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Enhancing Tomato Yield Grown under High Temperature Conditions by Using Bio-Stimulant Substrates, Potassium Silicate and its Effect on Whitefly Infestation

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Abstract: This study was conducted at El-Kassasein, station Ismailia Governorate, Horticulture Research Institute, Agriculture Research Center through 2020 and 2021 summer seasons to enhance tomato yield grown under high temperature and whitefly infestation conditions in soil amended with composted Azolla (1kg/m^2 soil) or without amended and using biostimulant extracts, Azolla and Duckweed at concentrates 0, 10, 15% and potassium silicate (10gm/L) as foliar spray beside Amida plus (70%) as chemical insecticide specific to whitefly (30gm/100L). The results revealed that Azolla as an organic fertilizer or foliar spraying treatment at high level 15% were sufficient to obtain utmost values of tomato vegetative growth and yield characters under heat stress. Similarly for chemical fruit content where produced augment total soluble solids and lycopene however recorded the lowest content of titratable acidity. Amida plus 70% followed by potassium silicate have the efficient ability to control whitefly infestation hence reducing the number of nymphs/3 leaves and percentage of occurrence. Also, data indicated the possibility to use Duckweed extract at 15% concentrate as a natural substance which can be used as pesticides to control the populations of whitefly safely without disadvantages effects on human health or environment pollution.

Key words: Tomato · Bio-stimulant extracts · Potassium silicate · Whitefly' infestation

INTRODUCTION

Tomato (*Solanum Lycopersicum* L) is the second worldwide consumed vegetable, cultivated for fresh market or processing [1]. Egypt is one of the biggest tomato producers in the world occupied the fiftieth worldwide in tomato production. Their production reached 6.73122 million kilos with an average of 3.94 kg/m2 cultivated on 170.862 hectares, the tomato growing area was almost 32% of the total vegetable growing in Egypt [2]. Tomato is an important source of vitamins, minerals, antioxidants and is high water content [3, 4].

High temperature is series abiotic stress, induces several changes in plants, *i.e.,* morphological, anatomical, physiological and biochemical which lead to decrease the yield and its quality [5]. Plants exposed to heat stress produced the reactive oxygen species (ROS) such as hydrogen peroxide, singlet oxygen, superoxide and hydroxyl radical, however the accumulation of ROS causes adverse effects of plant total yield [6]. Whitefly (Bemisia tabaci) is one of the most serious pests which cause damage in agriculture around the globe [7]. Hence, plants consider the source of feeding, shelter and reproduction sites, or indirectly by excreting honeydew as a substrate for fungus growth, or by transmitting hundreds of plant viruses' species. The most economically important viruses are (Begomo virus) which causes leaf yellow mosaic, mottling, leaf distortion and stunting [8-10]. Chemical insecticides control has been the dominant strategy in B. tabaci management but causes many harmful effects such as environmental contamination [11-12]. In addition, the pest has developed resistance and cross-resistance to a wide range of insecticides in the field [13]. Therefore, the control of whitefly has received attention to minimize damage to plants, yield and other hazards resulting. Currently,

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natural products from plants have been considered one of the most promising sources to manage whitefly [14-15]. Natural plant extracts-based insecticides are very safe to use for human health, the environment and non-target organisms [16]. The plant substances considered insecticides must contain one or more of several compounds such as terpenes, flavonoids, alkaloids, phenols, or other related components [17]. The biostimulant substrates include seaweed extract, plant extract and hydrolysate, beneficial microorganisms, humic and fulvic substances and animal protein hydrolysate, that increase crop productivity, quality enhancing plant physiological, biochemical and modifying plant root development which makes their absorption and translocate nutrients become more efficiently [18-20]. Moreover, these materials can encourage photosynthetic efficiency, promote the accumulation of sugars in fruits, fruit set and storability and in addition stimulate plant tolerance to biotic or abiotic stresses [21].

Azolla and Duckweed are aquatic green plants known as free-floating plants that can commonly be found in slowly-moving bodies of water like lakes, ponds, ditches and lagoons. Azolla forms a symbiotic relationship with blue-green algae, *Anabaena Azollae* (cyanobacteria) which fixes atmospheric nitrogen (N2). Azolla is a source of protein, minerals, vitamins, carotenoids, bio-active substances, bio-polymers, probiotics and essential amino acids [22, 23]. In addition, the phytochemical properties of Azolla spp. were characterized as alkaloids, flavonoids, phenols, saponins, quinones, tannins, carboxylic acids, proteins, xanthoproteins, coumarins, steroids and carbohydrates [24]. Duckweed has been of great interest as high protein content and favorable amino acid pattern and converts various materials into high-quality edible tissues [25]. The phytochemical screening of several species of duckweed revealed that they were rich in tannins, saponins and phytic acid [26, 27]. Potassium silicate considers an anti-transpirant that forms a double layer that reduces transpiration in plants [28]. Silicon as a foliar spray can improve plant leaf chlorophyll content and the activity of anti-oxidation enzymes under stress conditions, consequently increasing crop performance [29]. Various researches has proven silicon's vital role in reducing the damages caused by insect infestation through several mechanisms. First, silicon sprays increase leaf tissue hardness, weaken herbivore mouthparts and reduce leaf digestibility by reducing the availability of carbohydrates during the digestion process which causes failure in digestion. Second, the availability of silicon in plant tissues leads to changes in the metabolic process, which improved plant resistance and reduces the damage caused by insect infestation [30, 31].

The goal of this investigation is to turn the aquatic green plants *i. e.,* Azolla and Duckweed into biostimulant sources for tomato plant production cultivated under the high-temperature conditions in addition, using their extracts as natural insecticide especially against whitefly which is remarkable the important pest which transport several virus diseases causes loss in tomato yield and its quality.

