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Research article

Impact of Marine Fish Amino Acid on Yield Parameters and Preventive Antioxidant in Okra

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Abstract: A field experiment was carried out to evaluate the effects of foliar-applied marine fish amino acids (MFA) on the growth, yield, yield components, and preventive antioxidant capacity of okra, as well as the interaction between okra varieties and MFA concentrations. The study used a split-plot design with four replications. Three okra varieties — RED FINGER, KN–OYV–02, and LUCKY FILE 473 — were assigned to main plots. Five concentrations were tested in the subplots (0.00, 1.50, 3.00, 4.50, and 6.00 ml/l). Yield per plant — a key indicator for growers — did not differ significantly among the three varieties but responded to MFA levels-plants treated with 3.00, 4.50, or 6.00 ml/l. MFA showed no significant differences among these higher concentrations; however, all produced higher yields than the untreated control and the 1.50 ml/l treatment. The greatest yield (1,271.49 g/plant) was obtained at 3.00 ml/l, followed by 4.50 ml/l (1,251.22 g/plant) and 6.00 ml/l (1,215.51 g/plant). Reducing sugar content did not vary significantly among the okra varieties but was influenced by MFA levels. LUCKY FILE 473 recorded the highest reducing sugar (~1.77 mg/ml). The concentrations 3.00, 4.50, and 6.00 ml/l yielded the highest reducing sugar levels (1.89, 1.84, and 1.77 mg/ml, respectively), with no significant difference among them, while the control plants had the lowest value (1.53 mg/ml). Among pigment traits, RED FINGER exhibited the lowest chlorophyll a, chlorophyll b, and total chlorophyll contents (2.96, 1.51, and 4.47 mg/g FW, respectively) but had the highest carotenoid concentration (0.50 μg/g FW).

Keywords: Antioxidant; marine fish amino acid (MFA); okra; yield

1. Introduction

The okra (*Abelmoschus esculentus* L.) is widely cultivated in tropical and subtropical regions. It is recognized by diverse local names such as “bhindi” in India, “krajiab kheaw” in Thailand, “bamia” in the Middle East, “gumbo” in the USA and France, “lady’s finger” in England, “quiabo” in Portuguese-speaking areas including Angola, “quimbombo” in Cuba, “guino-gombo” in Spain, and “okura” in Japan [1-3]. Species within the *genus Abelmoschus exhibit* notable variation in chromosome numbers, reflecting broad genetic diversity [4, 5]. Okra is cultivated both commercially and in home gardens, with major producing regions including India, Turkey, Iran, West Africa, Pakistan, Myanmar, Japan, Malaysia, Thailand, and the southern United States [6]. Okra is considered economically important and nutritionally valuable [7]. Fresh pods provide carbohydrates, proteins, vitamin C, and minerals such as calcium and phosphorus in relatively high amounts compared with other fruit vegetables [8]. They also contain mucilage, which influences texture and functional properties. Besides its dietary role, okra has long been used in traditional medicine, and pharmacological studies confirm its antidiabetic, antioxidant, antihyperlipidemic, and antihyperglycemic activities [9-11]. These bioactivities are attributed mainly to phenolic compounds [12].

Marine fish–derived amino acids, commonly formulated as fish amino acid or fish hydrolysate fertilizers, have been widely reported as effective biostimulants in various crop species. Previous studies demonstrated that foliar application of fish-derived amino acids enhanced vegetative growth, nutrient uptake, and yield in vegetables and field crops, including okra, chilli, lettuce, tomato, and wheat. These positive effects have been associated with improved photosynthetic capacity, increased chlorophyll content, enhanced antioxidant metabolism, and better nitrogen assimilation [13]. Given its nutritional and health-promoting properties, demand for okra is increasing in Thailand and elsewhere [3, 6]. However, okra production faces several challenges, including inconsistent yields, pest and disease outbreaks, pesticide residues, and rising costs of synthetic fertilizers [6]. Consequently, there is growing interest in alternative nutrient sources, particularly liquid amino acid fertilizers. MFA, produced through fermentation of fish-processing byproducts, provides readily available amino acids that can enhance plant growth and yield [13]. Although fish amino acid application has been shown to significantly improve growth and yield attributes of okra, wheat, and leafy vegetables under organic farming systems, plant responses vary across crop species, cultivars, and application rates. Despite these reported benefits, information regarding the optimal concentration of MFAs and varietal responses in okra, particularly in relation to yield components and preventive antioxidant traits under tropical field conditions, remains limited. Therefore, this study aimed to evaluate the effects of foliar MFA application on growth, yield, and preventive antioxidant capacity of three okra varieties, contributing to sustainable production and value-added utilization of marine byproducts within a circular economy framework. Consequently, there is growing interest in alternative nutrient sources that can improve productivity while supporting sustainable agriculture in line with SDG 2 (Zero Hunger). MFAs are produced by fermenting fish-processing byproducts to release plant-available amino acids that enhance growth and yield. Therefore, this study aimed to evaluate the effects of foliar MFA application on the growth, yield, and preventive antioxidant capacity of okra varieties, thereby generating evidence to support sustainable production practices.

2. Materials and Methods

2.1 Area research

Field experiments were conducted at the Department of Plant Science, Faculty of Technology and Community Development, Thaksin University, Phatthalung Campus, Thailand (7°37′N, 100°5′E). The study area has a tropical climate suitable for okra cultivation.

