Gesunde Pflanzen (2022) 74:457–465
https://doi.org/10.1007/s10343-022-00622-5

ORIGINAL ARTICLE / ORIGINALBEITRAG

Exploiting *Eichhornia crassipes* Shoots Extract as a Natural Source of Nutrients for Producing Healthy Tomato Plants

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Received: 28 October 2021 / Accepted: 4 January 2022 / Published online: 21 January 2022

Abstract

Seeking for safe and cheap alternatives to provide the nutrient requirements of crops remains the most significant alternative for obtaining healthy and economical products. Thus, the present study aimed to assess the efficiency of aqueous water hyacinth shoot extract as a source of nutrients to feed tomato plants. Therefore, the effects of three fertilization treatments (without foliar spraying, commercial synthetic solution and natural solution of water hyacinth shoot extract) on the nutritional status and biomass yield of tomato were investigated. The experiment was designed in a randomized complete block design with three replicates. At different growth stages, several macro- and micronutrients, in addition to the final yield at harvest, were estimated. The results showed that at all growth stages of tomato (vegetative, flowering, fruiting and maturity), the natural solution of water hyacinth caused the maximum increases in phosphorus, iron, zinc, manganese, and selenium. However, the differences between the natural solution of water hyacinth and synthetic solution in nitrogen and potassium at the vegetative stage, phosphorus at the flowering and the fruiting stages, and manganese and selenium at the maturity stage were not significant. The increases in fresh and dry weights and fruit yield of tomato plants owing to the natural solution of water hyacinth application were 37.5, 56.8 and 72.2%, respectively, over the control. Natural organic solution of water hyacinth application increased the net return of tomato cultivation by approximately 1.84 and 1.63 times compared with the conventional practice (control) and synthetic chemical solution, respectively. It could be concluded that exploiting the natural organic solution of water hyacinth achieves several profits in agriculture via fertilization programs by enhancing the income of tomato farmers. Accordingly, it is recommended to benefit from the wastes of water hyacinth plants that are annually removed from the Nile River and other waterways.

Keywords Eichhornia weed · Enrichments · Healthy food · Natural nutrients · Nutrient content

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Nutzung von *Eichhornia crassipes*-Sprossenextrakt als natürliche Nährstoffquelle für die Produktion gesunder Tomatenpflanzen

Zusammenfassung

Die Suche nach sicheren und kostengünstigen Alternativen zur Deckung des Nährstoffbedarfs von Pflanzen ist nach wie vor die wichtigste Alternative zur Gewinnung gesunder und wirtschaftlicher Produkte. Daher zielte die vorliegende Studie darauf ab, die Wirksamkeit von wässrigem Wasserhyazinthen-Sprossenextrakt als Nährstoffquelle für Tomatenpflanzen zu bewerten. Daher wurde die Wirkung von drei Düngebehandlungen (ohne Blattspritzung, kommerzielle synthetische Lösung und natürliche Lösung aus Wasserhyazinthen-Sprossenextrakt) auf den Nährstoffstatus und den Biomasseertrag von Tomaten untersucht. Das Experiment wurde in randomisiertem vollständigen Blockdesign mit drei Wiederholungen konzipiert. In verschiedenen Wachstumsstadien wurden verschiedene Makro- und Mikronährstoffe sowie der endgültige Ertrag bei der Ernte geschätzt. Die Ergebnisse zeigten, dass in allen Wachstumsstadien von Tomaten (Vegetations-, Blüte-, Frucht- und Reifestadium) die natürliche Lösung der Wasserhyazinthe die maximale Zunahme von Phosphor, Eisen, Zink, Mangan und Selen verursachte. Die Unterschiede zwischen der natürlichen Lösung der Wasserhyazinthe und der synthetischen Lösung bei Stickstoff und Kalium im vegetativen Stadium, bei Phosphor im Blüte- und Fruchtstadium sowie bei Mangan und Selen im Reifestadium waren jedoch nicht signifikant. Die Zunahme des Frischgewichts, des Trockengewichts und des Fruchtertrags der Tomatenpflanzen durch die Anwendung der natürlichen Lösung der Wasserhyazinthe betrug 37,5, 56,8 bzw. 72,2 % gegenüber der Kontrolle. Die Anwendung der natürlichen organische Lösung der Wasserhyazinthe erhöhte den Nettoertrag des Tomatenanbaus um das etwa 1,84- bzw. 1,63-Fache gegenüber der herkömmlichen Praxis (Kontrolle) bzw. der synthetischen chemischen Lösung. Daraus lässt sich schließen, dass die Nutzung der natürlichen organischen Lösung der Wasserhyazinthe in der Landwirtschaft über Düngeprogramme mehrere Gewinne erzielt, indem sie das Einkommen der Tomatenbauern steigert. Dementsprechend wird empfohlen, die Abfälle von Wasserhyazinthenpflanzen, die jährlich aus dem Nil und anderen Gewässern entfernt werden, zu nutzen.

