

This study measured the agronomic characteristics including plant height, number of leaves, and leaf area were measured at 1 to 5 weeks after treatment (WAT) with a weekly interval, leaf thickness was measured from 3 to 5 WAT using a digital thickness gauge meter, while other agronomic characters such as root length and volume, shoot and root fresh weight, shoot and root dry weight, and shoot: root ratio were measured at 5 WAT. The measurement of leaf area was calculated using p×l×k (k= 0.759) based on Susilo (2015). The roots and shoots were separated, then weighed and dried in the oven at 65°C for 48 h (Seras, 1994) to obtain a constant dry weight. The shoot: root ratio was determined by comparing the dry weight of shoots and roots.

Physiological characteristics include chlorophyll content (a, b, total), nitrogen (N) content and uptake, as well as magnesium (Mg) content and uptake. Chlorophyll content measurements were carried out by collecting the second leaf from the apical bud, extracted with 70% ethanol, and then analyzed using a UV-Vis spectrophotometer at a wavelength of 645 nm (A645) and 663 nm (A663) based on Porra et al. (1989). Calculation of chlorophyll a, b, and total using equations 1-3. Measurement of N and Mg contents was carried out by collecting 150 g of leaf samples, analyzing with the Kjeldahl method, and drying ashing-HCl through Atomic Absorption Spectrophotometry (AAS). Nutrient uptake of N and Mg in the shoots were calculated using equation 4.

$$\text{Chlorophyll a} = \frac{[(12.7xA663)-(2.69xA645)]}{10} \quad (1)$$

$$\text{Chlorophyll b} = \frac{[(22.9xA645)-(4.68xA663)]}{10} \quad (2)$$

$$\text{Chlorophyll total} = \frac{[(8.02 \times A663)-(20.2 \times A645)]}{10} \quad (3)$$

$$\text{Nutrient uptake} = \text{nutrient content} \times \text{shoots dry weight} \quad (4)$$

$$\text{Fiber content} = \frac{\text{Fiber weight}}{\text{sample weight}} \quad (5)$$

Biochemical characteristics include the contents of nitrate, antioxidants, flavonoids, and fiber. Nitrate (NO_3^-) was analyzed using the colorimetric method through titration of salicylic acid (Cataldo et al., 1974). Measurement of antioxidants using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method by extracting leaf samples using ethanol (Blois, 1958). Measurement of flavonoids using UV-Vis Spectrophotometry at a wavelength of 450 nm (Das et al., 2014). Analysis of fiber content using the gravimetric method using H_2SO_4 solution (Sudarmadji et al., 1989). The fiber content was calculated using equation 5.

The plant density m^{-2} of Chinese cabbage was measured based on the gutter area (length= 1.8 m and width=0.12 m). The number of Chinese cabbage per gutter was 12 populations, and plant density was calculated using the equation 6:

$$\text{Plant density } m^{-2} = \frac{1 m^{-2}}{1.8 m \times 0.12 m} \times \text{number of plants per gutter} \quad (6)$$

$$= (1 m^{-2})/(0{,}216 m^{-2}) \times 12 \text{ populations} = 56 \text{ populations.}$$

$$\text{Yield (kg } m^{-2} \text{ year}^{-1}) = \text{Plant density } m^{-2} \times \text{number of harvests} \times \text{shoot fresh weight} \quad (7)$$

The yield of Chinese cabbage was measured by converting plant density, number of harvests, and shoots fresh weight (Barbosa et al., 2015). In this study, the F1-F3 treatments had a harvest age of 58 days or two months resulting in 6 times a year. Meanwhile, the F4 treatment was only 38 days or assumed to be one month and the number of harvests was 12 times a year. The yield of Chinese cabbage was calculated using the equation 7. The parameters were analyzed using ANOVA and proceeded with the Duncan test at $P<0.05$. The data of agrophysiology and biochemical were correlated with the yield of Chinese cabbage using Pearson's correlation.

Results and Discussion

Agronomic characteristics

The agronomic characteristics of Chinese cabbage plants due to formulations, concentrations, and their interactions could be seen in Tables 3-5. The solution formulations significantly affected plant height, number of leaves, leaf area and thickness, as well as root length of Chinese cabbage plants at the end of this study, but the concentrations and their interaction had an insignificant effect. The shoot fresh weight of Chinese cabbage plants could be influenced by the formulations, concentrations, and interactions. Likewise, the root dry weight was also significantly affected by their interaction. The F4 formulation dominantly increases the agronomic characteristics of Chinese cabbage plants compared to other natural solution formulations. Among the natural solution formulations, F3 (moringa leaves+onion peels+ bean sprouts) had a higher ability to increase plant height, the number of leaves, leaf area, leaf thickness, and shoot fresh weight of Chinese cabbage were 14.60 cm; 7.88 leaves; 16.88 cm^2; 0.68 mm; and 29.09 g, respectively. However, the highest root length was found in F1 (banana peels+bean sprouts+ eggshells) at 22.14 cm. Likewise, the concentration of 1,500 ppm increased the highest shoot fresh weight by 30.70 g compared to other concentrations. In addition, the interaction of F4C3 and F2C2 increased the highest shoot fresh weight and root dry weight were 51.28 and 0.63 g, respectively compared to the other interactions.

The agronomic performance of the Chinese cabbage plants due to formulation, solution concentration, and their interaction in the hydroponic solution visually at the end of the study could be seen in (**Figure 1)**. The leaf characters (color, area, and thickness) of the Chinese cabbage plants in the F3 interaction with a solution concentration of 600-1,500 ppm were greener than F1 and F2. In contrast, the AB mix solution (F4) due to different harvest times. The F1-F3 treatments had a harvest age of 58 days and the F4 treatment was only 38 days (**Tables 3, 4, 5**).

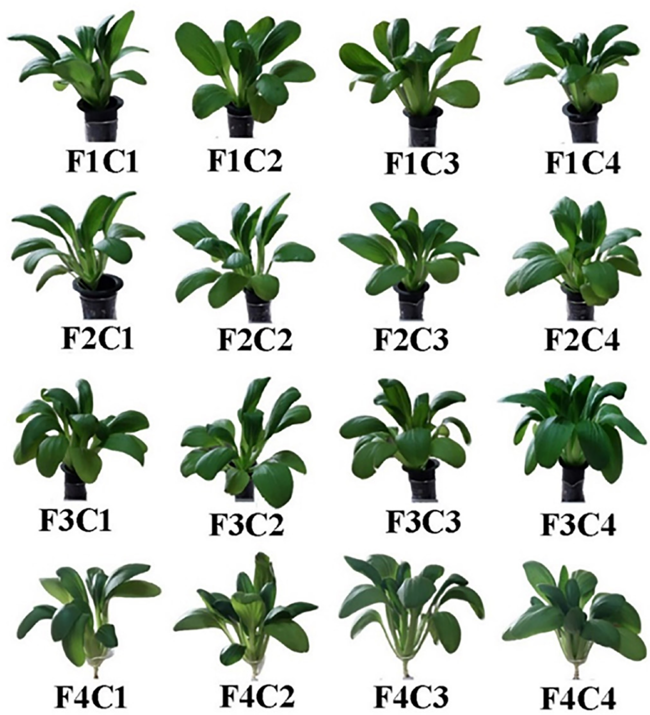

Figure 1. The agronomic performance of the Chinese cabbage plants due to formulation, solution concentration, and their interaction in the hydroponic solution visually.