2.2 Plant material and fish amino acid spray

Three okra varieties — KN–OYV–02, LUCKY FILE 473, and RED FINGER — were cultivated as main plots. Seeds were sown at 3–4 seeds per hill and later thinned to one seedling per hole after two weeks. Planting beds measured 1 m × 7 m, with 75 cm spacing between rows and plots. Manure was incorporated at 1,000 kg/ha, and a basal application of 15-15-15 fertilizer was applied at 20 kg/ha. Routine cultural practices included hand weeding every two weeks and morning-evening irrigation. MFAs were obtained from PLANEAT FARM CO., LTD. MFA is a liquid organic nutrient derived from the fermentation of marine fish byproducts, containing essential amino acids that enhance plant metabolism and yield [13]. Foliar spraying began in the second week after emergence and continued twice weekly. Five concentrations were tested (0.00, 1.50, 3.00, 4.50, and 6.00 ml/l), with 0.00 ml/l serving as the control. The MFA level is calculated by dividing the initial amount of amino acids by the volume of the solution (water, in liters).

2.3 Yield and yield component record

Morphological and yield parameters—including Morphological aspects, plant height, leaf width, canopy width, first date of flowering, firmness, number of good pods, good pod weight, total yield, number of pods/plant, yield/plant, harvesting index, and major elements—were measured.

2.4 Chemical analysis

MFAs were applied to okra plants as foliar sprays at 2-week intervals throughout the growing period. Quality and biochemical traits included pod firmness, carotenoid content, reducing sugar, dietary fiber, chlorophyll a, chlorophyll b, and total chlorophyll content.

Leaf pigments were determined using spectrophotometry adapted from standard protocols [14–16]. Chlorophyll content was estimated after extraction with 80% acetone; absorbance was recorded at key wavelengths (A645, A646, A663) using a UV–Vis spectrophotometer. Carotenoids were quantified following Rebecca et al. [15]. Anthocyanin content was determined by the pH differential method [16], and reducing sugars were analyzed by the Nelson–Somogyi method [17].

A. chlorophyll a (μg/mL) = -1.93A646 + 11.93A663
   chlorophyll b (μg/mL) = 20.36A646 – 5.50A663
   total chlorophyll (μg/mL) = 6.43A663 + 18.43A646
B. chlorophyll a (μg/mL) = 12.7 (A663) – 2.69 (A645)
   chlorophyll b (μg/mL) = 22.9 (A645) - 4.8 (A663)
   total chlorophyll (μg/mL) = 20.2 (A645) + 8.02 (A663)

2.5 Statistical analysis

The study employed a split-plot design with four replications and 20 plants per replicate. Okra varieties were assigned to main plots, and MFA concentrations to subplots. The design was based on a randomized complete block arrangement to minimize field variability. The growth and all data (plant height, leaf width, canopy diameter, first date of flowering, firmness, pod number, pod weight, total yield, harvest index, sugar content, and various essential elements) from the 4 replications of all varieties and concentrations were subjected to a variance analysis (ANOVA) using SPSS 16.0 for Windows. Significant treatment differences were separated using Duncan's new multiple range test (DMRT) at the 0.05 probability level

3. Results and Discussion

The Physicochemical properties of the soil before and after plantation are provided in Table 1. The total nitrogen content in the soil during okra planting was low (0.16% and 0.14%). Similarly, the soil exhibited a medium level of phosphorus (35.33 and 36.01 mg/kg) with a corresponding low level of potassium (81.35 and 63.01 mg/kg) before and after plantation, respectively. Organic matter was low in both years (1.15% and 1.15%), while the water pH was weakly acidic at about 4.57 and 4.58 before and after the season, respectively.

Table 1. Physicochemical properties of soil

Soil properties	**Soil properties**		**Method of analysis**
	Before planting	**After planting**	
Organic matter (%)	1.15	1.15	Walkley-Black method
Nitrogen (%)	0.16	0.14	McKenzie method
P_2O_5 (mg/kg)	35.33	36.01	Flame photometric
K (mg/kg)	81.35	63.01	Oxidation
pH (H2O)	4.57	4.58	pH meter method
EC (dS./m)	0.08	0.08	

In this experiment, amino acids were derived from the fermentation of various species of marine fish, including *Caesio erythrogaster*, *Sardinella gibbosa*, purple-spotted bigeye *Priacanthus tayenus*, and *Pyjama cardinalfish*. These fish were fermented to extract amino acids, which were subsequently tested in a standardized laboratory. The analysis confirmed the presence of 21 essential amino acids, including alanine, arginine, aspartic acid, cystine, glutamic acid, glycine, histidine, hydroxylysine, hydroxyproline, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, valine, and glutamine. Furthermore, when examining other parameters such as electrical conductivity, acidity-alkalinity, total nitrogen content, total phosphorus content, total potassium, total calcium, total magnesium, and sulfur, the values were determined to be 23.77, 4.26, 0.33, 0.71, 0.75, 0.76, 0.12, and 0.01 percent, respectively (Figure 1).

