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Influence of Spirulina Extract on Physiological, Qualitative, and Productive Traits of Four Sugarcane Genotypes

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Abstract: The study was conducted at El-Sabahia Research Station (latitude 31°12''N', longitude 29°58''E'), Alexandria, Egypt, to evaluate the effect of *Spirulina platensis* algae extract on the growth, yield, and juice quality of four sugarcane genotypes during the 2020/2021 and 2021/2022 seasons. The sugarcane genotypes tested (G.T. 54-9, G. 2003-47, G. 84-47, and G. 2004-27) were treated with four concentrations (0, 0.1, 0.2, and 0.3%) of Spirulina algae extract (SE) during their development as plant cane and first ratoon crops. At harvest, the growth, physiological, and juice quality characteristics were documented, while chlorophyll content was measured 210 days after sowing. Spraying canes with 0.2% of SE was the most effective treatment in enhancing all of the evaluated characteristics compared to those left without SE. Cane yield was more closely correlated with stalk weight (r = 0.88), followed by leaf area index (r = 0.82), chlorophyll content (r = 0.82), stalk length (r = 0.76), and number of tillers (r = 0.73), while recoverable sugar yield was closely correlated (P < 0.01) with sugar content% (r = 0.76).

Keywords: sugarcane; spirulina extract; foliar spray; growth; juice quality

1. Introduction

Growth promoters, which increase crop productivity per unit area, play a major role in improving agriculture. However, chemical-based growth agents are extremely dangerous for human health and the environment [1]. It then became a problem to meet the world''s' food demand while maximizing crop yields without endangering the environment. Because they may be used as effective fertilizers or growth-promoting agents for plants, microalgae and cyanobacteria have piqued interest [1].

Spirulina classified as a microalga within class Cyanophyceae according to the Botanists, but because of its prokaryotic structure, they categorized as a bacteria. [2]. As stated by Fenner et al. [3], Protein makes up 47% of the spirulina biomass, along with considerable amounts of Y-Linolenic acid (24.45 g 100 g-1 of fat), iron (16.27 mg 100 g-1), calcium (207 mg 100 g-1), and potassium (1675 mg 100 g-1). Poly-saturated fatty acids, plant pigments, proteins, amino acids, vitamin A, vitamin B, lipids, carbohydrates, and sugars are all present in *Spirulina platensis* algae [4,5]. Spirulina algae extract (SEs) promoted crop growth, enhanced yield, and enhanced plant absorption of nutrients from the soil. [6,7]. Applying SEs could increase sugarcane''s' production and sugar content [8,9]. In addition, the use of SEs could decrease fertilizer input and boost sugar yield. [8,9]. One type of bio stimulant that can enhance crop quality and growth is seaweed extracts (SEs). Natural hormones like auxin,

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cytokinin, gibberellin, and abscisic acid are mostly present, along with additional active ingredients such sugar alcohol, betaine, seaweed polysaccharide, and phenolic compounds[10,11], which have been used in agriculture for many years [12,13]. The enhanced growth-promoting action of seaweed extracts on plants can be attributed to a combination of active compounds that act either directly or by modulating gene expression in the plant. [14].

One of Egypt''s' primary sources of sugar production, sugarcane (*Saccharum* spp. L.) is a significant cash and industrial crop. It is a substantial source of renewable energy in the interim [15]. Sugarcane genotypes are regarded as the fundamental basis of the sugar industry. Furthermore, they exhibit genetic variations in their growth attributes, such as stalk length, diameter, fresh weight, and so on. Similarly, they vary in their quality attributes, such as sucrose content, levels of reduced sugars, juice purity, and sugar recovery percentage, among others, soil and agronomic practices have an impact on all characteristics of cane genotypes [16].

The sugar industry in Egypt hinges on Upper Egypt''s' refineries, representing 77% of the nation''s' sugarcane fields clustered there. While the Middle and Delta regions contribute a further 15% and 8%, respectively [17]. The Egyptian government''s' current concerns about sugar cane water requirements restrict the amount of land that can be grown with sugarcane. However, there is hope that Egypt's' sugarcane production can be optimized and that a sustainable solution to meet the country's' sugar needs may be found in the use of spirulina algae extract, a natural stimulant that has the potential to increase crop productivity and quality within existing fields.