Table 3. The plant height and number of leaves in Chinese cabbage due to formulations, concentrations, and their interactions in the hydroponic solution at 1-5 weeks after treatment (WAT)

Treatments	Plant height (cm)					Number of leaves				
	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT
Formulations (F)										
F1	4.22±0.06 b	6.41±0.08 b	8.42±0.12 c	11.25±0.07 b	12.64±0.17 c	3.68±0.03 b	4.52±0.02 bc	5.43±0.06 b	6.18±0.10 c	6.97±0.03 c
F2	4.13±0.07 b	6.45±0.13 b	8.61±0.24 bc	11.73±0.23 b	13.80±0.23 bc	3.63±0.06 b	4.40±0.04 c	5.42±0.08 b	6.58±0.17 bc	7.48±0.14 c
F3	4.36±0.06 b	6.76±0.05 b	9.51±0.15 b	12.18±0.13 b	14.60±0.14 b	3.67±0.07 b	4.73±0.02 b	5.87±0.00 b	7.15±0.11 b	7.88±0.12 b
F4	6.55±0.10 a	11.19±0.16 a	15.23±0.33 a	18.77±0.34 a	20.80±0.41 a	4.75±0.08 a	5.58±0.06 a	8.87±0.12 a	11.15±0.20 a	12.93±0.34 a
Concentrations (C)										
C1	4.69±0.32 ns	7.51±0.68 ns	10.58±0.98 ns	13.62±1.02 ns	15.25±0.98 ns	3.80±0.14 ns	4.70±0.13 ns	6.27±0.40 ns	7.58±0.61 ns	8.62±0.74 ns
C2	4.90±0.27 ns	7.56±0.47 ns	10.31±0.55 ns	13.15±0.63 ns	14.91±0.64 ns	4.00±0.09 ns	4.80±0.09 ns	6.40±0.34 ns	7.38±0.48 ns	8.30±0.48 ns
C3	4.94±0.36 ns	7.88±0.66 ns	10.55±0.98 ns	13.56±1.01 ns	15.59±1.05 ns	4.12±0.18 ns	4.87±0.17 ns	6.45±0.51 ns	8.05±0.66 ns	9.33±0.85 ns
C4	4.72±0.23 ns	7.87±0.53 ns	10.33±0.77 ns	13.59±0.93 ns	16.09±1.03 ns	3.82±0.16 ns	4.87±0.14 ns	6.47±0.43 ns	8.05±0.57 ns	9.02±0.71 ns
Interactions (F×C)										
F1C1	3.92±0.10 ns	5.96±0.13 ns	7.85±0.27 ns	11.01±0.41 ns	12.39±0.35 ns	3.60±0.09 ns	4.47±0.07 ns	5.40±0.06 ns	6.27±0.10 ns	6.87±0.12 ns
F1C2	4.27±0.05 ns	6.39±0.09 ns	8.91±0.06 ns	11.25±0.07 ns	12.51±0.09 ns	3.60±0.10 ns	4.53±0.06 ns	5.47±0.07 ns	5.60±0.08 ns	6.93±0.06 ns
F1C3	4.22±0.06 ns	6.53±0.07 ns	8.19±0.07 ns	11.07±0.35 ns	12.03±0.44 ns	3.87±0.09 ns	4.60±0.05 ns	5.13±0.02 ns	6.27±0.17 ns	6.93±0.11 ns
F1C4	4.46±0.04 ns	6.77±0.08 ns	8.71±0.04 ns	11.66±0.21 ns	13.62±0.11 ns	3.67±0.09 ns	4.47±0.09 ns	5.73±0.04 ns	6.60±0.00 ns	7.13±0.06 ns
F2C1	3.88±0.03 ns	5.87±0.02 ns	8.14±0.03 ns	11.09±0.11 ns	12.57±0.13 ns	3.60±0.08 ns	4.27±0.04 ns	5.20±0.03 ns	5.67±0.12 ns	6.80±0.00 ns
F2C2	4.39±0.09 ns	6.88±0.01 ns	9.94±0.09 ns	13.11±0.23 ns	14.82±0.22 ns	4.00±0.03 ns	4.53±0.04 ns	5.87±0.02 ns	7.07±0.10 ns	7.87±0.14 ns
F2C3	3.91±0.10 ns	6.14±0.13 ns	7.77±0.17 ns	11.52±0.17 ns	13.99±0.29 ns	3.53±0.12 ns	4.27±0.10 ns	5.33±0.09 ns	7.07±0.10 ns	8.00±0.10 ns
F2C4	4.32±0.03 ns	6.91±0.12 ns	8.57±0.04 ns	11.21±0.07 ns	13.80±0.12 ns	3.40±0.08 ns	4.53±0.03 ns	5.27±0.02 ns	6.53±0.04 ns	7.27±0.04 ns
F3C1	4.42±0.04 ns	6.67±0.03 ns	10.08±018 ns	12.75±0.18 ns	15.21±0.11 ns	3.40±0.08 ns	4.60±0.03 ns	5.87±0.07 ns	7.33±0.08 ns	7.80±0.08 ns
F3C2	4.44±0.05 ns	6.59±0.06 ns	8.85±0.05 ns	11.50±0.16 ns	13.81±0.21 ns	3.93±0.07 ns	4.80±0.05 ns	5.87±0.03 ns	6.73±0.04 ns	7.27±0.02 ns
F3C3	4.55±0.02 ns	7.03±0.04 ns	9.98±0.08 ns	12.07±0.04 ns	14.69±0.06 ns	3.87±0.06 ns	4.73±0.03 ns	5.87±0.03 ns	6.87±0.06 ns	8.00±0.03 ns
F3C4	4.04±0.09 ns	6.77±0.03 ns	9.13±0.11 ns	12.39±0.33 ns	14.69±0.25 ns	3.47±0.07 ns	4.80±0.03 ns	5.87±0.07 ns	7.67±0.13 ns	8.47±0.19 ns
F4C1	6.55±0.10 ns	11.52±0.21 ns	16.25±0.19 ns	19.64±0.20 ns	20.83±0.24 ns	4.60±0.21 ns	5.47±0.06 ns	8.60±0.19 ns	11.07±0.16 ns	13.00±0.10 ns
F4C2	6.52±0.18 ns	10.39±0.30 ns	13.52±0.49 ns	16.73±0.42 ns	18.49±0.22 ns	4.47±0.15 ns	5.33±0.11 ns	8.40±0.26 ns	10.13±0.31 ns	11.13±0.29 ns
F4C3	7.07±0.06 ns	11.83±0.20 ns	16.24±0.18 ns	19.60±0.08 ns	21.65±0.18 ns	5.20±0.15 ns	5.87±0.10 ns	9.47±0.12 ns	12.00±0.15 ns	14.40±0.14 ns
F4C4	6.06±0.08 ns	11.03±0.31 ns	14.92±0.42 ns	19.11±0.35 ns	22.23±0.23 ns	4.73±0.14 ns	5.67±0.06 ns	9.00±0.21 ns	11.40±0.20 ns	13.20±0.30 ns
CV (%)	11.36	10.97	11.64	10.30	9.08	10.57	7.89	10.36	10.42	10.60

Note: the mean followed by a different letter in the same column indicates significance by DMRT at $P<0.05$±standard error. ns= not significant. CV= coefficient of variation. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts). Concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm).