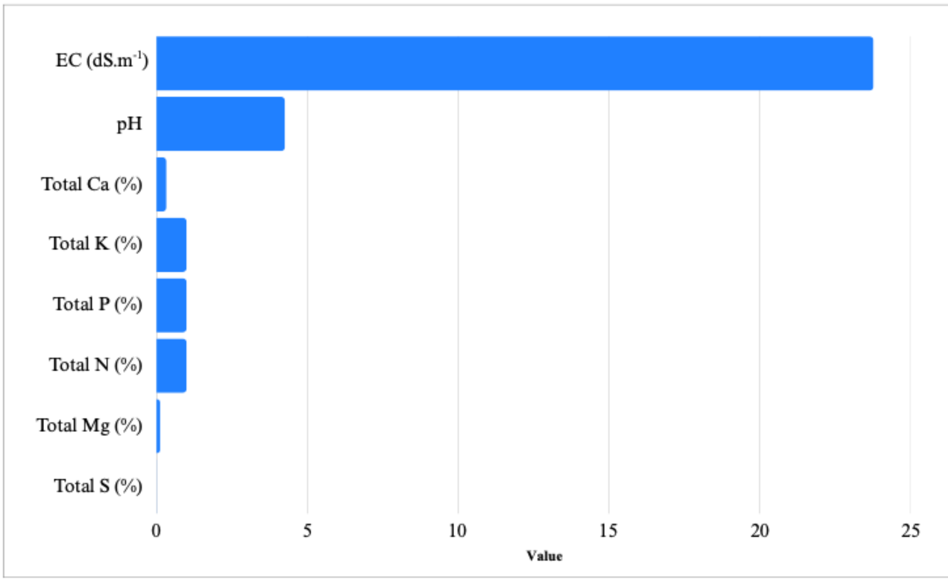

Figure 1. Acidity-alkalinity, electrical conductivity, and mineral content.

The MFAs were sprayed on the okra plant's foliage. Morphological aspects, leaf width, canopy width, first date of flowering, number of good pods, good pod weight, total yield, firmness, number of pods/plant, yield/plant, harvesting index, carotenoid, reducing sugar, fiber content, chlorophyll a, chlorophyll b, and total chlorophyll content were measured. It was found that each trait exhibited statistically significant differences across the various characteristics studied. Table 1 shows the physicochemical properties of soil, and the morphology of pod size, pod color, and pod length (Figure 2). The application of MFAs to the foliage of okra plants at 2-week intervals demonstrated a substantial influence on various aspects of plant physiology. Significant effects were observed on morphological characteristics [18], cell structure [6], trichome development [20], plant height and leaf width [19, 21], and canopy width [22]. Moreover, the application of MFAs significantly affected the first flowering date of bean plants. These findings underscore the multifaceted influence of MFAs on the overall growth and development of okra plants. Three okra varieties (KN–OYV–02, LUCKY FILE 473, and RED FINGER) were sprayed with MFAs twice per week at five concentration levels. Significant differences were observed in growth, yield, and yield components, as well as in preventive antioxidant traits, depending on okra variety, MFA concentration, and their interaction. Plant height differed significantly among okra varieties and MFA concentration levels (Table 2). Leaf width, an indicator of leaf size, showed a response pattern similar to that of plant height, with significant differences among varieties, MFA concentrations, and their interaction. KN–OYV–02 exhibited the widest leaf width (29.17 cm), while the highest mean leaf width across MFA treatments (27.89 cm) was recorded at an MFA concentration of 4.50 ml/L. Canopy width, reflecting the size of the mature okra canopy, was also significantly affected by both okra variety and MFA concentration. KN–OYV–02 recorded the largest canopy width (81.43 cm), whereas the highest mean canopy width among MFA concentrations (79.67 cm) was obtained at 3.00 ml/l. The interaction between okra varieties and MFA concentrations for leaf width and canopy width was statistically significant ($p < 0.05$)

Three varieties of okra, consisting of KN – OYV – 02, LUCKY FILE 473, and RED FINGER, were sprayed 2 times a week. The concentrations of MFAs were divided into 5 levels. Statistical analysis revealed significant differences in growth, yield, and yield components; preventive antioxidant levels; interaction between varieties; and amino acid content of okra. Statistical differences in plant height were observed between the okra varieties and MFA concentration levels. (Table 2). Leaf width, indicating leaf size pod after

MFA injection, had a similar effect as the height characteristics. Statistical differences were observed between the two okra varieties and the MFA concentrations. KN-OYV-02 displayed the widest leaf width (29.17 cm), while the highest value (27.89 cm) occurred at an MFA concentration of 4.50 ml/l. The canopy width, which measured the size of the mature okra canopy, showed statistical differences after spraying with MFA, affecting both okra varieties and MFA concentrations. KN-OYV-02 had the largest canopy width (81.43 cm), while the highest value (79.67 cm) was recorded at an MFA concentration of 3.00 ml/l. The interaction between varieties and MFA levels concerning leaf width and canopy width of okras showed a statistically significant difference ($p < 0.05$).