MATERIALS AND METHODS

Material Sources: Tomato seeds (*Solanum lycopercicum* L) cv. 010 F1 was obtained from (Makka Company for Vegetables Seeds, Bab El-Khalk, Cairo). Two aquatic green plants namely Azolla (*Azolla pinnata* L) and Duckweed (*Lemna minor* L) were obtained from Soil, Water and Environment Research Institute, Agriculture Research Center, Giza governorate. Also Potassium silicate (K_2Sio_3) in powder form was obtained from (El Gomhouria Company for Trading Chemicals and Medical Appliances, Cairo). Amida Plus (70%) for whitefly insect was brought from (Nafaa for Trading Agricultural and Insecticides, Bab El-Khalk, Cairo).

Preparation of Biostimulant Extracts: One kg of each previous aquatic green plant were soaked in one liter of ethanol (90% aq.) for 24 h and mixed by the blender. The mixture filtered twice through two layers of gauze cloth. The obtained crud solution was considered as 100% concentrate [32]. Ten and 15ml of crude solution was taken and diluted using 90 ml and 85ml distilled water to obtain extracts at concentrate of 10 and 15% respectively. The extracts were kept in the refrigerator at 4°C till use. The chemical compositions of Azolla and Duckweed basis on dry weight are shown in Table 1.

Experimental Lay out and Cultivated the Open Field: This investigate was set up at the experimental farm of El-Kassasein, Ismailia Governorate, Horticulture Research Institute, Agriculture Research Center. Seeds of tomato (*Solanum lycopercicum* L) cv. 010 F1 were sown in seedlings trays at second and third week of July during seasons 2020 and 2021 respectively. Seedlings trays (84 cells) were filled with mixture of peat-moss and vermiculite 1:1 (v/v). After appearance of the first true leaf, the agricultural practices were done in trays through the nursery stage according to the recommendation of the Ministry of agriculture. The experimental soil was treated

Table 1: The chemical composition of Azolla and Duckweed basis on dry weight

	Chemical compositions										
	($mg.g^{-1}$ dw)		Macro elements (%)					Micro elements (ppm)			
Aquatic green plants	Total phenolic	Tannins	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe
Azolla *pinnata*	5.46	4.23	4.5	1.31	1.04	2.23	0.45	30.02	26.29	348.17	533.12
Lemna minor	45.00	21.00	4.10	0.28	0.66	1.63	0.31	6.81	0.53	33.9	245.90

Table 2: Soil physical and chemical analyses

				Soil chemical analyses																
Soil physical analyses							Soluble cations (M/L)				Soluble anions (M/L)			Macro elements (ppm)			Micro elements (ppm)			
Text.	Sand (%)	Silt (%)	Loam (%)	pH	E.C. (dSm^{-1})	$CaCo_3$ (%)	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO^{-3}	Cl^{-2}	SO_4^{-2}	N	P	K	Fe	Cu	Zn	Mn
Sandy loam	80.3	2.0	17.6	8.4	0.2	5.2	1.0	0.5	0.3	0.2	0.2	0.5	1.3	40	66	40	3.0	0.8	1.0	1.5

Table 3: Mean of meteorological data during the two growing seasons of 2020 and 2021

	Temperature °C				Relative humidity (RH %)			
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Months	2020		2021		2020		2021	
June	37	24	35	26	75	41	70	43
August	36	24	35	26	80	45	73	45
September	34	22	34	24	74	40	71	42
October	28	19	30	23	68	37	69	38
November	26	24	28	23	65	38	63	32

with 20 m^3/feddan cattle manure during the third plowing as follow in tomato cultivation. The experimental soil was irrigated to speed up the decomposition process of organic substrate. Before 3 days of transplanting soil was divided in tow sections, first one was treated by composted Azolla (1kg/m^2 soil) in powder form in depth of 15-20cm then irrigated immediately and the second was left without Azolla additive. Seedlings were transplanted at 50 cm apart in one side of the row. The plot area was (18 m^2) includes 3 rows (5 m length and 1.20 m width). The fertilizers and other agricultural practices were done according to the recommendation of the Ministry of Agriculture for tomato plants in open field. The experimental was arranged in split plot design with three replicates. The amended with composted Azolla was arranged in main plot while spraying applications by bio stimulant extracts (0.0, 10 and 15%) of Azolla or Duckweed in additive to potassium silicate at 10g/L and Amida Plus (70%) at 30g/100L for whitefly was arranged in the sup plot. The physical and chemical analysis of experimental soil before transplanting as described by Chapman and Pratt [33] is shown in Table 2.

The temperature and relative humidity thorough the period of tomato growth and productivity in open field is shown in Table 3.

Agricultural Research Center, Central Laboratory for Agricultural Climate, Ministry of Agricultural and Land Reclamation.

Vegetative Growth Parameters: A sample of five plants were taken randomly from each plot at the flowering stag in order to determine plant length (cm), number of branches, number of clusters/plant and plant fresh weight (g). The plants were dried at 70 Cº till constant weight and then dry matter accumulation (%) was estimated as formula: (Dry weigh / Fresh weight) x 100. The total leaf chlorophyll content at the fourth upper leaves was recorded using Minolta chlorophyll meter SPAD-501 was recorded as SPAD unit.

Fruit Yield and its Quality: A sample of ten tomato fruits at marketable stage were randomly taken from each plot at the third picking to determine the following data: fruit length (cm), fruit diameter (cm), average fruit weight (g) and number of fruit/plant in addition to total fruit yield (total weight of picked fruits throughout the picking season in kg per plant converted to ton/feddan). The fruits were slides and dried at 70 Cº till constant weight to estimate the percentage of dry matter accumulation.

Fruit Chemical Content:

- Total soluble solids (TSS) of fruit expressed as Brix (%) were measured by hand held refractometer (ATAGOS 28 E model).
- Titratable acidity (TA) expressed as percent citric acid, were obtained by titrating 10 ml of tomato juice to pH 8.2 with 0.1N NaOH. The TA (%) was calculated from the following formula:

TA = [(Titra x 0.1 N NaOH X 0.67)/1000] X 100. [34].