Table 4. The leaf area and thickness of Chinese cabbage due to formulations, concentrations, and their interactions in the hydroponic solution at 1-5 weeks after treatment (WAT)

Treatments	Leaf area (cm²)					Leaf thickness (mm)		
	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	3 WAT	4 WAT	5 WAT
Formulations (F)								
F1	1.68±0.07 b	4.03±0.16 b	6.88±0.19 c	11.78±0.26 b	14.53±0.17 c	0.37±0.00 b	0.43±0.00 c	0.48±0.00 d
F2	1.52±0.06 b	4.12±0.20 b	7.18±0.40 c	12.21±0.22 b	15.79±0.31 bc	0.35±0.01 b	0.46±0.01 c	0.56±0.01 c
F3	1.84±0.02 b	4.59±0.12 b	8.68±0.22 b	13.48±0.36 b	16.88±0.39 b	0.38±0.00 ab	0.54±0.00 b	0.68±0.00 b
F4	3.50±0.14 a	11.29±0.34 a	15.66±0.33 a	19.43±0.36 a	24.93±0.49 a	0.41±0.01 a	0.61±0.02 a	1.21±0.02 a
Concentrations (C)								
C1	1.82±0.18 ns	5.71±1.07 ns	9.66±1.31 ns	14.17±1.16 ns	18.29±1.45 ns	0.38±0.01 ns	0.51±0.02 ns	0.73±0.08 ns
C2	2.36±0.32 ns	5.66±0.67 ns	9.71±0.75 ns	13.81±0.63 ns	17.42±0.82 ns	0.39±0.01 ns	0.52±0.02 ns	0.72±0.07 ns
C3	2.13±0.24 ns	6.45±1.05 ns	9.46±1.19 ns	14.24±1.00 ns	17.93±1.36 ns	0.36±0.01 ns	0.51±0.03 ns	0.73±0.09 ns
C4	2.23±0.19 ns	6.22±0.75 ns	9.58±0.94 ns	14.69±0.85 ns	18.49±1.17 ns	0.39±0.00 ns	0.50±0.01 ns	0.75±0.08 ns
Interactions (F×C)								
F1C1	1.34±0.04 ns	3.08±0.05 ns	6.06±0.38 ns	10.27±0.56 ns	14.06±0.69 ns	0.38±0.01 ns	0.44±0.00 ns	0.49±0.01 ns
F1C2	1.52±0.04 ns	4.15±0.19 ns	7.89±0.14 ns	12.33±0.12 ns	15.08±0.28 ns	0.36±0.00 ns	0.43±0.00 ns	0.48±0.00 ns
F1C3	1.92±0.01 ns	4.33±0.07 ns	6.62±0.04 ns	11.92±0.87 ns	13.86±0.94 ns	0.34±0.00 ns	0.40±0.00 ns	0.46±0.00 ns
F1C4	1.94±0.06 ns	4.57±0.10 ns	6.96±0.07 ns	12.58±0.28 ns	15.11±0.40 ns	0.39±0.00 ns	0.45±0.00 ns	0.50±0.00 ns
F2C1	1.34±0.02 ns	3.28±0.03 ns	5.88±0.08 ns	11.42±0.14 ns	14.28±0.18 ns	0.32±0.01 ns	0.43±0.01 ns	0.52±0.01 ns
F2C2	1.72±0.08 ns	4.75±0.16 ns	9.34±0.20 ns	13.47±0.36 ns	17.27±0.64 ns	0.37±0.00 ns	0.48±0.00 ns	0.58±0.00 ns
F2C3	1.28±0.13 ns	3.59±0.33 ns	6.00±0.34 ns	12.21±0.49 ns	16.05±0.68 ns	0.32±0.01 ns	0.43±0.01 ns	0.53±0.01 ns
F2C4	1.74±0.05 ns	4.88±0.12 ns	7.50±0.12 ns	11.75±0.23 ns	15.56±0.27 ns	0.39±0.00 ns	0.50±0.00 ns	0.60±0.00 ns
F3C1	1.72±0.06 ns	4.38±0.04 ns	9.63±0.32 ns	14.30±0.27 ns	18.39±0.24 ns	0.39±0.00 ns	0.55±0.00 ns	0.69±0.00 ns
F3C2	1.93±0.07 ns	4.08±0.10 ns	7.52±0.14 ns	11.99±0.45 ns	15.24±0.37 ns	0.38±0.00 ns	0.54±0.00 ns	0.68±0.00 ns
F3C3	1.84±0.05 ns	5.22±0.05 ns	8.85±0.04 ns	12.58±0.16 ns	15.84±0.16 ns	0.36±0.00 ns	0.52±0.00 ns	0.66±0.00 ns
F3C4	1.85±0.01 ns	4.68±0.04 ns	8.72±0.30 ns	15.06±0.59 ns	18.06±0.48 ns	0.38±0.00 ns	0.54±0.00 ns	0.68±0.00 ns
F4C1	2.89±0.07 ns	12.08±0.27 ns	17.06±0.16 ns	20.68±0.11 ns	26.43±0.26 ns	0.42±0.00 ns	0.62±0.02 ns	1.22±0.02 ns
F4C2	4.26±0.10 ns	9.68±0.31 ns	14.07±0.57 ns	17.44±0.49 ns	22.09±0.52 ns	0.44±0.02 ns	0.61±0.03 ns	1.11±0.01 ns
F4C3	3.50±0.11 ns	12.66±0.19 ns	16.38±0.32 ns	20.24±0.30 ns	25.96±0.23 ns	0.41±0.01 ns	0.70±0.02 ns	1.28±0.02 ns
F4C4	3.38±0.28 ns	10.73±0.40 ns	15.13±0.51 ns	19.36±0.38 ns	25.22±0.40 ns	0.39±0.01 ns	0.52±0.01 ns	1.21±0.02 ns
CV (%)	28.27	20.49	18.00	14.85	13.10	11.86	15.17	8.64

Note: the mean followed by a different letter in the same column indicates significance by DMRT at $P<0.05$±standard error. ns= not significant. CV= coefficient of variation. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts). Concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm).