Schlüsselwörter Eichhornia-Unkraut · Anreicherung · Gesundes Essen · Natürliche Nährstoffe · Nährstoffgehalt

Introduction

Globally, tomato (*Solanum lycopersicon* L.) is considered one of the most important vegetables (FAO 2014) since it has several uses and health benefits for humans (Sanchez-Moreno et al. 2006; Piccardi and Manissier 2009; Singh et al. 2011).

Commercially, in nonorganic horticultural production, plant nutrition is mainly performed using synthetic mineral fertilizers. However, application of traditional mineral fertilizers to soil and plants has many disadvantages, such as increasing economic costs and negatively affecting the environment and human health. Therefore, there is a general interest in shifting to the use of organic fertilizers produced from available organic wastes in the surrounding environment (Mahanta et al. 2012). In organic cultivations, the uses of inorganic chemical additives, synthetic fertilizers, insecticides, and herbicides are excluded, while the use of natural extracts is allowable to improve soil biodiversity and decrease hazards to human health (Luttikholt 2007). Additionally, compared with conventional farming systems, organic farming practices lower the ecological issues by obtaining more tasty and healthy products (Woese et al. 1997). However, the yield is more unstable and/or lower in organic farming systems than in conventional farming systems (De Ponti et al. 2012; Vallverdu-Queralt et al. 2012). For sustainable production, the nutrient requirements of crops cannot be met by using a single source of nutrients such as mineral fertilizers; thus, an appropriate integration of organic and inorganic fertilizers is desirable for better yield (Khan et al. 2017). Kumar and Sharma (2004) reported that the use of organic fertilizer sources with mineral nitrogen, phosphorus and potassium fertilizers was more beneficial in terms of maximum yield and in providing macronutrients in tomato.

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) has received great attention worldwide owing to the ecological concerns that it causes to waterways (Feng et al. 2017). It is a free-floating aquatic plant that commonly grows in freshwater bodies such as lakes, rivers, streams, and ponds. The abundance of water hyacinth produces serious issues due to increased water loss and evaporation, retardation of water flow, interference with navigation, health hazards and alteration in the physicochemical characteristics of water (Awad 2008). The biomass of water hyacinth changes the water temperature and pH and reduces the percentage of water dissolved oxygen, which threatens water ecosystems, causing eutrophication phenomena (Mohamed and Rashad 2020).

Water hyacinth is very efficient in absorbing nutrients from irrigation water, such as Ca, Mg, S, Fe, Mn, Al, B, Cu, Mo, Zn, N, P, and K, which affects the quality of irrigation water and consequently the fertility of agricultural soils (Dandelot et al. 2008). Based on dry weight, water-hyacinth plants contained 15.7%, 13.1%, 3.7%, 21.1%, and 46.4% protein, ash, fat, fibers, and nitrogen, respectively, as well as 1234.6 mg 100 g^{-1} and 771.8 mg 100 g^{-1} potassium and calcium, respectively (Abdel Shafy et al. 2016). Water hyacinth consists of more than 70% organic matter on a dry basis (Jafari 2010) and high levels of N, P, and K content (Ilo et al. 2020). Accordingly, a remarkable number of studies have emerged for the potential use and conversion of water hyacinth into value-added products, suggesting a positive aspect of the weed (Sindhu et al. 2017; Li et al. 2021). Water hyacinth can be either mulched (Indulekha and Thomas 2018), composted (Ali et al. 2020), vermicomposted (Nath and Singh 2016) or anaerobically digested (Sharma and Suthar 2021) for biofertilization purposes. Water hyacinth can be used in compost and could then be applied to plants as a source of N, P and K (Kwabiah et al. 2003; Wasonga et al. 2008). However, the efficiency of water hyacinth plant extract as a biological source of nutrients still requires more investigation.