- Ratio of TSS/TA (sugar to acid ratio) was calculated by dividing TSS reading, by the TA values [35].
- Lycopene (mg/100g fresh weight) was determined spectrophotometrically by extraction with hexane/ethanol/acetone and absorbance measurement at 503 nm [34].

Insect Infestation: For estimating the whitefly infestation of tomato plants samples of 10 composite leaves from each replicate, in total 30 leaves from three replicates were randomly picked at weekly intervals before 20 days from the first sprayer treatment till the end of spray application at first harvest. Each sample was kept in a tightly closed paper bag and transferred to the laboratory in the same day for inspection under stereomicroscope. Number of nymphs/ three leaves of whitefly (*Bemisia tabaci*) and the percentage of occurrence (%) was calculated using the following equation: (Number of insect per treatment /total numbers per all treatments) x 100, according to Amer [36].

Statistical Analysis: All data were subjected to statistical analysis according to the procedures reported by Snedecor and Cochran [37] using Statistix 8 program, the means were compared by L.S.D multiple range tests at the 0.05 level of probability in the two seasons.

RESULTS AND DISCUSSION

Vegetative Growth Parameters: Vegetative growth-related attributes by the plants subjected to different applications were presented in Table (4). The average increasing of two growing seasons in tomato plant parameters according to Azolla-treated soil *i.e.,* plant length, number of branches/plant, average fresh weight, dry matter accumulation percentage and leaf chlorophyll content reached 7.23, 37.95, 17.03, 5.53 and 4.35% overall the control treatment (soil without Azolla). Such encouragement related to compost Azolla amended soil is explained in Table (2) which shows Azolla dry weight amounts of nutrients that aid tomato plants to healthy growth. Several authors had reported that Azolla can fix nitrogen through forms a nitrogen-fixing symbiosis with the cyanobacterium Anabaena azollae, which is present in the leaf cavity of the fern, most of the fixed nitrogen becomes available after the Azolla has decomposed through four days if added in composting powder form, availability of N in the soil enhance its pH, therefore, providing a significant amount of P and increase the uptake of Ca and K. Also, Azolla as organic fertilizer increase soil content of organic carbon, urease, phosphatase activity, the population of heterotrophic bacteria, protein and essential amino acids, enhancing soil porosity, decreasing the specific gravity and bulk density [38, 42]. These results are in harmony with those proven by Shankar [43] on tomato treated with composted Azolla. The benefit related to foliar applications of different stimulant solutions Azolla, Duckweed and potassium silicate is appearing in Table (4) where, Azolla followed by Duckweed at high concentrate 15% (T4 then T6) were sufficient to obtain the maximum values of the all previous vegetative growth. Potassium silicate obtained lower results compared to Azolla or Duckweed (T1). This result was confirmed by Chrysargyris *et al.* [44] who reported that the application of stimulant extracts increased tomato plant vegetative growth and chlorophyll content compared to the control (tap water). On the other side, insecticide treatment (T2) Amida Plus (70%) has a depressing action of the vegetative growth (average two growing seasons) overall the control treatment reached 5.20, 14.41, 5.03, 5.28 and 6.97% for plant length, number of branches/plant, average fresh weight, dry matter accumulation percentage and leaf chlorophyll content respectively. The hazard impacts of Amida Plus (70%) which appear on our study may be attributed to the changes in physiological and metabolic processes in plant that led to loss of their vegetative growth as stated by Yıldıztekin *et al.* [45] or decrease photosynthetic pigment amounts and affect photosynthesis negatively [46]. These harmful effects resulting from the use of the insecticide on the tomato plant are in agreement with those obtained by Parween *et al.* [47] on mung bean, Zang *et al*. [48] on wheat, Ivanov *et al*. [49] on pea, Coskun *et al.* [50] on maize and Yildiztekin *et al.* [51] on tomato. This study was conducted under a high temperature and humidity environment during the months of June, August and September (Table 3). But Azolla and Duckweed treatments could alleviate the adverse effects of climate where, some literature state that biostimulant extracts contain phytohormones such auxins, cytokinins, gibberellins, abscisic acid and polyphenol compounds that improve plant photosynthesis, increase plant stomatal conductance, CO_2 assimilation rate, relative water content, cooling down the leaf temperature, improves the activity of catalase, peroxide degreaser, superoxide dismutase and nitrate reductase and reduces the concentration of malondialdehyde, H_2O_2 and $O_{2.}$ which expressed as healthy growth of plants under heat stress [52-54[. These results are in agreement with Mphande *et al.* [55] who reported that foliar spray is one of the widely accepted methods that support plants to tolerate heat stress though reflect the excessive sunlight, regulate plant metabolism processes and form leaf physical light film.

Table 4: Tomato plant vegetative growth as affected by bio stimulant extracts, potassium silicate and insecticide during the two growing seasons of 2020 and 2021