Table 5. Root and biomass of Chinese cabbage due to formulations, concentrations, and their interactions in the hydroponic solution

Treatments	Root length (cm)	Root volume (mL)	Fresh weight (g)		Dry weight (g)		Shoot: root ratio
			Root	Shoot	Root	Shoot	
Formulations (F)							
F1	22.14±1.27 b	3.00±0.20 ns	2.74±0.15 ns	16.61±0.66 c	0.26±0.01 ns	4.23±0.30 ns	16.31±1.00 ns
F2	20.79±0.27 b	3.00±0.29 ns	2.88±0.31 ns	23.85±1.87 b	0.36±0.06 ns	7.86±0.81 ns	26.36±2.88 ns
F3	18.82±0.30 b	3.21±0.28 ns	3.10±0.29 ns	29.09±2.09 ab	0.33±0.04 ns	10.72±0.85 ns	36.48±3.40 ns
F4	42.35±0.98 a	4.21±0.21 ns	4.03±0.18 ns	34.90±3.22 a	0.38±0.03 ns	7.63±0.94 ns	21.47±2.54 ns
Concentrations (C)							
C1	27.98±3.13 ns	3.44±0.37 ns	3.01±0.38 ns	22.75±2.66 b	0.31±0.04 ns	5.65±0.71 ns	21.02±2.87 ns
C2	27.76±3.08 ns	3.38±0.18 ns	3.29±0.20 ns	21.23±1.37 b	0.33±0.05 ns	7.55±0.71 ns	26.33±3.08 ns
C3	23.73±2.61 ns	3.25±0.29 ns	3.01±0.27 ns	29.77±3.77 a	0.29±0.02 ns	9.61±0.81 ns	34.92±3.39 ns
C4	24.63±2.37 ns	3.35±0.29 ns	3.44±0.22 ns	30.70±2.19 a	0.40±0.03 ns	7.63±1.33 ns	18.35±1.80 ns
Interactions (F×C)							
F1C1	28.77±0.98 ns	3.67±0.40 ns	2.55±0.21 ns	14.52±0.62 ef	0.23±0.02 bc	2.55±0.37 ns	10.93±1.86 ns
F1C2	23.45±0.41 ns	3.67±0.22 ns	3.62±0.18 ns	15.38±0.20 ef	0.30±0.01 abc	4.72±0.43 ns	15.72±0.99 ns
F1C3	18.05±0.89 ns	2.50±0.31 ns	2.27±0.27 ns	16.13±1.68 ef	0.27±0.04 abc	5.28±0.45 ns	19.81±6.00 ns
F1C4	18.28±0.82 ns	2.17±0.11 ns	2.52±0.09 ns	20.42±0.78 def	0.23±0.02 bc	4.38±0.31 ns	18.79±2.75 ns
F2C1	19.67±1.55 ns	1.50±0.07 ns	1.22±0.07 ns	12.68±0.40 f	0.12±0.00 c	4.27±0.51 ns	36.57±3.21 ns
F2C2	21.55±1.07 ns	4.17±0.37 ns	4.17±0.38 ns	28.60±0.61 b-e	0.63±0.06 a	11.38±0.71 ns	17.97±7.37 ns
F2C3	20.08±0.32 ns	3.67±0.18 ns	3.20±0.22 ns	27.25±0.97 b-f	0.27±0.02 abc	9.60±1.20 ns	36.00±2.80 ns
F2C4	21.85±0.14 ns	2.67±0.21 ns	2.95±0.14 ns	26.87±1.01 b-f	0.42±0.05 abc	6.20±1.02 ns	14.88±2.76 ns
F3C1	18.12±0.51 ns	3.50±0.31 ns	3.48±0.23 ns	30.98±1.55 bcd	0.40±0.03 abc	9.03±0.76 ns	22.58±2.89 ns
F3C2	19.95±0.45 ns	2.50±0.19 ns	2.25±0.12 ns	21.00±0.76 c-f	0.18±0.02 bc	7.82±0.37 ns	42.64±2.14 ns
F3C3	17.48±0.68 ns	2.17±0.11 ns	2.10±0.09 ns	24.42±0.42 ab	0.20±0.00 bc	10.50±0.76 ns	52.50±3.80 ns
F3C4	19.72±0.46 ns	4.67±0.44 ns	4.55±0.39 ns	39.95±3.46 bcd	0.55±0.07 ab	15.52±2.38 ns	28.21±0.68 ns
F4C1	45.37±2.43 ns	5.08±0.16 ns	4.78±0.07 ns	32.83±0.60 bcd	0.48±0.02 abc	6.77±0.82 ns	14.00±2.18 ns
F4C2	46.08±2.13 ns	3.17±0.22 ns	3.13±0.20 ns	19.93±1.04 def	0.22±0.02 bc	6.28±0.71 ns	29.00±2.16 ns
F4C3	39.30±2.11 ns	4.67±0.04 ns	4.47± 0.05ns	51.28±0.71 a	0.42±0.01 abc	13.07±1.54 ns	31.36±3.40 ns
F4C4	38.65±2.49 ns	3.92±0.25 ns	3.75±0.22 ns	35.55±2.19 bc	0.38±0.04 abc	4.42±0.32 ns	11.52±1.38 ns
CV (%)	16.13	20.65	10.64	7.53	11.07	36.67	37.60

Note: the mean followed by a different letter in the same column indicates significance by DMRT at $P<0.05$±standard error. ns= not significant. CV= coefficient of variation. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts). Concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm).

Physiological characteristics

The solution formulations significantly affected chlorophyll b and Mg contents in the shoot of Chinese cabbage plants. Their interactions significantly affected the nitrogen content in the shoot. The solution concentrations had an insignificant effect on all the physiological characteristics of Chinese cabbage plants (**Table 6**). The F2 (banana humps+onion peels+bean sprouts+moringa leaves) and F3 (moringa leaves+onion peels+bean sprouts) formulations significantly increased the highest chlorophyll b and Mg content in the shoot were 14.19 and 29.82% compared to the F4 formulation. The interaction of moringa leaves+onion peels+bean sprouts with a concentration of 900 ppm (F3C2) could be increased highest the nitrogen content in the shoot by 3.08% compared to other interactions.

Biochemical characteristics

The formulations significantly affected the contents of nitrate and flavonoids of Chinese cabbage plants. The concentrations and their interaction had an insignificant effect on all the biochemical characteristics (**Table 7**). It can be seen that the F1-F3 formulations showed significantly different contents of nitrate and flavonoids compared to the F4 formulation. There was the highest increase in the contents of nitrate and flavonoids in the F1 formulation were 89.04 and 195.35%, respectively compared to the F4 formulation.

Yielding characteristics

The formulations, concentrations, and their interactions significantly increased the yield of Chinese cabbage plants in hydroponic culture (**Table 8**). The F4 formulation (AB mix) significantly increased the highest yield of 4.69 kg m^{-2} $year^{-1}$ compared to the F1-F3 formulations. Nevertheless, the F3 formulation also showed the highest yield of 1.95 kg m^{-2} $year^{-1}$ compared to other natural formulations (F1 and F2). A solution concentration of 1,200-1,500 ppm also significantly increased the yield of Chinese cabbage plants compared to other concentrations and the highest was found in a concentration of 1,200 ppm by 2.86 kg m^{-2} $year^{-1}$. Likewise, the interaction of the AB mix formulation with a concentration of 1,200 ppm (F4C3) significantly increased the highest yield of Chinese cabbage plants by 6.89 kg m^{-2} $year^{-1}$ compared to other interactions.