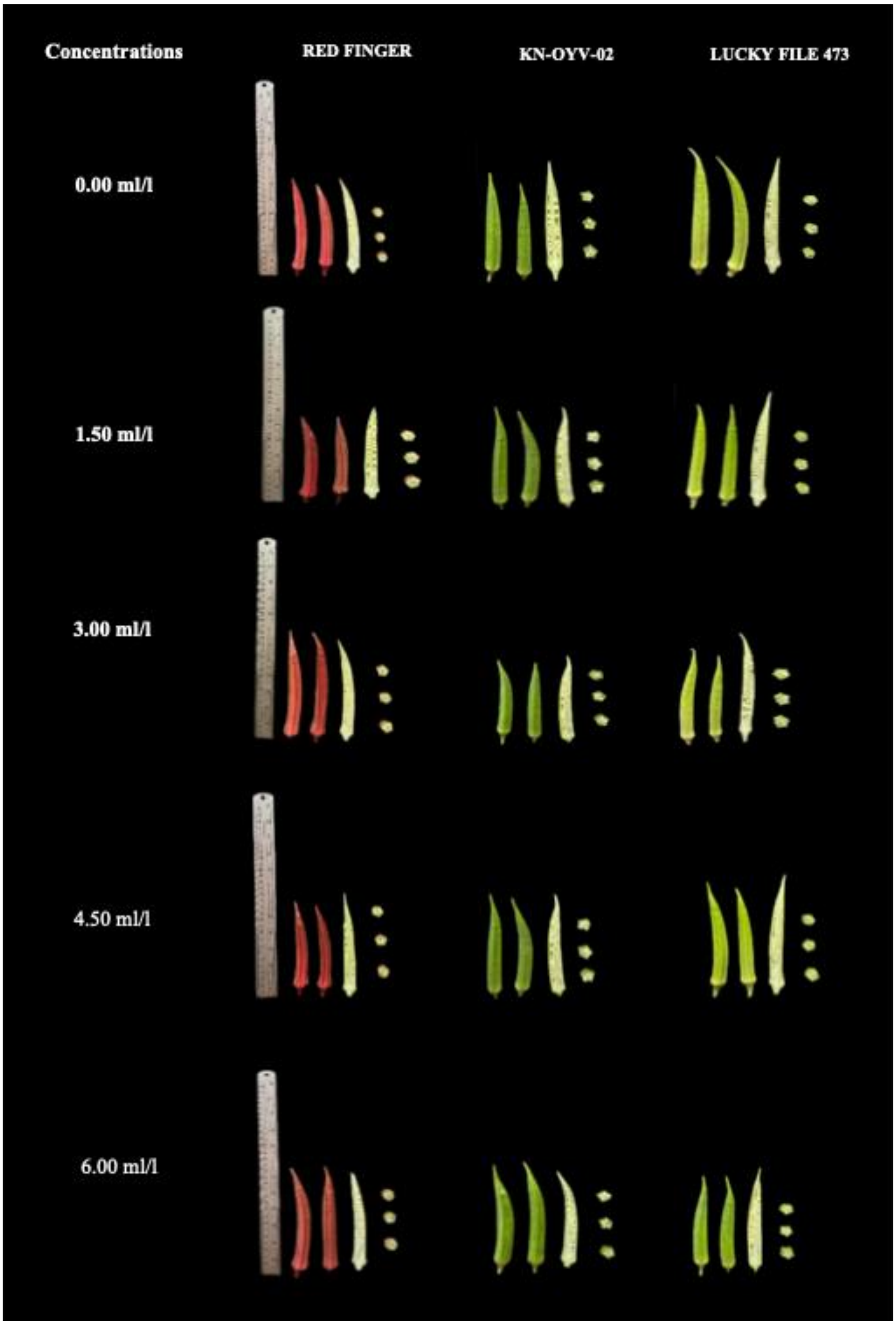

Figure 2. Pod size and pod color of okra sprayed with different concentrations of MFAs.

Table 2. Plant height, leaf width, and canopy width of okra after being sprayed by MFAs

Plant height (cm)	**Concentrations (ml/l)**					**Varieties (V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	162.67	170.33	171.33	164.50	177.83	169.33a
KN-OYV-02	147.66	163.16	163.26	167.00	172.00	162.62b
LUCKY FILE 473	131.50	166.50	124.83	145.33	155.17	144.67b
Concentrations Means (A)	147.28B	166.66A	153.14AB	158.94A	168.33A	
P-VALUE (F-TEST)						
VARIETIES (V)	= 0.0028*					
AMINO ACID (A)	= 0.0022*					
VxA	= 0.0024*					
(CV.%)	= 7.1394					
Leaf width (cm)	**Concentrations (ml/l)**					**Varieties (V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	25.00	25.83	21.50	19.83	23.33	23.10b
KN-OYV-02	24.67	24.50	25.33	35.66	35.68	29.17a
LUCKY FILE 473	28.50	30.50	27.00	28.17	16.17	26.07ab
Concentrations Means (A)	26.06A	26.94A	24.61B	27.89A	25.06AB	
P-VALUE (F-TEST)						
VARIETIES (V)	= 0.0021*					
AMINO ACID (A)	= 0.0046*					
VxA	= 0.0064*					
(CV.%)	=12.0521					
Wide canopy (cm)	**Concentrations (ml/l)**					**Varieties (V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	74.17	73.33	74.67	78.00	73.33	74.70b
KN-OYV-02	77.00	86.16	86.00	78.66	79.33	81.43a
LUCKY FILE 473	71.67	79.17	78.33	79.33	87.50	79.20a
Concentrations Means (A)	74.27B	79.55A	79.67A	78.66AB	80.05A	
P-VALUE (F-TEST)						
VARIETIES (V)	=0.0435*					
AMINO ACID (A)	=0.0012*					
VxA	=0.0031*					
(CV.%)	=5.4912					

Uppercase letters are horizontal comparison, lowercase letters are vertical comparison, ns, and * means not significant, significant at 0.05 level of probability.