The current study hypothesized that the properties of aqueous water hyacinth shoot extracts could be exploited in crop fertilization programs to improve tomato nutritional status. Thus, this study aimed to determine the effect of water hyacinth shoot extract on the yield and nutritional health status of tomato plants as a substitute for synthetic foliar fertilizers to meet crop fertilization requirements.

Material and Methods

An experiment was conducted during the summer season of 2019 under greenhouse conditions at the Faculty of Agriculture, Ain Shams University, Qalubia Governorate, Egypt. Some physical and chemical analyses of the studied soil were determined according to the methods outlined by Cottenie et al. (1982) and Klute (1986), and the obtained results are shown in Table 1.

Table 1 Some physical and chemical characteristics of the studied soil sample (0–20 cm)

Character	Value	Character	Value
Particle size distribution		Available nutrients (µg g^{-1})	
Coarse sand (%)	14.5	N	67.0
Fine sand (%)	19.5	P	11.7
Silt (%)	33.7	K	818
Clay (%)	32.3	Fe	3.11
Textural class	Silty clay	Mn	7.74
Organic matter (g kg^{-1})	10.1	Zn	0.70
pH (1:2.5)	7.90	Cu	3.37
Total soluble salts (%)	1.54	Pb	2.12
EC_e (dS m^{-1})	3.65	Co	0.15

Preparation of Water Hyacinth Shoots Extract

Since the roots of water hyacinth (especially that grown in drains) are rich in enormous amounts of toxic heavy metals (Mohamed and Rashad 2020), we removed the roots and used only the shoots for preparing the aqueous extract. In this respect, a total of 500 g of fresh weight of water hyacinth shoot plants was grinded with 6 L distilled water under ambient conditions (25 °C ± 2). The extract was obtained by filtering the mixture through Whatman #1 filter paper. This filtrate was kept in the refrigerator until use. The chemical composition of the final aqueous extract is shown in Table 2.

The Treatments and Experimental Procedures

The experiment involved three fertilization treatments arranged in a randomized complete block design with three replicates based on the mathematical model presented in Eq. 1 (Casella 2008). Details of each treatment were as follow:

1. Control: Without foliar spraying and with soil addition of P and N fertilizers as a basal application adopted by the farmers (common farmer practice). In this respect, ordinary superphosphate (15.5% P_2O_5) at a rate of 144 kg ha^{-1} was applied during soil preparation. Moreover, ammonium nitrate (33.5% N), at a rate of 360 kg ha^{-1}, was divided into three portions and added through fertigation during the different physiological growth stages (see Table 3).
2. Chemical foliar fertilizer: In addition to soil application of P and N fertilizers as a basal application, foliar spraying of commercial synthetic chemical solution, which is relatively similar to the water hyacinth extract, was applied. The spray solution was applied in three applications during the different physiological growth stages (see Table 3).
3. Natural foliar fertilizer: In addition to soil application of P and N fertilizers as a basal application, foliar spraying of water hyacinth shoot extract as a natural organic solution was applied. The spray solution was applied six times during the different physiological growth stages (see Table 3).

Each spray solution was separately applied using a manual back-pack knapsack sprayer fitted with a flat-fan nozzle and calibrated to deliver 476 L water ha^{-1}.

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \tag{1}$$

where:

Y_{ij} is response, µ is an overall mean effect, τ_i is the treatment, β_j is the block effect, and ε_{ij} is error.