Treatments		Plant length (cm)	No. of branches/plant	Fresh weight (g)	Dry matter accumulation (%)	Chlorophyll (Spad)	Plant length (cm)	No. of branches/plant	Fresh weight (g)	Dry matter accumulation (%)	Chlorophyll (SPAD)
				1st season					2nd season		
Without Azolla	T0	55.96	9.82	415.66	14.06	48.62	53.25	11.40	487.33	13.18	50.52
	T1	59.75	10.85	441.67	16.66	52.39	57.96	13.12	504.33	16.78	52.04
	T2	51.46	9.15	409.84	12.92	47.92	51.02	10.38	454.17	14.27	46.91
	T3	63.32	12.86	458.17	18.98	59.10	62.74	14.30	524.06	19.79	58.76
	T4	69.08	13.87	593.37	22.21	62.26	68.76	14.64	567.04	24.00	63.23
	T5	59.86	12.03	445.67	17.46	55.11	60.52	12.38	510.19	17.20	54.71
	T6	66.76	12.93	561.00	19.12	59.73	64.45	12.96	545.67	18.95	60.56
With Azolla	T0	57.96	14.37	418.39	15.01	51.85	57.82	15.20	522.50	15.86	55.43
	T1	64.47	15.87	474.01	16.76	54.70	62.91	16.86	542.05	17.40	60.10
	T2	55.42	11.53	417.33	13.52	48.03	55.31	12.41	462.27	15.20	49.03
	T3	64.68	17.79	604.39	20.78	59.79	68.62	17.94	638.00	20.81	60.60
	T4	76.79	20.28	791.52	22.23	64.81	74.20	19.50	819.35	24.26	64.51
	T5	61.36	17.64	543.31	17.84	55.13	68.28	17.13	582.17	17.94	57.88
	T6	68.22	19.75	634.69	19.85	61.90	69.90	18.10	647.50	21.77	61.84
L.S.D at 5%		2.10	0.48	14.49	0.67	0.88	1.93	0.33	12.85	0.49	1.05
Spraying applications	T0	56.96	12.09	417.03	14.54	50.23	55.53	13.30	504.92	14.74	52.98
	T1	62.11	13.36	457.84	16.71	53.55	60.43	14.99	523.19	17.09	56.07
	T2	53.44	10.34	413.59	13.22	47.97	53.17	11.39	458.22	14.52	47.97
	T3	64.00	15.36	531.28	19.42	59.76	65.51	15.53	581.03	20.30	60.30
	T4	72.93	17.07	692.45	22.22	63.53	71.48	17.07	693.20	24.13	63.87
	T5	60.61	14.83	494.49	17.65	55.12	64.57	14.76	546.18	17.57	56.29
	T6	67.49	16.21	596.85	19.95	60.50	67.17	16.12	596.58	20.36	60.58
L.S.D at 5%		1.49	0.34	10.25	0.47	0.62	1.36	0.23	9.08	0.35	0.74
Without Azolla		60.88	11.62	475.05	17.34	55.02	59.81	12.74	513.26	17.74	55.25
With Azolla		64.13	16.74	554.81	18.00	56.60	65.29	16.73	601.98	19.03	58.48
L.S.D at 5%		0.78	0.24	7.04	0.36	0.60	1.07	NS	6.60	0.39	0.34

T0= Spray by tap water (0 concentrate) T1= Spray by potassium silicate (10g/L) T2= Spray by Amida Plus (70%) (30g/100L) T3= Spray by Azolla (10% concentrate) T4= Spray by Azolla (15% concentrate) T5= Spray by Duckweed (10% concentrate) T6= Spray by Duckweed (15% concentrate)

From this point, stimulant solutions in particular silicate foliar spray specially under abiotic stress may be appear beneficial effects to rise the plants tolerant of heat stress thus strengthen the leaf cortex wax layer consequently reduce transpiration, improve the plant leaf chlorophyll and total soluble sugar content, biomass accumulation, maintain membrane function and the activity of antioxidative enzymes as mentioned by Verma *et al.* [29], Hu *et al.* [56] and Saha *et al.* [57]. Plants grown in Azolla-soil and interacted by being sprayed with bio stimulant extracts (T3, T4, T5 and T6) influenced positively on previous plant growth parameters according to both types and rate of bio-stimulant treatment. The posted results are significantly occurring in plants grown in soil treated with composted Azolla and sprayed by Azolla at a concentration of 15% (T4). The augment data obtained by Azolla may be due to that Azolla symbiosis with cyanobacterium (Anabaena azollae) releases the nutrients like gibberellins, cytokinins, auxins, abscisic acid, vitamins, antibiotics and amino acids into the soil and as a foliar spray in an easily available form to plants resulting in vigorous growth as noticed by Bohlool *et al.* [58] and Wagner [59]. On the other side, plants grown in soil supplied by composted Azolla combined with potassium silicate (T1) as foliar spray under our experiment condition (high temperature) obtained high vegetative growth parameters compared to control treatment, but at the same time were lowest than bio-stimulant extracts (Azolla and Duckweed sprayed). Concerning the insecticide application data in Table (4) cleared that plants treated with Amida plus (70%) recorded fewer vegetative parameters as compared to control or other treatments. The negative effect of insect pesticide treatments may be due to the less amount of chlorophyll obtained by Amida plus (70%) this in turn affected photosynthesis and physiological processes leading to decrease in vegetative growth Hopkins [46] and Yildiztekin *et al.* [51].

Fruit Yield and its Quality: The effects of supplied soil with composted Azolla was found to be statistically significant to produce highest yield and fruit physical characters in terms of number of cluster fruits/plant, number of fruits/plant, average fruit weight, fruit length, fruit dry matter accumulation and total yield as ton per feddan, but was insignificant effect for fruit diameter in second season only (Table 5). The average percentage of increase in the two growing seasons was 13.81, 21.5, 4.69, 4.06, 2.71, 5.10 and 14.34% overall the control (soil without Azolla) respectively. Our results attributed to that composted Azolla as organic fertilizer increases the soil fertility regarding to its high nutrient content of N, P, K, Ca, Mg, Mn, Fe and the C/N ratio ranged 15-18% as

Table 5: Tomato fruit characters and yield as affected by biostimulant extracts, potassium silicate and insecticide during the two growing seasons of 2020 and 2021