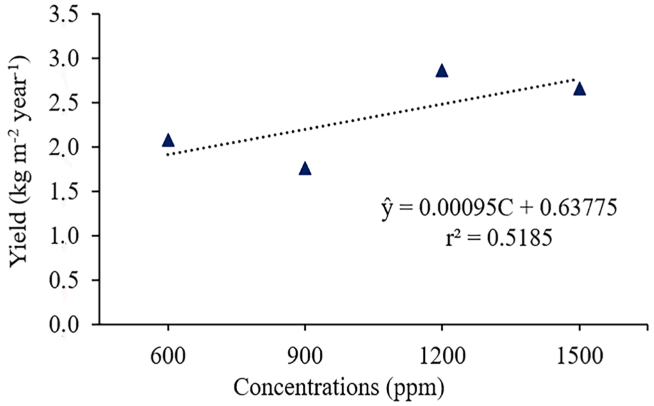

Figure 2. The relationship between the concentrations of the hydroponic solution with the yield of Chinese cabbage plants.

The relationship between the concentrations of the hydroponic solution with the yield of Chinese cabbage plants could be seen in (**Figure 2)**. The concentrations of the hydroponic solution had a linear relationship ($\hat{y}$= 0.00095K+0.63775) to the yield of Chinese cabbage plants. The higher the hydroponic solution concentration up to 1,500 ppm could be increased the yield of Chinese cabbage and the relationship was 51.85%.

Correlation value

The plant height, number of leaves, leaf area and thickness, root length and volume, root and shoot fresh weight, root and shoot dry weight, as well as nitrogen uptake, were positively correlated and significantly increased the yield of Chinese cabbage plants in hydroponic solution (**Table 9**). Among these parameters, plant height, the number of leaves, leaf area, and thickness, as well as shoot fresh weight have a very strong correlation (>0.80) to increased yields of Chinese cabbage. Similarly, the magnesium uptake had a positive correlation (0.202) but it had an insignificant effect on the yield. However, other parameters such as shoot: root ratio, chlorophyll content (a, b, total), N and Mg contents, nitrates, flavonoids, antioxidants, and fiber have a negative correlation with the yield of Chinese cabbage plants.

Formulations effect

The agrophysiology, biochemical, and yielding characteristics of Chinese cabbage plants

Table 6. Physiological characteristics of Chinese cabbage due to formulations, concentrations, and their interactions in the hydroponic solution

Treatments	Chlorophyll content (mg L^{-1})			Nitrogen-shoot		Magnesium-shoot	
	a	b	total	Content (%)	Uptake (mg kg^{-1})	Content (%)	Uptake (mg kg^{-1})
Formulations (F)							
F1	49.09±1.00 ns	22.30±0.23 b	71.39±1.18 ns	2.81±0.03 ns	11.95±0.87 ns	0.72±0.01 a	3.18±0.23 ns
F2	54.67±1.17 ns	24.46±0.24 a	79.13±1.30 ns	2.76±0.07 ns	21.73±1.73 ns	0.63±0.02 ab	4.68±0.32 ns
F3	48.48±1.84 ns	22.27±0.36 b	70.75±2.20 ns	2.75±0.06 ns	30.17±2.53 ns	0.74±0.02 a	8.56±1.03 ns
F4	49.07±2.13 ns	21.42±0.37 b	70.50±2.46 ns	2.59±0.02 ns	19.65±2.52 ns	0.57±0.02 b	3.83±0.50 ns
Concentrations (C)							
C1	48.25±2.22 ns	22.32±0.46 ns	70.57±2.66 ns	2.75±0.05 ns	15.56±1.67 ns	0.65±0.03 ns	3.80±0.49 ns
C2	54.36±1.39 ns	22.78±0.48 ns	77.14±1.86 ns	2.71±0.06 ns	20.48±2.03 ns	0.65±0.03 ns	4.68±0.42 ns
C3	47.80±1.74 ns	22.44±0.40 ns	70.24±2.13 ns	2.69±0.05 ns	25.59±1.94 ns	0.65±0.02 ns	5.79±0.39 ns
C4	50.90±0.52 ns	22.92±0.42 ns	73.82±0.76 ns	2.75±0.04 ns	21.87±3.95 ns	0.70±0.03 ns	5.99±1.44 ns
Interactions (F×C)							
F1C1	43.08±0.61 ns	21.41±0.15 ns	64.49±0.76 ns	2.81±0.04 a-d	7.45±1.16 ns	0.70±0.03 ns	1.95±0.35 ns
F1C2	50.88±0.42 ns	22.20±0.10 ns	73.08±0.52 ns	2.68±0.04 a-d	12.09±1.03 ns	0.79±0.01 ns	3.60±0.32 ns
F1C3	51.51±1.65 ns	23.60±0.38 ns	75.11±2.01 ns	2.94±0.06 abc	15.89±1.42 ns	0.71±0.03 ns	4.13±0.47 ns
F1C4	50.88±1.36 ns	22.00±0.23 ns	72.88±1.59 ns	2.80±0.05 a-d	12.36±0.91 ns	0.67±0.01 ns	3.05±0.24 ns
F2C1	53.97±1.18 ns	24.31±0.12 ns	78.28±1.30 ns	3.03±0.07 ab	13.99±1.82 ns	0.75±0.03 ns	3.74±0.52 ns
F2C2	61.46±0.40 ns	24.96±0.12 ns	86.42±0.51 ns	2.60±0.03 bcd	30.19±2.07 ns	0.54±0.02 ns	6.45±0.54 ns
F2C3	50.96±1.88 ns	23.19±0.33 ns	74.15±2.22 ns	2.47±0.01 d	23.81±3.02 ns	0.59±0.03 ns	4.86±0.55 ns
F2C4	52.30±1.11 ns	25.38±0.77 ns	77.68±1.83 ns	2.93±0.04 a-d	18.95±3.22 ns	0.64±0.01 ns	3.69±0.57 ns
F3C1	38.59±2.82 ns	20.20±0.84 ns	58.79±3.63 ns	2.55±0.02 cd	23.45±2.08 ns	0.67±0.02 ns	6.50±0.62 ns
F3C2	56.01±0.51 ns	23.53±0.10 ns	79.55±0.56 ns	3.08±0.02 a	23.86±0.94 ns	0.72±0.01 ns	5.75±0.34 ns
F3C3	51.34±0.11 ns	22.89±0.05 ns	74.23±0.08 ns	2.67±0.02 a-d	28.38±2.11 ns	0.70±0.02 ns	7.36±0.63 ns
F3C4	47.98±1.65 ns	22.45±0.23 ns	70.43±1.87 ns	2.69±0.04 a-d	44.98±7.35 ns	0.86±0.02 ns	14.63±2.47 ns
F4C1	57.37±1.31 ns	23.35±0.40 ns	80.72±1.71 ns	2.60±0.02 bcd	17.37±2.11 ns	0.48±0.03 ns	3.02±0.39 ns
F4C2	49.09±0.74 ns	20.42±0.20 ns	69.51±0.93 ns	2.50±0.02 cd	15.78±1.78 ns	0.57±0.03 ns	2.89±0.30 ns
F4C3	37.39±1.93 ns	20.08±0.27 ns	57.47±2.20 ns	2.65±0.01 a-d	34.27±3.93 ns	0.59±0.03 ns	6.81±0.60 ns
F4C4	52.45±1.03 ns	21.84±0.37 ns	74.29±1.40 ns	2.59±0.03 bcd	11.19±0.70 ns	0.63±0.02 ns	2.60±0.11 ns
CV (%)	15.61	9.69	13.27	8.53	23.55	19.65	38.39