Table 2 Chemical composition of the water hyacinth shoots extract

pH	EC ($dS\ m^{-1}$)	N ($mg\ L^{-1}$)	P	K	Fe ($mg\ L^{-1}$)	Mn	Zn	Cu	Pb	Co	Cd	As	Se
7.45	1.75	24.1	35.4	130	1.25	1.32	0.12	0.04	< 1.50	< 0.20	< 0.10	0.20	0.19

Table 3 Fertilization management program of tomato plants under different nutrient supply

Tomato growth stage	Week no after transplanting. (date)	Treatment		
		Control	Synthetic chemical solution	Natural organic solution
Before planting		Adding 144 kg ha^{-1} of ordinary superphosphate (15.5% P_2O_5)		
Vegetative	4 (8/7/2019)	Adding 144 kg ha^{-1} of ammonium nitrate (33.5% N) through fertigation		
		–	Spraying tomato shoots with N–P–K liquid fertilizer (prepared from BAS commercial foliar fertilizer by weighing 200 g fertilizer and dissolving in 100 L tap water, contains 20% N, 19% P_2O_5, and 19% K_2O), 20 mL per plant	Spraying tomato shoots with water hyacinth shoots extract (10 mL per plant)
	5 (14/7/2019)	–	–	Spraying tomato shoots with water hyacinth shoots extract (20 mL per plant)
Flowering	7 (28/7/2019)	Adding 144 kg ha^{-1} of ammonium nitrate (33.5% N) through fertigation		
		–	Spraying tomato shoots with potassium sulfate (Eversol commercial fertilizer, 5 g L^{-1}, contains 50% K_2O, 18% S, and 46% SO_3), 20 mL per plant	Spraying tomato shoots with water hyacinth shoots extract (10 mL per plant)
	8 (4/8/2019)	–	–	Spraying tomato shoots with water hyacinth shoots extract (10 mL per plant)
Fruiting	10 (18/8/2019)	Adding 72 kg ha^{-1} of ammonium nitrate (33.5% N) through fertigation		
		–	Spraying tomato shoots with growth regulators (Flowering commercial fertilizer, 50 g L^{-1}, contains Naphthylacetic acid 1.5%, phthalamamide 0.6%, beta-naphthoxy acetic acid 0.6%, improvers 97.3%), 20 mL per plant	Spraying tomato shoots with water hyacinth shoots extract (10 mL per plant)
	11 (25/8/2019)	–	–	Spraying tomato shoots with water hyacinth shoots extract (10 mL per plant)

The total area of the experimental plot was 140 m^2, involving 3 ridges (1.5 m width and 31 m length). Tomato seedlings (c.v. Hybrid 010) were transplanted on the 24th of June 2019, with a distance of 30-cm between plants on the ridge. Tomato plants were irrigated through a trickle irrigation system, and emitter discharge 4.0 L hr^{-1}, at operating pressure of 1.0 bar.

Assessments

Tomato plant samples were collected randomly at different physiological growth stages (vegetative, flowering, fruiting, and maturity stages). Plant samples were dried at 70 °C and wet digested by a mixture of H_2SO_4 and H_2O_2 according to the method outlined by Cottenie et al. (1982). The total N content in the plants was determined by micro Kjeldahl using 5% boric acid and 40% NaOH as described by Chapman and Pratt (1961). The total P content was determined using a Spectrophotometer according to the method described by Watanabe and Olsen (1965). The total K content was determined using a Flame photometer (Chapman and Pratt 1961). Total micro- and heavy elements were determined using ICP Mass Spectrometry (Benton 2001).

At maturity, tomato plants were harvested on the 24th of September 2019 (92 days after transplanting). The harvested plants were collected to estimate the fresh and dry weight per plant. Moreover, fruit yield ha^{-1} was estimated.