Treatments		No. of cluster fruits/plant	No. of fruits/plant	Av. fruit weight (g)	Av. fruit length (cm)	Av. fruit diameter (cm)	Dry matter accumulation (%)	Total yield (ton/fedd)	No. of cluster fruits/ plant	No. of fruits/ plant	Av. fruit weight (g)	Av. fruit length (cm)	Av. fruit diameter (cm)	Dry matter accumulation (%)	Total yield (ton/fedd.)
					1st season							2nd season			
Without azolla	T0	3.13	30.80	79.35	4.03	4.53	4.21	17.09	3.34	28.90	94.28	4.16	4.53	4.41	19.04
	T1	3.26	32.61	103.96	4.71	5.02	4.45	23.70	3.52	29.99	109.62	4.75	5.12	4.61	21.54
	T2	2.85	29.96	65.80	4.23	4.34	3.83	13.78	3.18	24.91	71.19	4.06	4.63	4.12	12.40
	T3	3.65	33.45	114.18	5.45	5.50	5.48	27.84	3.79	32.04	114.10	5.30	5.60	5.75	25.53
	T4	3.85	35.18	119.98	5.52	5.61	6.41	29.49	3.84	32.50	117.38	5.60	5.74	6.19	26.70
	T5	3.37	32.98	113.08	5.14	5.30	5.10	24.50	3.65	31.31	113.20	5.17	5.52	5.26	25.01
	T6	3.70	34.03	116.91	5.33	5.47	5.20	26.36	3.70	31.89	114.93	5.43	5.61	5.95	25.83
With azolla	T0	3.39	36.55	95.67	4.48	4.71	4.72	27.69	3.96	30.28	99.55	4.32	4.18	4.52	21.10
	T1	3.81	37.87	104.50	5.15	5.04	4.88	30.08	4.14	31.31	104.76	5.22	5.24	4.71	23.17
	T2	2.79	32.71	81.27	4.27	4.54	4.23	18.64	3.45	28.42	78.89	4.11	4.69	4.15	15.68
	T3	3.55	39.04	116.16	5.37	5.66	5.50	30.68	4.42	32.24	118.21	5.54	5.64	5.98	26.78
	T4	4.19	41.37	119.90	5.67	5.82	6.77	31.68	4.81	34.29	121.78	5.70	5.93	6.21	28.80
	T5	3.87	37.95	114.21	5.22	5.45	5.29	30.15	4.13	31.74	115.78	5.42	5.57	5.39	26.16
	T6	3.95	39.20	117.58	5.50	5.77	6.04	31.44	4.67	33.05	120.00	5.67	5.86	6.02	28.20
L.S.D at 5%		0.15	1.04	1.69	0.13	0.10	0.12	0.72	0.14	0.59	1.58	0.10	0.16	0.06	0.43
Spraying applications	T0	3.26	33.67	87.51	4.26	4.62	4.46	20.79	3.65	29.59	96.92	4.24	4.67	4.47	20.07
	T1	3.54	35.24	104.23	4.93	5.03	4.66	25.70	3.83	30.80	103.69	4.98	5.15	4.66	22.35
	T2	2.82	31.34	73.53	4.25	4.44	4.03	16.21	3.32	26.66	75.04	4.08	4.00	4.14	14.04
	T3	3.80	36.25	115.17	5.35	5.57	5.35	28.58	4.09	32.18	115.70	5.42	5.66	5.88	26.02
	T4	4.02	38.27	119.94	5.60	5.71	6.59	30.51	4.32	33.71	119.58	5.65	5.83	6.20	27.74
	T5	3.62	35.46	113.65	5.18	5.37	5.20	28.60	3.89	32.14	114.94	5.29	5.54	5.32	25.89
	T6	3.71	36.61	117.25	5.48	5.62	5.81	29.64	4.17	33.02	117.47	5.55	5.69	5.96	27.17
L.S.D at 5%		0.11	0.74	1.19	0.09	0.07	0.09	0.51	0.14	0.41	1.11	0.07	0.11	0.04	0.31
Without azolla		3.39	32.72	101.89	4.91	5.10	4.95	23.51	3.57	30.20	103.96	4.92	5.25	5.18	22.23
With azolla		3.71	37.81	107.04	5.09	5.27	5.36	27.93	4.22	32.11	108.42	5.14	5.36	5.28	24.43
L.S.D at 5%		0.02	0.39	0.84	0.04	0.04	0.06	0.43	0.01	0.09	0.19	0.03	NS	0.02	0.06

T0= Spray by tap water (0 concentrate) T1= Spray by potassium silicate (10g/L) T2= Spray by Amida Plus (70%) (30g/100L) T3= Spray by Azolla (10% concentrate) T4= Spray by Azolla (15% concentrate) T5= Spray by Duckweed (10% concentrate) T6= Spray by Duckweed (15% concentrate)

reported by Djojosuwito [60], this rising soil ability to retain water enhancing soil microbial activity and promoting crop production [61-62]. similarly, in other comparative studies, the incorporation soil with Azolla biomass increased the total yield of many crops as reported by Milica and Favilli [63] on tomatoes, Ram *et al*. [64] on mung bean, Tekle-Haimanot and Doku [65] on taro, Plessner *et al*. [66] on cucumber, Singh *et al.* [67] on rice and Tejaswini *et al*. [68] on French bean. Regarding to foliar applications, Azolla followed by Duckweed as bio stimulant extracts then the potassium silicate gave greatest results of tomato yield and fruit attributes, the differences between these treatments were significant so all treatments (T1, T3, T4, T5 and T6) achieved values significantly higher than that observed in the control treatment. The maximum measurements in all previous traits gained with the high level 15% of Azolla then Duckweed concentrations (T4 and T6). These probably because that, the chemical composition of Azolla and Duckweed basis on dry weight (Table 1) revealed the presence of an appropriate amount of macro and micro nutrients, as well as that components encourage the tomato plant to resist the abiotic stress (high temperature) thereby reflected on plant productivity and fruits characters, in addition, presented tannins and phenols protect tomato plants from microbial infections, several authors confirms that tannins possess antimicrobial and fungal activity [69-71]. Our findings are in harmony with those obtained by Appenroth *et al.* [72] and Herawati *et al.* [73]. Using biostimulant extracts especially when plants grown under high temperature these led to an increase in the aforementioned traits compared to the control treatment (Table 5) it may be attributed to the potential of the biostimulants against some negative impacts of a changing climate on agriculture as reported by Yakhin *et al.* [21]. Furthermore, the applications of biostimulants have the ability to enhance plant metabolism, induce physiological responses and modification of biochemical processes in the treated plants [74, 75]. Therapy increase yield components compared to the control under high temperature condition. This finding is consistent with that found by EL-Shymaa [76] where it was explained that Azolla extracts increase plant yield and help to overcome the adverse effect of abiotic stress. Meanwhile, the potential of Duckweed extracts in promoting tomato plant yield and fruit quality may be related to the presence of several bioactive compounds and plant regulators that can trigger changes in metabolic processes in plants according to Del Buono [19] thus maintain plant crop and quality under our