Table 3 shows the characteristics of the first date of flowering and firmness. No statistical difference in the first flowering date was found among the okra cultivars, but a statistical difference in the concentrations of MFAs received by each plant was observed. RED FINGER exhibited the earliest first date of flowering at 38.20 days, while the MFA concentration was 3.00 ml/l. The earliest first date of flowering was 40.67 days. The harvest showed statistically significant differences among the cultivated okra varieties and the MFA concentration levels administered at each level. Specifically, KN-OYV-02 demonstrated the longest harvest period, lasting 48 days. Firmness, a crucial characteristic indicating consumer preference, showed no statistical differences in the traits of the cultivated okra cultivars. However, there were statistical differences in MFA concentrations across levels. KN-OYV-02 had the lowest firmness at 918.16 g with an MFA concentration of 3.00 ml/L, a value not statistically different from those at 4.50 and 6.00 ml/L.

Table 3. First date of flowering and firmness of okra after MFAs were sprayed

First date of flowering (day)	**Concentrations (ml/l)**					**Varieties mean (V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	37.00	37.00	39.00	39.00	39.00	38.20
KN-OYV-02	39.33	43.01	43.02	42.00	41.00	41.67
LUCKY FILE 473	41.00	39.12	40.00	40.00	40.00	40.02
Concentrations Means (A)	39.11B	39.71AB	40.67A	40.33A	40.00A	
P-VALUE (F-TEST)						
VARIETIES (V)	=0.3485ns					
AMINO ACID (A)	=0.0031*					
VxA	=0.0066*					
(CV.%)	=12.0014					
Harvest index (d)	**Concentrations (ml/l)**					**Varieties mean(V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	40.15	42.15	42.48	45.15	43.59	42.70b
KN-OYV-02	44.00	48.00	50.00	51.00	47.00	48.00a
LUCKY FILE 473	40.25	42.35	45.25	45.16	44.25	43.45b
Concentrations Means (A)	41.47C	44.17B	45.91A	47.10A	44.95AB	
P-VALUE (F-TEST)						
VARIETIES (V)	=0.0001*					
AMINO ACID (A)	=0.0085*					
VxA	=0.0042*					
(CV.%)	=4.6884					
Firmness (g)	**Concentrations (ml/l)**					**Varieties mean(V)**
	0.00	**1.50**	**3.00**	**4.50**	**6.00**	
RED FINGER	1012.35	999.14	982.15	989.30	979.58	992.50
KN-OYV-02	989.81	989.07	842.73	878.92	890.25	918.16
LUCKY FILE 473	1011.60	1003.12	990.25	989.68	998.25	998.58
Concentrations Means (A)	1004.59A	997.11AB	938.38C	952.63C	956.3BC	
P-VALUE (F-TEST)						
VARIETIES (V)	=0.2158ns					
AMINO ACID (A)	=0.0097*					
VxA	=0.0262*					
(CV.%)	=7.1658					

Uppercase letters are horizontal comparison, lowercase letters are vertical comparison, ns, and * means not significant, significant at 0.05 level of probability.

Yield/plant was the most important factor in farmers' decision-making. The results of this experiment indicated that there was no statistical difference in the characteristics of the Okra cultivars planted across all three species. However, there were statistical differences in the concentrations of MFAs obtained at each level: 3.00, 4.50, and 6.00 ml/l. No statistical difference was obtained among these levels. Nevertheless, a statistical difference was noted between the non-injection of MFA and the infusion of MFAs at a concentration of 1.50 ml/l. Injection of MFAs at a concentration of 3.00 ml/l resulted in the highest yield at 1,271.49 g/plant, followed by the application of MFAs at concentrations of 4.50 and 6.00 ml/l, with mean values of 1,251.22 and 1,215.51 g/plant, respectively (Figure 3A). The number of pods/plant, which was an important component of the three varieties, showed no statistical differences in the characteristics of the three okra varieties after spraying with MFA. However, there were statistical differences in MFA concentrations across levels. KN-OYV-02 had the number of pods/plant (67.99 pods). At an MFA concentration of 3.00 ml/l, the number of pods/plant (73.55

pods) was recorded, which was statistically different from MFA concentrations of 6.00, 1.50, and 0.00 ml/l, where the number of pods/plant was 67.72, 63.66, and 55.02 pods, respectively (Figure 3B). The number of pods/plant, a critical parameter for all okra varieties, showed no statistical differences in its characteristics after spraying with MFAs. However, there were significant variations in MFA concentrations at each level. KN-OYV-02 had the highest number of pods/plant (67.99). At an MFA concentration of 3.00 ml/l, the highest number of pods/plant (73.55 pods) was recorded, presenting a statistically significant difference from MFA concentrations of 6.00, 1.50, and 0.00 ml/l, where the number of pods/plant was 67.72, 63.66, and 55.02 pods, respectively and Yield/plant emerged as the most influential factor in farmers' decision-making. Findings from this experiment indicated no statistical difference in the characteristics of Okra cultivars planted, encompassing all three species. However, there were statistical differences in the concentrations of MFAs obtained at each level: 3.00, 4.50, and 6.00 ml/l. No statistical difference was noted among these levels. Nevertheless, a statistical difference was observed between the non-injection of MFA and the infusion of MFAs at a concentration of 1.50 ml/l. Injection of MFAs at a concentration of 3.00 ml/l resulted in the highest yield at 1,271.49 g/plant, followed by the application of MFAs at concentrations of 4.50 and 6.00 ml/l, with mean values of 1,251.22 and 1,215.51 g/plant, respectively. Similarly, Seyedi et al. [23] reported that amino acids affect growth and yield in many plants [24]. The weight per pod, an important constituent, showed that after MFAs were inoculated, there was no statistical difference in the characteristics of okra cultivars, but there were statistical differences in the concentrations of MFAs at each level. A statistical difference was observed in the absence of MFA intake. KN-OYV-02 had the highest weight per pod (17.99 g) at an MFA concentration of 0.00 ml/l, while it had the lowest weight per pod (16.85 g) at 0.00 ml/l (Figure 3C). The harvesting index, a biomarker of okra harvest time, showed that after inoculation with MFAs, there were significant differences in okra cultivar characteristics and MFAs concentrations at each level. KN-OYV-02 had the longest harvest index time at 48 days, while the MFA concentration of 4.50 ml/l had the longest harvest time of 47.10 days, but was not statistically different from the MFAs of 3.00 and 6.00 ml/l (Figure 3D).