Profitability

The economic evaluation was estimated by calculating the cost of cultivation for different agro-inputs, i.e., labors, fertilizers, irrigation, insect control, harvesting, and other necessary experimental requirements. The returns of each tested treatment were calculated ($ ha^{-1}) on the basis of the local market price according to Cimmyt (1988) as follows:

$$\text{Gross returns} = \text{Fruit yield x price of tomato yield ha}^{-1}\ (\$\ \text{ha}^{-1}) \quad (2)$$

$$\text{Net returns} = \text{Gross returns} - \text{cost of treatment}\ (\$\ \text{ha}^{-1}) \quad (3)$$

$$\text{Benefit/Cost (B/C) ratio} = \frac{\text{Gross return from treatment}}{\text{Total cost of treatment}} \quad (4)$$

The average prices were taken from the local market ($110 per ton of tomato).

Statistical Analysis

Analysis of variance (ANOVA) for the data was performed (Casella 2008) using the Costat software program, Version 6.303 (2004). Mean separation was performed only when the F-test indicated significant ($P \leq 0.05$) differences among the treatments, according to Duncan's multiple range test.

Results

Vegetative Stage

At the vegetative growth stage of tomato, N, P, K, Fe, Zn, Mn, and Se significantly responded to nutrient applications, while Cu, Co, Cr, and Ni were not affected (Table 4). The natural organic solution of water hyacinth along synthetic chemical solution increased N by 59.5 and 38.5% as well as K by 29.7 and 40.5%, respectively, greater than the control. Moreover, the natural organic solution of water hyacinth showed the highest values of P, Fe, Zn, Mn, and Se, surpassing both the control and synthetic chemical solutions.

Flowering Stage

All tested elements were significantly affected by nutrient application at the flowering stage of tomato, except Cu, Co, and Ni (Table 5). In this respect, application of the natural organic solution of water hyacinth was an efficient practice

Table 4 Effect of the natural organic solution of water hyacinth versus synthetic chemical solution on macro- and micronutrient contents in tomato plant at vegetative growth stage

Variable	Macronutrient			Micronutrient							
	N (%)	P	K	Fe (μg g^{-1})	Zn	Mn	Se	Cu	Co	Cr	Ni
Control	1.22^{b}	0.26^{c}	2.05^{b}	10.10^{b}	2.23^{b}	24.85^{b}	41.18^{b}	33.48^{a}	0.31^{a}	0.025^{a}	0.057^{a}
Synthetic solution	1.69^{a}	0.35^{b}	2.88^{a}	10.63^{b}	2.37^{b}	25.67^{b}	42.21^{b}	33.67^{a}	0.32^{a}	0.055^{a}	0.047^{a}
Natural solution	1.58^{a}	0.46^{a}	2.66^{a}	12.26^{a}	13.60^{a}	40.05^{a}	72.31^{a}	33.75^{a}	0.32^{a}	0.060^{a}	0.048^{a}

N nitrogen, *P* phosphorus, *K* potassium, *Fe* iron, *Zn* zinc, *Mn* manganese, *Se* selenium, *Cu* copper, *Co* cobalt, *Cr* chromium, *Ni* nickel
Different letters within columns indicate that there are significant differences at 0.05 level of probability

Table 5 Effect of the natural organic solution of water hyacinth versus synthetic chemical solution on macro- and micronutrient contents in tomato plant at flowering stage

Variable	Macronutrient			Micronutrient							
	N (%)	P	K	Fe (μg g^{-1})	Zn	Mn	Se	Cu	Co	Cr	Ni
Control	1.07^{c}	0.16^{b}	2.82^{b}	11.43^{b}	1.62^{b}	26.58^{b}	50.31^{b}	33.29^{a}	0.32a	0.028^{b}	0.046^{a}
Synthetic solution	1.21^{b}	0.25^{a}	3.49^{b}	11.20^{b}	2.22^{b}	27.18^{b}	54.76^{b}	34.34^{a}	0.32a	0.067^{b}	0.049^{a}
Natural solution	1.51^{a}	0.27^{a}	4.29^{a}	12.70^{a}	6.93^{a}	45.41^{a}	83.72^{a}	32.05^{a}	0.33^{a}	0.204^{a}	0.046^{a}