experiment conditions. Presented data in Table (5) showed that foliar application by potassium silicate enhanced tomato yield and fruit quality, it was proposed that silicon can alleviate the adverse effects of abiotic stress thought increase the photosynthesis and proline concentration, enhance the plant water status, mineral balance and antioxidant defense also decrease the transpiration from stomata according to Hattori *et al*. [77], Gao *et al*. [78], Gong *et al.* [79] and Gong and Chen [80], therefore supports tomato plant growth and yield components under heat stress. These results are an agreement with those obtained by Lobato *et al.* [81] on pepper, Marodin *et al.* [82] on tomato and Pilon *et al.* [83] on potato. The obtained data in the current study also demonstrated that Amida Plus (70%) as insecticide had inhibitor influenced subsequently recorded less values on all tomato fruit traits and yield compared to the control treatment (T2) the average decreasing percentage (two growing seasons) estimated at 11.26, 8.41, 19.27, 13.38, 9.11, 8.51 and 26.12% for number of cluster fruits/plant, number of fruits/plant, average fruit weight, fruit length, fruit dry matter accumulation and total yield as ton per feddan, respectively. several studies pointed out that pesticide application causes a reduction of carbon and/or nitrogen metabolism this reduces the yield quantity and quality where crops mobilize their carbon and nitrogen reserves to re-orient their development from the growth process to defense pathways in order to overcome the stress generated by the chemical treatments as deduced by Gaëlle and Clément [84]. Our results are in harmony with those found by Hall and Forsyth [85], Caruso and Ramsdell [86] and Prange and DeEll [87]. About the interactions and its effect on plant productivity and fruit quality the plants grown in soil treated with composted Azolla and sprayed with biostimulant extracts produced high yields and good fruit characteristics. Also, for the plants that were treated with silicate, the interaction gave positively effect, despite their yield and fruit traits at a lowest rate.

The interaction resulting from Amida Plus (70%) as a foliar spray on plants grown in soil treated by composted Azolla was affirmative to obtain more yields compared to plants grown in soil without treatment.

Fruit Chemical Content: The response of tomato chemical content expressed as total soluble solids (TSS), titratable acidity (TA), the ratio of TSS/TA and lycopene (L) are differ according to soil treatments. Azolla amended soil had insignificantly affected fruit titratable acidity in the two growing seasons and TSS in the second season only, however, the significance was appear with respect to the ratio of TSS/TA and lycopene content (Table 6). Ratio of TSS/TA considers one of reasons which demonstrate fruit quality which characterize as good if the ratio content is within the range of 10 to 15 [88]. It was observed that plots supplied with composted Azolla produced fruit with lowest content of TA and high content of TSS this led to rise TSS/TA ratio trait, such given data may be returned to that tomato plants grown in plots amended with composted Azolla were achieved vigor vegetative growth and high leaf chlorophyll content as obtained above in Table (4) thus enhance photosynthesis rate and carbohydrate accumulation so tomato fruit content was increased of TSS. Data of TA according to soil amended with organic fertilizer as composted Azolla had less organic acids content than that grown in plots without treatment, this causing the lower content of TA in fruits as explained by Hallmann, [89] such results were confirmed by Bilalis *et al.* [90] who state that TSS/TA ratio could be related to the tomato plants vegetative growth. It was observed that the highest value of lycopene content recorded 4.44 and 4.19% in plots supplied with Azolla compost in two seasons respectively (Table 6). Lycopene content in tomatoes differs according to nutrient source and climatic conditions [91]. In stance, fruit lycopene content was more in plots of amended organic fertilizer than untreated one as reported by Adeniyi and Ademoyegun [92]. Plants spraying by Azolla and Duckweed significantly increase fruit chemical traits *i. e.,* TSS, ratio of TSS/TA and lycopene (L) with high concentrates 15% (T4 and T6). These results probably, because of the present of phytohormones contained in biostimulant extracts increase plant photosynthesis, secondary metabolism and induce physiological responses in the treated plants thereby enhance tomato fruit chemical content [93[. Furthermore, Duckweed extract suggests potential biostimulant activity that's contain phytochemical compounds which are an efficient to rise plant assimilate nutrients causes increasing in chlorophyll content consequently the physiological processes in treated plant since it is closely related to enhance fruit chemical quality [18]. These results are in consistent with those obtained by Gajewski *et al.* [94] in Chinese cabbage, Dobromilska and Gubarewicz [95] in tomato, Shehata *et al.* [96] in celery, Kaluzewicz *et al.* [97] and Del Buono *et al.* [19] on maize. These results revealed high fruit chemicals in terms of above traits with silicate application (T2) compared to control. The beneficial effects of silicate are ssociated with an increase in photosynthetic efficiency

Table 6: Tomato fruit chemical content as affected by biostimulant extracts, potassium silicate and insecticide during the two growing seasons of 2020 and 2021