Statistical analyses of plants, as documented in various studies [21,6], revealed substantial variation in growth, yield, yield components, antioxidant levels, interactions among varieties, and amino acid content of okra. Differences were notable in plant height among okra varieties and MFA concentration levels [25]. Leaf width, an indicator of leaf size post-MFA injection, showed effects similar to those of height characteristics, with statistical differences observed between okra varieties and MFA concentrations [26]. KN-OYV-02 exhibited the widest leaf width at 29.17 cm, with the highest value (27.89 cm) recorded at an MFA concentration of 4.50 ml/l. In terms of canopy width, the mature okra canopy size showed significant differences after MFA spraying, with effects on both okra varieties and MFA concentrations. KN-OYV-02 displayed the largest canopy width (81.43 cm), while the highest value (79.67 cm) was noted at an MFA concentration of 3.00 ml/l. The interaction between varieties and MFA levels regarding leaf width and canopy width of okra exhibited statistically significant differences. The first date of flowering and firmness indicated that although no statistical difference was found in the first date of flowering among okra cultivars, there was a significant difference in the concentrations of MFAs received by each plant. RED FINGER displayed the earliest first date of flowering at 38.20 days, with the MFA concentration at 3.00 ml/l, while the earliest first date of flowering was 40.67 days. Regarding firmness, a critical consumer preference indicator, there were no statistical differences in the traits of the cultivated okra cultivars. However, statistical differences were observed in the concentrations of MFAs obtained at each level. KN-OYV-02 had the lowest firmness at 918.16 g when the MFA concentration was 3.00 ml/l, a value not statistically different from those at 4.50 and 6.00 ml/l. This is consistent with the report of Baqir and Naqeeb [27], who reported that amino acid extracts had an effect on growth in wheat or tested the influence of marine fish amino extracts on okra yield [23]. Moreover, MFA of okra proteins shows that glutamic acid is predominantly present, with values ranging from 12.01 to 19.31 mg/100 g protein. This finding agrees with other previous studies, which reported that glutamic acid is always present in abundance in plant-based foods [28, 29]

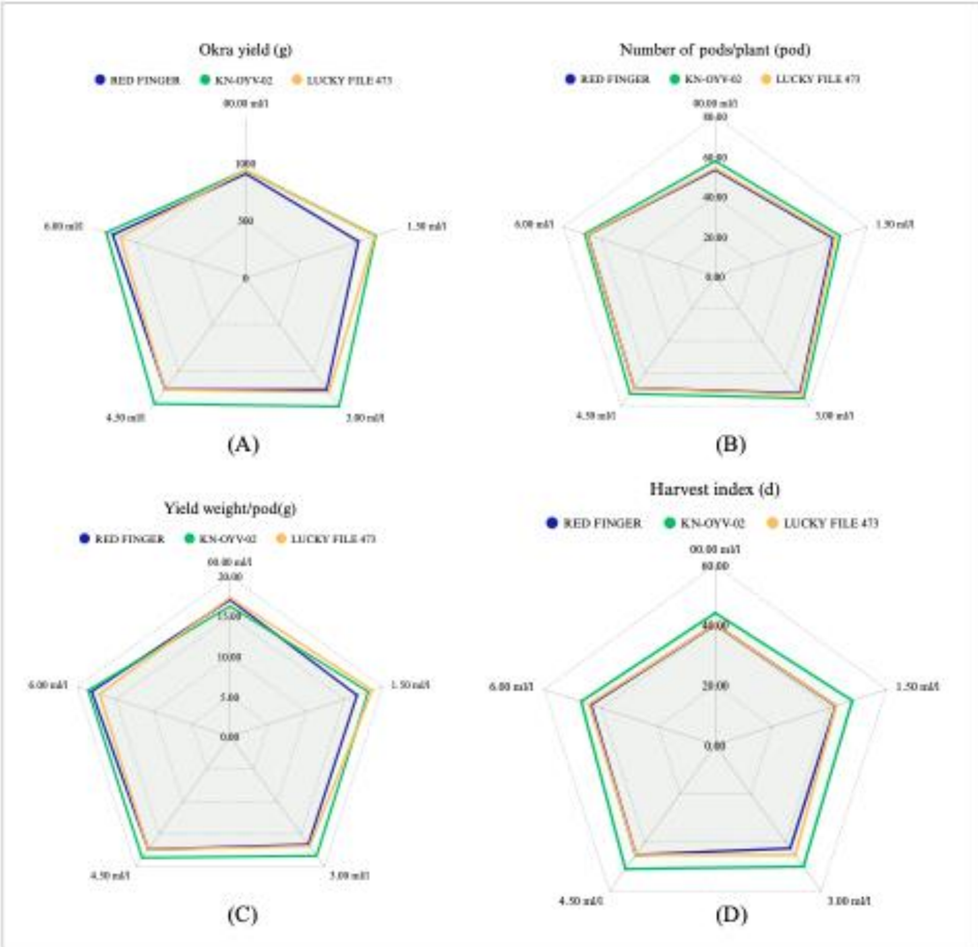

Figure 3. Yield and yield components of okra as affected by MFA treatments.