N nitrogen, *P* phosphorus, *K* potassium, *Fe* iron, *Zn* zinc, *Mn* manganese, *Se* selenium, *Cu* copper, *Co* cobalt, *Cr* chromium, *Ni* nickel
Different letters within columns indicate that there are significant differences at 0.05 level of probability

Table 6 Effect of the natural organic solution of water hyacinth versus synthetic chemical solution on macro- and micronutrient contents in tomato plant at fruiting stage

Variable	Macronutrient			Micronutrient							
	N (%)	P	K	Fe (μg g^{-1})	Zn	Mn	Se	Cu	Co	Cr	Ni
Control	2.84^{a}	0.25^{b}	3.09^{a}	10.20^{b}	1.26^{c}	27.29^{c}	41.30^{b}	33.32^{a}	0.320^{a}	0.058^{a}	0.047^{a}
Synthetic solution	3.35^{a}	0.33^{a}	3.44^{a}	10.86^{b}	2.33^{b}	35.47^{b}	41.63^{b}	33.25^{a}	0.313^{a}	0.052^{a}	0.048^{a}
Natural solution	3.43^{a}	0.33^{a}	3.99^{a}	13.30^{a}	7.49^{a}	41.42^{a}	53.84^{a}	33.58^{a}	0.325^{a}	0.073^{a}	0.046^{a}

N nitrogen, *P* phosphorus, *K* potassium, *Fe* iron, *Zn* zinc, *Mn* manganese, *Se* selenium, *Cu* copper, *Co* cobalt, *Cr* chromium, *Ni* nickel
Different letters within columns indicate that there are significant differences at 0.05 level of probability

Table 7 Effect of the natural organic solution of water hyacinth versus synthetic chemical solution on macro- and micronutrient contents in tomato plant at maturity stage

Variable	Macronutrient			Micronutrient							
	N	P	K	Fe	Zn	Mn	Se	Cu	Co	Cr	Ni
	(%)			(μg g^{-1})							
Control	2.39[a]	0.17[c]	2.53[c]	9.97[b]	1.63[b]	22.81[b]	40.59[b]	33.62[a]	0.322[a]	0.029[a]	0.046[a]
Synthetic solution	2.50[a]	0.22[b]	2.85[b]	10.37[b]	2.30[b]	28.09[ab]	41.62[ab]	33.36[a]	0.321[a]	0.072[a]	0.044[a]
Natural solution	2.53[a]	0.36[a]	3.21[a]	12.60[a]	5.15[a]	31.89[a]	44.29[a]	33.74[a]	0.323[a]	0.019[a]	0.048[a]

N nitrogen, *P* phosphorus, *K* potassium, *Fe* iron, *Zn* zinc, *Mn* manganese, *Se* selenium, *Cu* copper, *Co* cobalt, *Cr* chromium, *Ni* nickel
Different letters within columns indicate that there are significant differences at 0.05 level of probability

for enhancing N, P, K, Fe, Zn, Mn, Se, and Cr causing 41.1, 68.7, 52.1, 11.1, 327.7, 70.8, 66.4, and 628.5% increases, respectively, compared to the control. The difference between the natural organic solution of water hyacinth and synthetic chemical solution was not significant for phosphorus.

Fruiting Stage

At the fruiting stage of tomato, the natural organic solution of water hyacinth caused the maximum increases in P, Fe, Zn, Mn, and Se and equaled the synthetic chemical solution in P (Table 6). The other tested elements did not respond to nutrient applications.

Maturity Stage

P, K, Fe, Zn, Mn, and Se showed the maximum values at the maturity stage of tomato with application of the natural organic solution of water hyacinth. However, the differences between the natural organic solution of water hyacinth and synthetic chemical solution for Mn and Se were not significant (Table 7).

The fresh and dry weights and fruit yield of tomato were recorded, and the natural organic solution of water hyacinth significantly equaled the synthetic chemical solution. Moreover, fruit yield produced with the synthetic chemical solution was similar to that of the control. The increases in fresh and dry weights and fruit yield $plant^{-1}$ owing to natural organic solution of water hyacinth application were 37.5, 56.8 and 72.2%, respectively, over the control (Fig. 1).