Treatments		TSS (%)	TA (%)	TSS/TA	Lycopene (mg/100g)	TSS (%)	TA (%)	TSS/TA	Lycopene (mg/100g)
				1st season				2nd season	
Without Azolla	T0	3.44	0.80	4.28	1.65	3.36	0.75	4.46	1.81
	T1	3.76	0.73	5.15	2.42	3.68	0.66	5.53	2.54
	T2	3.06	0.77	3.96	1.39	3.11	0.75	4.12	1.39
	T3	3.88	0.36	10.88	2.75	4.17	0.44	9.67	2.92
	T4	4.62	0.35	13.40	4.23	4.24	0.38	10.07	4.48
	T5	3.40	0.47	7.24	2.51	4.07	0.51	8.15	2.50
	T6	4.24	0.44	9.78	4.02	4.11	0.40	11.19	4.08
With Azolla	T0	3.76	0.75	5.02	2.75	3.79	0.75	5.05	2.68
	T1	3.95	0.68	5.80	3.39	4.01	0.60	6.64	3.13
	T2	3.21	0.75	4.32	1.93	3.27	0.73	4.48	2.01
	T3	4.50	0.36	12.37	5.72	4.95	0.36	13.91	5.08
	T4	5.18	0.28	18.22	6.82	5.07	0.22	22.65	6.58
	T5	4.12	0.32	12.93	4.45	4.50	0.38	12.62	4.54
	T6	4.78	0.32	14.99	6.05	4.60	0.34	13.34	5.28
L.S.D at 5%		0.16	0.02	0.70	0.19	0.14	0.02	0.90	0.14
Spraying applications	T0	3.60	0.77	4.65	2.20	3.57	0.75	4.75	2.25
	T1	3.85	0.70	5.47	2.95	3.84	0.63	6.08	2.83
	T2	3.13	0.76	4.14	1.66	3.19	0.74	4.30	1.70
	T3	4.19	0.36	11.63	4.24	4.37	0.39	11.79	4.10
	T4	4.90	0.32	15.81	5.52	4.59	0.31	16.36	5.53
	T5	3.76	0.39	10.09	3.43	4.33	0.43	10.39	3.52
	T6	4.51	0.38	12.38	5.03	4.51	0.36	12.26	4.58
L.S.D at 5%		0.11	0.01	0.49	0.14	0.10	0.02	0.64	0.09
Without Azolla		3.77	0.56	7.81	2.71	3.82	0.55	7.60	2.82
With Azolla		4.21	0.49	10.52	4.44	4.30	0.48	11.24	4.19
L.S.D at 5%		0.03	NS	0.16	0.07	NS	NS	0.04	0.03

T0= Spray by tap water (0 concentrate) T1= Spray by potassium silicate (10g/L) T2= Spray by Amida Plus (70%) (30g/100L) T3= Spray by Azolla (10% concentrate) T4= Spray by Azolla (15% concentrate) T5= Spray by Duckweed (10% concentrate) T6= Spray by Duckweed (15% concentrate)

which produced more quantity of sugar due to rise fruit TSS as recorded by Valencia *et al.* [98] and Al-Aghabary *et al.* [99], improve tomato fruit content of beta-carotene and lycopene [100]. This is an agreement with Guixin *et al.* [101] and Soundharya *et al.* [102] however silicon application improve chemical quality of tomato fruits, thus led to increase soluble solids, titratable acidity ratio to total sugars (TSS/TA) and lycopene while reduction percentage (average two seasons) was observed in tomato fruit acidity (TA) trait regarding to different applications used as compared with control treatment which estimate 13, 1, 50, 59, 46 and 51% for (T1, T2, T3, T4, T5 and T6) respectively. It was reported by Abdelkader *et al.* [75] that the acidity rate in tomato tended to decrease as an effect of biostimulant treatment this is confirmed with Tarantino *et al.* [103]. Presented data in Table (6) indicate that Amida Plus (70%) as insecticide recorded the lowest values for all traits as compared to control or other treatments. Regarding the interaction effect, fruit chemical content *i., e.,* TSS, ratio of TSS/TA and lycopene were significantly increased with biostimulant extracts or potassium silicate foliar application especially in fruits grown in plots treated by composted Azolla, while the other interaction treatments led to a reduction results in fruit total acidity that was positive related to fruit quality. On the other hand, Amida Plus (70%) treatment was the worst obviously on the aforementioned traits and its values estimated the least at all.

Insect Infestation: The insect infestation expressed as the number of nymphs/three leaves and the percentage of occurrence were detected (Table 7). A significant reduction was witness in plots treated with composted Azolla, several literatures were gained the effect of nitrogen source and insects' reproduction and activity such Sudhakar *et al.* [104], Sashidhra [105], Balasubramanian and Muralibhaskara [106] and Samota *et al.* [107]. Thus, organic N source possibility causes changes in biochemical and enzyme activity in plants that make it unsuitable for sucking insects. Moreover, reduced the succulence of the foliage led to

Table 7: Effect of bio stimulant extracts, potassium silicate and insecticide on whitefly number of nymphs/ three leaves and percentage of occurrence on tomato plant during the two growing seasons of 2020 and 2021