Carotenoids are yellow, orange, red, and orange-red pigments commonly found in plants. Organisms capable of photosynthesis use chlorophyll, a green pigment that absorbs energy from sunlight for photosynthesis and provides protection against light as an antioxidant. Statistical differences in carotenoid levels were obtained. RED FINGER showed the highest carotenoid content at 0.50 µg/g fresh weight, while KN-OYV-02 and LUCKY FILE 473 showed similar values at 0.06 and 0.07 µg/g fresh weight, respectively. The optimal value was found at MFA levels at 3.00 ml/l, with 0.26 µg/g fresh weight. However, there was no statistical difference in MFA intake at 4.50 and 6.00 ml/l, which were 0.22 and 0.23 ml/l, respectively, while non-injected MFA carotenoids contained the least number of carotenoids, 0.16 µg/g fresh weight (Figure 4). The determination of reducing sugar was performed using the 3,5-dinitrosalicylic acid (DNS) method. The results showed that reducing sugar levels was not different between varieties. However, a statistical difference was observed among the MFA levels used to treat okra. LUCKY FILE 473 showed the highest amount of reducing sugar, approximately 1.77 mg/ml. The optimal values were obtained with MFA intake at 3.00, 4.50, and 6.00 ml/l, with no statistical difference among them. The corresponding values were 1.89, 1.84, and 1.77 mg/mL, while the lowest reducing sugar content was 1.53 mg/mL. Dietary fiber, mainly found in fruits, vegetables, whole grains, and legumes, is well known for its ability to relieve constipation. The dietary fiber content of okra, after the infusion of MFA, exhibited statistical differences among the characteristics of okra varieties and the MFA at each level. LUCKY FILE 473 recorded the highest dietary fiber content at 1.22 g/100 g of solvent, while MFA levels of 1.50, 3.00, 4.50, and 6.00 ml/l showed no statistical difference. However, a statistical difference was observed compared to the control. MFA at 4.50 ml/l showed the highest dietary fiber content (1.21 g/100 g of solvent), followed by 3.00, 1.50, and 6.00 ml/l. with a dietary fiber content of 1.20, 1.18, and 1.17 g/100 g of solvent, respectively.

Chlorophyll a, chlorophyll b, and total chlorophyll content are important factors in farmers' decision-making. The RED FINGER variety had the lowest chlorophyll A content, averaging 2.96 mg/g fresh weight, while the concentrations of MFA obtained at each level showed statistical differences. The control treatment with MFA had the lowest value (5.04 mg/g fresh weight). The chlorophyll b content and total chlorophyll content varied among the cultivated okra varieties. KN-OYV-02 had the highest chlorophyll b (4.66 mg/g fresh weight). MFA treated at 3.00, 4.50, and 6.00 ml/l were the best and did not differ statistically. The values of chlorophyll b were 3.60, 3.92, and 4.15 mg/g fresh weight, respectively. In contrast, the control treatment (non-injection MFA) found that chlorophyll b contained the lowest amount of chlorophyll b (2.69 mg/g fresh weight). The total chlorophyll content was similar to the results shown in Figure 4. Statistical differences were observed in carotenoid levels, reducing sugar, fiber content, and chlorophyll among okra varieties. RED FINGER exhibited the highest carotenoid content at 0.50 μg/g fresh weight, while KN-OYV-02 and LUCKY FILE 473 showed similar values at 0.06 and 0.07 μg/g fresh weight, respectively. The optimum carotenoid value was observed at MFA levels of 3.00 ml/l, corresponding to 0.26 μg/g fresh weight. However, no statistical difference was observed in MFA intake at 4.50 and 6.00 ml/l, which were 0.22 and 0.23 μg/g, respectively, while the non-injected MFA carotenoids contained the fewest carotenoids, 0.16 μg/g fresh weight. Reducing sugar analysis revealed no differences between okra varieties. However, a statistical difference was observed among the MFA levels used to treat okra. LUCKY FILE 473 exhibited the highest reducing sugar content, approximately 1.77 mg/mL, as reported by Wiedemair et al. [30]. The optimal values were obtained with MFA intake at 3.00, 4.50, and 6.00 ml/l, with no statistical difference among them. The dietary fiber content of okra, after MFA infusion, showed statistical differences among okra varieties and MFA concentrations at each level. LUCKY FILE 473 recorded the highest dietary fiber content at 1.22 g/100 g of solvent, while MFA levels of 1.50, 3.00, 4.50, and 6.00 ml/l showed no statistical difference compared to the control. MFA at 4.50 ml/l demonstrated the highest dietary fiber content (1.21 g), followed by MFA concentrations of 3.00, 1.50, and 6.00 ml/l, with dietary fiber contents of 1.20, 1.18, and 1.17 g, respectively, as reported by [26]. The RED FINGER variety had the lowest chlorophyll A content, averaging 2.96 mg/g fresh weight, while MFA concentrations at each level showed statistical differences. The control treatment with MFA had the lowest value (5.04 mg/g fresh weight). The chlorophyll b content and total chlorophyll content varied among the cultivated okra varieties. KN-OYV-02 had the highest chlorophyll b (4.66 mg/g fresh weight). MFA treated at 3.00, 4.50, and 6.00 ml/l did not differ statistically, with values of 3.60, 3.92, and 4.15 mg/g fresh weight, respectively. In contrast, the control treatment (non-injection MFA) found that chlorophyll b contained the lowest amount of chlorophyll b (2.69 mg/g fresh weight). Ofosu-Anim and Leitch [31] reported that Microbes also play a role in chlorophyll levels, and the effects of microbes have been previously reported. demonstrated a significantly higher chlorophyll content in barley leaves, reflecting differences in the N content and uptake of organic manures. Moreover, Reghuvaran and Das Ravindranath [32] also reported that leaf chlorophyll content is important because photosynthetic activity and crop yields might increase with higher leaf chlorophyll.