Profitability

The economic analysis clarified that conventional treatment (control) was the cheapest practice, while synthetic solution was the most expensive practice (Table 8). In contrast, the highest gross and net returns as well as benefit/cost were achieved with application of the water hyacinth natural solution.

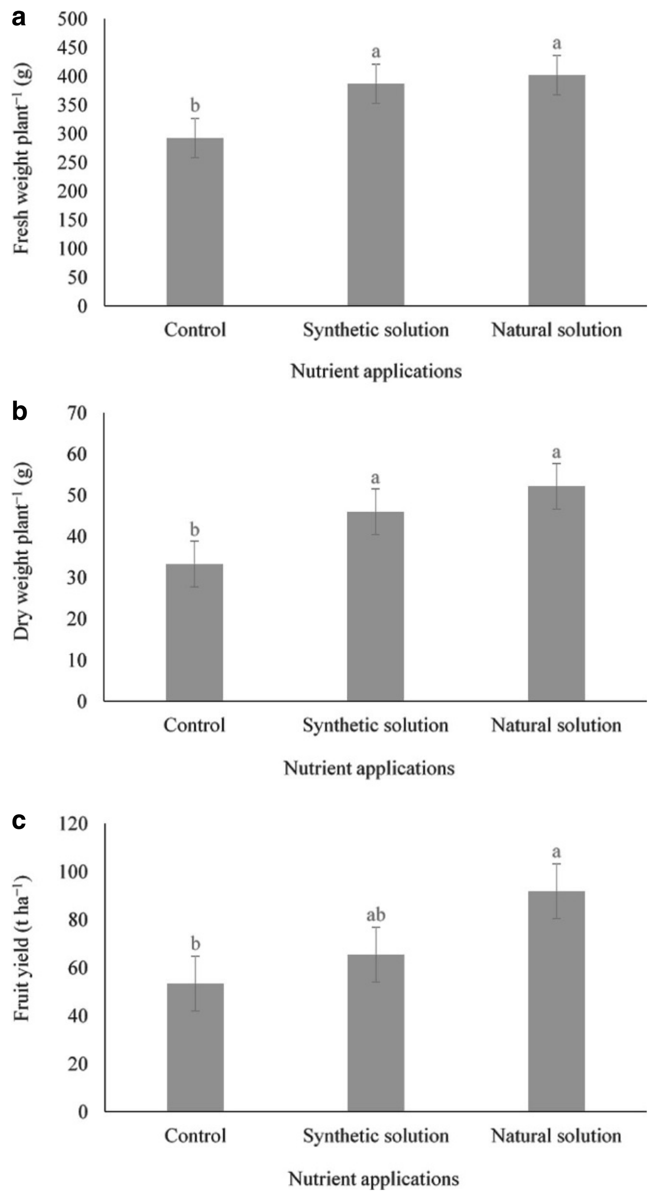

Fig. 1 Effect of the natural organic solution of water hyacinth versus synthetic chemical solution on fresh weight (**a**), dry weight (**b**) and fruit yield (**c**) of tomato plants

Table 8 Economic evaluation of tomato yield as affected by nutrient applications

Treatment	Cost of treatment ($ ha^{-1})	Gross returns	Net returns of treatment	Benefit/ Cost ratio
Control	1014.0	5865.2	4851.2	5.78
Synthetic solution	1724.3	7189.6	5465.3	4.16
Natural solution	1176.8	10,098.6	8951.8	8.58