Note: the mean followed by a different letter in the same column indicates significance by DMRT at P<0.05±standard error. ns= not significant. CV= coefficient of variation. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts). Concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm).

Table 7. The biochemical characteristics of Chinese cabbage plants due to the formulations, concentrations, and their interactions in the hydroponic solution

Treat-ments	Biochemical characteristics			
	Nitrate (mg kg^{-1})	Antioxidants (ppm)	Flavonoids (ppm)	Fiber (%)
Formulations (F)				
F1	145.09±4.71 a	6039.40±211.24 ns	12.70±0.46 a	1.21±0.01 ns
F2	113.87±4.60 a	6222.00±141.18 ns	10.45±0.64 a	1.19±0.01 ns
F3	134.91±5.47 a	6415.34±54.26 ns	11.61±0.45 a	1.17±0.00 ns
F4	76.75±7.80 b	5822.82±187.77 ns	4.30±0.13 b	1.15±0.01 ns
Concentrations (C)				
C1	119.23±10.55 ns	5854.12±87.02 ns	9.53±0.80 ns	1.17±0.00 ns
C2	123.61±7.24 ns	6442.19±118.17 ns	9.19±1.05 ns	1.17±0.01 ns
C3	126.89±5.88 ns	6013.47±162.84 ns	10.02±1.17 ns	1.18±0.01 ns
C4	100.90±11.41 ns	6189.78±234.19 ns	10.32±1.08 ns	1.18±0.01 ns
Interactions (F×C)				
F1C1	169.65±1.26 ns	6162.93±30.26 ns	10.34±0.68 ns	1.18±0.01 ns
F1C2	130.05±1.95 ns	6560.34±44.69 ns	12.35±0.31 ns	1.23±0.02 ns
F1C3	150.05±4.40 ns	6624.78±19.36 ns	14.66±0.54 ns	1.23±0.01 ns
F1C4	130.60±4.61 ns	4809.57±273.47 ns	13.46±0.55 ns	1.18±0.01 ns
F2C1	98.27±9.29 ns	5744.03±174.17 ns	10.20±0.87 ns	1.17±0.01 ns
F2C2	97.65±11.41 ns	6893.31±92.90 ns	6.90±1.00 ns	1.16±0.01 ns
F2C3	129.02±5.45 ns	5765.51±233.66 ns	12.46±0.29 ns	1.19±0.01 ns
F2C4	130.55±1.17 ns	6485.15±80.20 ns	12.24±0.22 ns	1.24±0.02 ns
F3C1	135.57±4.94 ns	6098.48±55.88 ns	12.59±0.24 ns	1.19±0.02 ns
F3C2	161.73±1.74 ns	6538.86±125.06 ns	13.09±0.39 ns	1.16±0.01 ns
F3C3	134.22±2.08 ns	6452.93±44.69 ns	9.09±0.27 ns	1.14±0.00 ns
F3C4	108.13±2.22 ns	6571.08±102.00 ns	11.67±0.60 ns	1.18±0.01 ns
F4C1	73.42±3.28 ns	5411.06±340.38 ns	5.01±0.18 ns	1.16±0.01 ns
F4C2	105.00±5.39 ns	5776.25±362.13 ns	4.41±0.28 ns	1.14±0.00 ns
F4C3	94.28±5.63 ns	5210.66±266.57 ns	3.87±0.12 ns	1.18±0.02 ns
F4C4	34.30±3.45 ns	6893.31±145.67 ns	3.91±0.37 ns	1.12±0.00 ns
CV(%)	18.68	19.43	18.68	6.58

Note: the mean followed by a different letter in the same column indicates significance by DMRT at $P<0.05$±standard error. ns= not significant. CV= coefficient of variation. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts). Concentrations (C1= 600; C2= 900; C3= 1,200; C4= 1,500 ppm).

in the hydroponic system could be affected by the formulations. The formulas of LOF (F1-F3) had less impact on the agronomic and yielding characteristics of Chinese cabbage plants compared to the liquid chemical fertilizer (F4), but it had more response to physiological and biochemical characteristics. It can be seen that the F4 formulation had a greater performance of Chinese cabbage plants such as the plant height, number of leaves, leaf area and thickness, root length, shoot fresh weight, and yield ha^{-1}. However, the F3 (moringa leaves+onion peels+ bean sprouts) had a higher ability to increase plant height, the number of leaves, leaf area and thickness, as well as shoot fresh weight of Chinese cabbage compared to the F1 and F2 formulations. In physiologically, the F2 and F3 formulations could be increased the highest chlorophyll b and Mg content in the shoot by 14.19 and 29.82% compared to the F4 formulation. In biochemically, the F1 formulation could be increased the highest contents of nitrate and flavonoids were 89.04 and 195.35%. The greater performance of Chinese cabbage plants in the F4 formulation was due to the nutrients being dissolved in water and more readily available than liquid organic fertilizers (F1-F3 formulations). These findings were supported by Upendri & Karunarathna (2021) that most of organic fertilizers are generally insoluble in water, and nutrients are not available to plants as they are converted into soluble forms by microorganisms. Phibunwatthanawong & Riddech (2019) added that the number of leaves, and shoot fresh and dry weight of lettuce plants in liquid chemical fertilizer was higher than a liquid organic fertilizer at 28 days after treatment.