		No of nymphs/three leaves	Percentage of occurrence (%)	No. of nymphs/three leaves	Percentage of occurrence (%)
Treatments		1st season		2nd season	
Without Azolla	T0	17.18	7.56	19.96	8.00
	T1	7.73	3.34	8.17	3.63
	T2	5.86	2.58	6.28	2.42
	T3	13.52	5.74	14.00	6.04
	T4	13.04	6.02	14.99	5.79
	T5	11.08	4.88	8.98	5.32
	T6	7.52	3.98	8.17	3.69
With Azolla	T0	14.17	7.50	14.41	7.72
	T1	6.32	3.16	6.54	3.15
	T2	4.47	2.38	3.12	1.72
	T3	11.38	5.22	10.87	5.41
	T4	9.86	5.96	10.13	5.63
	T5	9.18	4.80	8.22	4.56
	T6	7.19	3.41	6.66	3.47
L.S.D at 5%		0.78	0.37	0.71	0.32
Spraying applications	T0	15.67	7.53	17.18	7.85
	T1	6.76	3.25	7.41	3.42
	T2	5.17	2.48	4.70	2.07
	T3	11.11	5.30	12.06	5.52
	T4	12.45	5.99	12.93	5.91
	T5	10.47	5.05	10.98	4.94
	T6	7.63	3.69	7.76	3.55
L.S.D at 5%		0.55	0.26	0.50	0.22
Without Azolla		10.80	4.76	12.30	4.80
With Azolla		8.98	4.65	8.56	4.76
L.S.D at 5%		0.39	0.10	0.34	0.14

T0= Spray by tap water (0 concentrate) T1= Spray by potassium silicate (10g/L) T2= Spray by Amida Plus (70%) (30g/100L) T3= Spray by Azolla (10% concentrate) T4= Spray by Azolla (15% concentrate) T5= Spray by Duckweed (10% concentrate) T6= Spray by Duckweed (15% concentrate)

hardness pest's incidence [108]. As comparing between the foliar spray, it was notice that Amida plus (70%) as specific chemical application against whitefly was more influenced to induce maximum reduction in insect infestation, followed by potassium silicate, then Duckweed at 15% concentrate consequently (Table 7). Chemical insecticides are the most widely used method to control *B. tabaci* infestation the excessive use of these chemicals has led to disadvantages effects such humans' health risk, environment pollution, destruction of non-target organisms, beside causes rapid development of whitefly resistance [109-110]. Recently scientists developed a new strategy to increase the use of safe chemicals to overcome the problems resulting from intensive use of conventional pesticides as many natural substances which can be used as pesticides [111]. Therefore, products derived from plants with many active substances such Duckweed and Azolla are very important in this field. Bio-stimulants can induce chemical defenses inside plant tissues that affect herbivores directly, through toxic or repellent secondary metabolites and indirectly by the release of volatile organic compounds attractive to herbivores' natural enemies [112]. These induced defenses can be exploited in insects management through application of substances that induce or strengthen plant defenses prior to herbivores [113]. Instances, the extracts obtained from aquatic green plants should be contains secondary metabolites such as saponins, fatty acids, flavonoids, terpenoids, phenolic and some secondary minor chemicals compound these botanical products can be taken as insecticidal activity and characterized an alternative to chemical pesticides [114-115]. Duckweed extract had insecticidal action against the mosquito, contained synomones which consider oviposition, causes larval malformed and reduced survival [116]. The potential of Duckweed extract at high level 15% compared to Azolla extract may be because of the rise of its extract phytochemical of phenols and tannins as shown in Table (1) compared to Azolla. In this study it was observed that application of

potassium silicate significantly decreased in the population of immature whiteflies (T1). The basic mechanism of silicon applications on the pests is mechanical barriers (single or double-layer of silicon) which are connected directly under the cuticle [117]. Silicon provides protection through two defense mechanisms, Physical and biochemical defense. The physical conclude accumulation of absorbed silicon in the epidermal tissue increasing hardness that causes wear to insect mandibles and reducing digestibility [118]. Biochemical defense is attributed to enhanced production of defensive enzymes and phenolic compounds, increased accumulation of chitinases, peroxidases, lignin and phenolics [119]. Silicon application has been shown to decrease development, reproductive period, longevity and fecundity of insects [120]. Deposition of silicon on epidermis of leaves reduced the whitefly (*Bemisia tabaci)* populations through increased development time and nymph mortality as reported by Correa *et al.* [121] on cucumber and Ferrira *et al.* [122] on soybean. It is evident from the above findings that all the treatments were effective in reducing whitefly infestation after each spray in comparison to untreated control. Moreover, this finding indicates the possibility of reducing the amount of synthetic insecticides that will go into the ecosystem when botanicals are incorporated. Main factors regulating whitefly biology and population dynamics are climatic (temperature, rainfall and relative humidity), host-plant suitability, natural enemies, the temperature and host plant effects have been identified as important factors affecting development, mortality and fecundity rates in whitefly population modeling efforts [123]. Warm weather encourages the population of *B. tabaci* in tomato; a negative linear relationship was observed between number of whitefly/leaf, plant infestation and both high and low temperature and humidity [124]. Our study was carried out through high temperature and humidity as shown in Table (1). High temperature resulted in a decrease in the *B. tabaci* population and plant infestation possibly due to the fact that this weather achieves unfavorable conditions for survival of the immature stages of *B. tabaci* and which become desiccated Gerling *et al.* [125[and Salinas and Sumalde]126] this results are in line with that obtained by Nava-Camberos and Harris [127]. The interaction between composted Azolla as soil treatment and foliar spray by Amida plus (70%), potassium silicate and Duckweed at high level showed less whitefly infestation on plants respectively (T2, T1 and T6) as shown in Table (7).

CONCLUSION

This study highlighted to convert Azolla and Duckweed into fertilizer in various forms and then use it to improve plant productivity and alleviate abiotic (high temperature) or biotic stress (whitefly infestation). Tomatoes cultivated under high temperature can appear healthy growth and produce fruit with high quality by cultivation in soil supplied with composted Azolla and spraying plants with biostimulant extracts Azolla and Duckweed beside potassium silicate. High level 15% of Azolla followed by Duckweed was sufficient to enhance tomato vegetative growth, fruit yield and chemical content. Amida plus (70%) as a specific pesticide followed by potassium silicate are strongly active to reduce the whitefly infestation. Natural extracts derived from various plants such as Duckweed and containing chemical compounds act as pesticides *i. e.* terpenoids, phenolic and tannins prefer to be incorporated in insect control programs to avoid the worst effects of chemical pesticide.

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