Discussion

The findings of the current study clearly showed the beneficial effect of the water hyacinth shoot extract for increasing the concentration of the measured elements in tomato plants during their different growth stages (Table 4, 5, 6 and 7). Since the natural organic solution of water hyacinth involves several macro- and micronutrients (Table 2), it is considered a natural nutritional supply for crop plants. Mineral analysis revealed that Na, K, Mg, Ca, Fe, Zn, Mn, Cu and Co were detected in water hyacinth plant tissues (Abdel Shafy et al. 2016). Water hyacinth contains a high percentage of raw protein, up to 13.6%, and 1.5% fats and 24.8% fibers, in addition to 0.30% K, 1.43% Ca, 1.16% Mg, and 0.17% Fe (Al-Gasimi et al. 2018). Moreover, the extracts of water hyacinth shoots contain biologically active phytochemicals, including antiviral, antifungal, antitumor, and antibacterial agents (Abdelhamid et al. 2004), with functional groups of flavonoids, alkaloids, tannins, carotenoids, and phenols (Baral et al. 2011; Baral and Vaidya 2011). Moreover, anaerobic digestion experiments proved that water hyacinth could be an effective biofertilizer due to the presence of phytohormones, nutrients (N, P and K) and other bioactive compounds that enhance plant growth (Yu et al. 2010; Unpaprom et al. 2021). Additionally, water hyacinth is rich in oxidative enzymes and nonenzymatic antioxidant metabolites that may reduce plant pathogens (Mohamed and Rashad 2020). Haggag et al. (2017) found that foliar spray using a water hyacinth extract significantly decreased wheat leaf spots and increased grain yield.

Since the acidity of the spray solution plays an important role in absorbing nutrients by leaves (Peirce et al. 2019), the prepared water hyacinth aqueous extract had a pH of 7.45 (Table 2), which may enhance its efficiency as a source of nutrients. Thus, improvements in the nutritional status of tomato along all growth stages were obtained (Table 4, 5, 6 and 7). The aqueous water hyacinth extract increased the utilization of nutrients and dry matter accumulation (Fig. 1). The use of organic fertilizers from unexploited natural resources perceived as weeds, such as water hyacinth, would be a better alternative to improve soil fertility and increase crop yield (Osoro et al. 2014).

As foliar fertilization with natural organic solutions or synthetic chemicals caused significant increases in growth and yield, the nutrient supplying power of the soil to the fast-growing crops, such as tomato, did not fulfill the plant requirements of the crop. Foliar fertilization is essential for production, and water hyacinth extract is more efficient (Poudel et al. 2018). The results show that water hyacinth was superior, possibly due to its higher nutrient content as well as due to organic acids and amino acids and other small molecules present in the cell sab that not only facilitate absorption by leaves but also increase plant metabolism (Abdel Shafy et al. 2016).

It is interesting to clarify that the adequate limits of Ni, Co, Cr and Se (that considered mainly as heavy metals) within plant tissues range between 0.10–5.0, 0.02–1.0, 0.02–0.05 and 0.10–2.0 μg g^{-1}, respectively. While the toxic concentrations of such elements are 10–100, 15–50, approximately 30.0 and 5.0–30 μg g^{-1}, respectively (Kabata-Pendias and Pendias 2000). Accordingly, the concentrations of the estimated heavy metals in different plant parts of tomato, particularly in the fruit, still safe under tested treatments.

Since the natural organic solution of water hyacinth produced higher fruit yield, higher profitability was expected (Table 8). The increases in net return obtained with natural organic solution of water hyacinth application amounted to 1.84 and 1.63 times than the conventional practice (control) and synthetic chemical solution, respectively. This will undoubtedly improve the income of tomato farmers.

Conclusion

The current study suggests that water hyacinth could be converted into opportunities by using its biomass in useful and low-cost aspects. The analysis of natural components of water hyacinth clarified the possibility of safely using its natural organic extract in crop fertilization programs as a substitutional/integral source of nutrients. Due to its ability to improve cultivation profitability, it is recommended to fertilize tomato with water hyacinth shoot extract as an eco-friendly and costless biological origin fertilizer. However, future studies should be carried out in other field crops to generalize the benefits.

Funding This research was technically supported by the Faculty of Agriculture, Ain Shams University, Egypt.

Conflict of interest A. M. Elgala, S. H. Abd-Elrahman, H. S. Saudy and M. I. Nossier declare that they have no competing interests.

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