Research on organic farming and organic food production is rapidly increasing worldwide because organic agricultural products are generally considered safer and healthier than conventionally grown food [24]. The current report confirms that MFA is the best form of liquid organic nutrients for maintaining soil fertility, as it supports a higher microbial population and promotes a more sustainable system of food production with a high nutritive value. This low-cost liquid technology could play a major role in protecting the environment, increasing the number of living biota in cultivable soil, and increasing yields in future agricultural practices. Moreover, the preparation of this MFA is quite simple, and every farmer can follow it; the ingredients are available in their farmyard at a low cost.

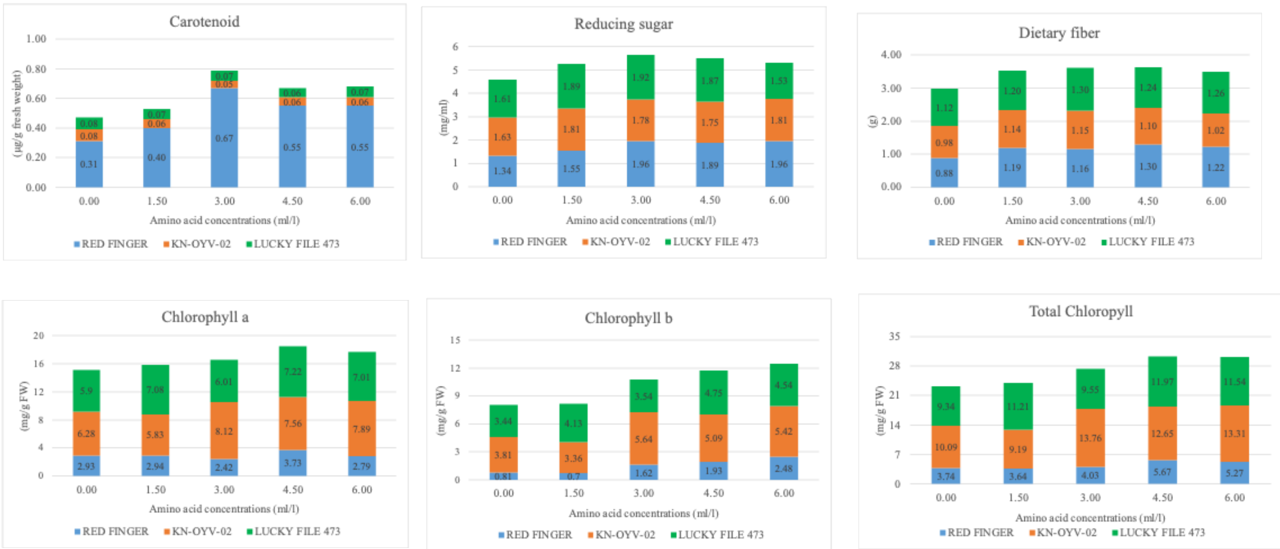

Figure 4. Carotenoid, reducing sugar, fiber, and chlorophyll contents of okra as affected by MFA concentrations.

4. Conclusions

The present study sheds light on the potential impact of MFA foliar applications on okra plant growth, yield, and antioxidant levels. Recognized for its pharmacological and health benefits, okra has shown promise for further enhancement through strategic MFA use. Key findings indicate that MFA at 3 ml/l had the most substantial effect on increasing plant growth, pod morphology, and yield. Additionally, notable improvements in various yield parameters, including plant height, pod length and width, yield/pod, and yield/plant, were observed in plants treated with 3.00, 4.50, and 6.00 ml/l, emphasizing their practical significance for yield enhancement. Furthermore, those dosages exhibited higher dietary fiber and reduced sugar concentrations, along with higher concentrations of carotenoids, anthocyanins, and total Chl, underscoring the potential of MFA composition to facilitate the biosynthesis of those phytochemical compounds. These outcomes reveal the promising potential of MFA foliar sprays to maximize okra growth, yield, and photosynthesis-related phytochemical concentrations. The practical implications of our research are noteworthy, offering a strategic approach for enhancing okra cultivation. This study has significant implications for sustainable agriculture practices and enhances the agricultural and pharmaceutical industries by improving both the nutritional and therapeutic qualities of this exceptional crop.

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