On the other hand, the greater physiological performance in the F2 and F3 formulations could be due to higher nutrient content, such as N, P, K, Mg, and Mn compared to the F1 formulation (Table 2). The higher content of nutrients in these formulations had an impact on chlorophyll b and Mg contents in the shoots and affected the agronomic characteristics. This can be seen from the characteristics of plant height, number of leaves, leaf area and thickness, root volume, fresh and dry weight, shoot: root ratio, and yield ha^{-1} in the F3 and F2 formulations which were higher than the F1 formulation (Tables 3-5 and 8). These findings were supported by Cendrero-Mateo et al. (2016); Dellero et al. (2021) that nitrogen affects the increase in chlorophyll contents. Coria-Cayupán et al. (2009) found that the Mn, Mg, Cu, Zn, and Ca nutrients affected the biosynthesis and production of chlorophyll levels and Mn also contributed to the structure of chloroplasts in lettuce plants. The composition of macro and micronutrients from a mixture of several organic wastes such as banana humps, onion peels, bean sprouts, and moringa leaves have been reported previously can to increase plant physiology and biochemistry. Dejene et al. (2020) found that LOF from mixing chicken manure+onion peels had significantly higher K, Ca, Mg, and Na than control and significantly increased the number of leaves and biomass of lettuce plants. Kechasov et al. (2021) also added that a hydroponic solution from organic waste had significantly higher Ca^{2+}, Mg^{2+}, and NO_3^- than the control solution and significantly increased chlorophyll and carbohydrates (glucose, fructose, sucrose). In addition, Ozobia (2014) reported that moringa leaf extract per 100 g had the highest nutrient contents sequentially, namely Ca, K, S, P, and Mg were 440; 259; 137; 70; and 24 mg, respectively.

The organic waste used as a hydroponic media solution was reported to have PGRs such as IAA, GA_3, and zeatin which affect plant physiological and biochemical processes. Although this study did not measure the

Table 8. The yield (kg m^{-2} year^{-1}) of Chinese cabbage plants due to the formulations, concentrations, and their interactions in the hydroponic solution.

Formulations	Concentrations (ppm)				Average
	600	900	1,200	1,500	
F1	0.98±0.04 d	1.03±0.01 d	1.08±0.11 d	1.37±0.05 d	1.12±0.04 c
F2	0.85±0.03 d	1.92±0.04 cd	1.83±0.07 cd	1.81±0.07 cd	1.60±0.13 bc
F3	2.08±0.10 cd	1.41±0.05 cd	1.64±0.03 cd	2.68±0.23 c	1.95±0.14 b
F4	4.41±0.08 b	2.68±0.14 c	6.89±0.10 a	4.78±0.29 b	4.69±0.43 a
Average	2.08±0.41 b	1.76±0.18 b	2.86±0.68 a	2.66±0.38 a	

Note: the mean followed by a different letter in the same column indicates significance by DMRT at *P*<0.05±standard error. Formulations (F1= banana peels+bean sprouts+eggshells; F2= banana humps+onion peels+bean sprouts+moringa leaves; F3= moringa leaves+onion peels+bean sprouts).

PGRs content of each formulation, Siahaan et al. (2022) reported that the highest IAA, GA_3, and zeatin were found in the organic wastes of banana humps, moringa leaves, and onion peels compared to banana peels and bean sprouts. Kurniati et al. (2019) also found that banana humps and onion peels had IAA, GA_3, and zeatin were 147.25; 223.64; 123.44 ppm, and 156.01; 230.67; 122.34 ppm, respectively. In addition, Basra & Lovatt (2016) also added that moringa leaves had PGRs such as IAA, zeatin, GA_3, and abscisic acid. According to Singh & Prasad (2015); Li et al. (2019); Mir et al. (2020) that the IAA had a role in increasing pigment content, chlorophyll contents, photosynthetic and transpiration rates, stomatal conductance, leaf area, and accumulation of carbohydrates (glucose, fructose, total soluble sugars) in plants. Nagar et al. (2021) reported that there was an increase in the rates of photosynthesis and transpiration, as well as stomatal conductance due to GA_3 treatment. Gajdošová et al. (2011) also added that there was an increase in chlorophyll due to cis-zeatin treatment compared to the control.

Concentrations effect

The concentrations of the hydroponic solution significantly increased the shoot fresh weight and yield ha^{-1} of Chinese cabbage plants, but it had an insignificant effect on other agronomic, physiological, and biochemical characteristics. The concentrations of 1,200 and 1,500 ppm increased the highest yield and shoot fresh weight by 2.86 kg m^{-2} year^{-1} and 30.70 g compared to other concentrations. Although the effect was insignificant, low concentrations (600-900 ppm) also had the highest effect on root length and volume, chlorophyll a, and antioxidants compared to the high concentrations (1,200-1,500 ppm). The higher increase in shoot fresh weight and yield ha^{-1} at a concentration from 1,200 to 1,500 ppm could be due to the resulting photosynthate rates. This can be seen from the highest leaf area and chlorophyll b was found at a concentration of 1,500 ppm (Tables 4 and 6). Likewise, the highest nitrogen and magnesium uptake was found at a concentration ranging from 1,200 to 1,500 ppm (Table 6). This finding was supported by Santoso & Widyawati (2020) that there was a positive and significant correlation (0.996*) between leaf area and fresh weight of Chinese cabbage plants in the hydroponic culture. The increasing leaf area results in a higher rate of photosynthesis in producing photosynthates. Djidonou & Leskovar (2019) reported an increase in lettuce biomass along with an increase in the N concentration in the hydroponic solution from 100 to 400 mg L^{-1}. Tripama & Yahya (2018) also added that the higher concentration of the hydroponic solution from 1,050 to 1,250 ppm had a significant impact on plant height, the number of leaves, root length, and biomass in three species of brassica plants.

Interactions effect

The interactions of formulations and concentrations in the hydroponic solution significantly increased shoot fresh weight, root dry weight, N content, and yields of Chinese cabbage. The F4C3 interaction (AB mix at a concentration of 1,200 ppm) significantly increased shoot fresh weight and yield by 51.28 g and 6.89 kg m^{-2} year^{-1} compared to other interactions. Likewise, interactions of F2C2 (banana humps+onion peels+bean sprouts+moringa leaves at a concentration of 900 ppm) and F3C2 (moringa leaves+onion peels+bean sprouts at a concentration of 900 ppm) significantly increased root dry weight and N content were 0.63 g and 3.08%.

The highest shoot fresh weight in the F4C3 interaction was caused by a higher number of leaves and leaf thickness compared to other interactions (Tables 3-4) and an impact on yield ha^{-1}. There was an increase in the shoot fresh weight with the increase in the number of leaves and leaf thickness, this increase was closely related to root development, such as root length and volume. A significantly correlated between root volume to the shoot fresh weight (0.374** and 0.671**) of Chinese cabbage plants. There was also found that the number of leaves and leaf thickness had a significantly correlated

Table 9. Correlation matrix between agrophysiology and biochemical with the yield of Chinese cabbage plants due to the formulations, concentrations, and their interactions in the hydroponic solution

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	PH	1																						
2	NL	0.933**	1																					
3	LA	0.933**	0.873**	1																				
4	LT	0.894**	0.888**	0.808**	1																			
5	RL	0.672**	0.677**	0.707**	0.696**	1																		
6	RV	0.412**	0.440**	0.515**	0.334*	0.383**	1																	
7	RFW	0.482**	0.483**	0.576**	0.386**	0.423**	0.948**	1																
8	SFW	0.662**	0.652**	0.712**	0.522**	0.374**	0.671**	0.737**	1															
9	RDW	0.354*	0.280	0.472**	0.188	0.235	0.728**	0.807**	0.705**	1														
10	SDW	0.129	0.189	0.184	0.118	0.089	0.435**	0.465**	0.564**	0.360*	1													
11	SRR	-0.222	-0.160	-0.274	-0.138	-0.239	-0.265	-0.291*	-0.116	-0.388**	0.531**	1												
12	CA	-0.106	-0.117	-0.186	-0.138	-0.097	-0.162	-0.128	-0.286*	-0.114	0.135	0.306*	1											
13	CB	-0.257	-0.245	-0.298*	-0.302*	-0.265	-0.236	-0.228	-0.282	-0.158	0.174	0.323*	0.834**	1										
14	TC	-0.142	-0.148	-0.215	-0.177	-0.136	-0.183	-0.153	-0.294*	-0.126	0.147	0.319*	0.993**	0.893**	1									
15	NC	-0.356*	-0.308*	-0.453**	-0.281	-0.308*	-0.257	-0.322*	-0.251	-0.217	0.075	0.339*	0.311*	0.376**	0.334*	1								
16	NU	0.086	0.144	0.132	0.078	0.049	0.408**	0.428**	0.539**	0.352*	0.991**	0.535**	0.152	0.208	0.168	0.178	1							
17	MgC	-0.395**	-0.380**	-0.530**	-0.308*	-0.360*	-0.337*	-0.385**	-0.267	-0.322*	0.016	0.215	0.046	0.051	0.048	0.528**	0.090	1						
18	MgU	0.006	0.036	0.032	-0.017	-0.074	0.354*	0.364*	0.490**	0.352*	0.908**	0.458**	0.117	0.146	0.126	0.215	0.938**	0.329*	1					
19	Ni	-0.606**	-0.616**	-0.541**	-0.520**	-0.377**	-0.465**	-0.536**	-0.405**	-0.355*	-0.060	0.273	-0.020	0.091	0.003	0.217	-0.033	0.253	0.013	1				
20	Ao	-0.111	-0.058	-0.007	-0.154	0.089	0.189	0.160	0.019	0.130	0.221	0.100	0.182	0.176	0.186	-0.023	0.207	-0.150	0.134	-0.065	1			
21	Fl	-0.624**	-0.632**	-0.561**	-0.693**	-0.565**	-0.374**	-0.351*	-0.338*	-0.097	-0.166	-0.020	0.016	0.140	0.043	0.207	-0.126	0.214	-0.023	0.605**	0.022	1		
22	Fi	-0.302*	-0.239	-0.347*	-0.255	-0.373**	-0.205	-0.192	-0.283	-0.263	-0.074	0.105	0.071	0.275	0.117	0.092	-0.059	0.140	-0.029	0.261	-0.260	0.268	1	
23	Y	0.874**	0.915**	0.859**	0.821**	0.634**	0.553**	0.607**	0.856**	0.463**	0.347*	-0.145	-0.239	-0.309*	-0.261	-0.274	0.306*	-0.356*	0.202	-0.519**	-0.048	-0.582**	-0.267	1

Note: * and ** showed a significant correlation at the level of 5% and 1%. PH= plant height; NL= number of leaves; LA= leaf area; LT= leaf thickness; RL= root length; RV= root volume; RFW= root fresh weight; SFW= shoot fresh weight; RDW= root dry weight; SDW= shoot dry weight; SRR= shoot: root ratio; CA= chlorophyll a; CB= chlorophyll b; TC= total chlorophyll; NC= nitrogen content; NU= nitrogen uptake; MgC= magnesium content; MgU= magnesium uptake; Ni= nitrates; Ao= antioxidants; Fl= flavonoids; Fi= fiber; Y= yield.

to the shoot fresh weight (0.652** and 0.522**). A similar result showed a significantly correlated (0.856**) between shoot fresh weight and yield ha^{-1}. It was influenced by the nutrients of the liquid chemical fertilizer more readily available to uptake by plants, thereby affecting root development in translocating nutrients to the plant shoots and forming a greater number of leaves and leaf thickness. This finding was supported by Maselesele et al. (2022) that root length and biomass were significantly correlated to the increase in the number of leaves, shoot biomass, and leaf area index of Chinese cabbage plants. Other results, the highest root dry weight in the F2C2 interaction was due to the high levels of chlorophyll a and total in these interactions compared to other interactions (Table 6). According to Chen et al. (2018) that total chlorophyll significantly correlated to the nitrate reductase enzyme in roots which reduces nitrate to nitrite and is closely related to N uptake.

In overall, the F2-F4 interactions with concentrations ranging from 900 to 1,200 ppm had macro and micronutrients that increase the growth of Chinese cabbage. This finding was supported by Dejene et al. (2020); Kechasov et al. (2021) that a hydroponic solution from organic waste had higher macronutrients such as K, Ca, Mg, Na, and NO_3^- than the control. In addition, LOF from organic waste significantly increased chlorophyll and carbohydrates (glucose, fructose, sucrose) and it had an impact on increasing the number of leaves and plant biomass. Enrawan (2019) also added that chemical LOF solutions (AB mix interaction at 7.5 ml L^{-1}) and natural LOF (interaction of bay-leaf+dry rice straw+banana stems+coconut fiber+cattle manure at 20 ml L^{-1}) significantly increased plant height, number of leaves, relative growth rate, net assimilation rate, shoot: root ratio, and yield index of Chinese cabbage plants in the hydroponic culture.

Organic wastes such as moringa leaves, onion peels, bean sprouts, banana humps, banana peels, and eggshells can be used as a liquid organic fertilizer for natural hydroponic solutions and are recommended as a substitute for using chemical solutions (AB mix). It was caused by the ability of organic wastes to show a greater response in physiology and biochemistry than comparison formulation (AB mix). Overall, this study indicated that F3C4 interaction (moringa leaves+onion peels+bean sprouts at a concentration of 1,500 ppm) can be used to produce a greater yield of Chinese cabbage in hydroponic culture as a substitute for using liquid chemical fertilizers.

Conclusions

There were an increase in the contents of Mg and chlorophyll b by 29.82 and 14.19% in the F3 (moringa leaves+onion peels+bean sprouts) and F2 (banana humps+onion peels+bean sprouts+moringa leaves) formulations. Likewise, there was an increase in nitrate and flavonoid contents by 89.04 and 195.35% in the F1 formulation (banana peels+bean sprouts+eggshells). The solution concentrations ranged from 1,200 to 1,500 ppm significantly increased the yield and shoot fresh weight by 2.86 kg m^{-2} $year^{-1}$ and 30.70 g. Among the organic interactions, F3C4 showed a higher yield and it can be recommended as a hydroponic medium.

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Wijaya, V.T., Teo, S.S. 2019. Evaluation of eggshell as organic fertilizer on sweet basil. International Journal of Sustainable Agricultural Research 6: 79-86. Table 1. Determination of natural solution formulations based on the highest N, P, K, and Ca nutrients from each organic waste

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.