The primary objectives of this study were to assess the impact of different concentrations of *Spirulina platensis* algae extract on the growth, yield, and juice quality of specific genotypes of sugarcane. Additionally, the study aimed to examine the relationship between various characteristics of this crop.

2. Materials and Methods

The current study examined the effects of spraying four levels of spirulina algae extract treatments (0.0, 0.1, 0.2, and 0.3%) on the growth yield, and juice quality of four sugarcane genotypes (G.T. 54-9, G. 2003-47, G. 84-47, and G. 2004-27), as well as their interactions, at El-Sabahia Research Station (latitude of 31°12'N and longitude of 29°58'E), Alexandria, Egypt, during the 2020/2021 and 2021/2022 seasons. Figure 1 provides an overview of the meteorological data collected during the research term in Alexandria.

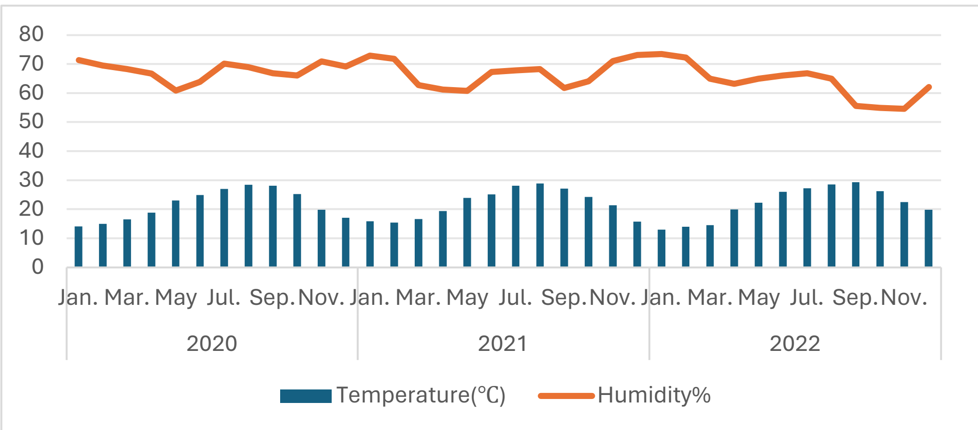


Figure 1. Monthly average temperature (℃) and humidity %.

***Spirulina platensis* Extract:** The powdered extract of spirulina algae was obtained from the National Research Center located in Dokki, El-Giza, Egypt. Table 1 announces the findings of the analysis conducted on the *Spirulina platensis* extract.

Table 1. Chemical examination of *Spirulina platensis* algae per 100 g as reported by Koru et al. [18].

Components	Value (in mgs)	Components	Value (in mgs)
Moisture	3500	Sodium	1090
Protein	63500	Magnesium	250
Fat (Lipids)	9500	Provitamin A	213
Fibre	3000	Thiamin (V.B1)	1.92
Ash	6700	Riboflavin (V. B2)	3.44
N- free extract	15000	Vitamin B6	0.49
Phycocyanin	15600	Vitamin B12	0.12
Carotenoids	456	Vitamin E	10.40
Chlorophyll- a	1300	Niacin	11.30
Phosphorus	916	Folic acid	40
Iron	53	Pantothenic acid	0.94
Calcium	168	Inositol	76
Potassium	1830		

The tested sugarcane genotypes were planted at random in the main plots of a randomized complete block design with four replications. In the sub-plots, spirulina algae extract levels were sprayed on the sugarcane three times at 60, 90, and 120 days after planting. Genotypes were planted on the third week of March 2020 and harvested at the age of 12 months in both seasons. The sub-plot area was 35 m^2, including seven rows of five meters long and a width of one meter. The Sugar Crops Research Institute's' recommendations were followed, and other necessary agronomic operations were carried out accordingly.

The recorded data

Physiological trait: Chlorophyll content was determined 210 days after the sowing date. While, leaf length (cm), width (cm), and leaf area index were performed at the harvest, the chlorophyll content was quantified using a portable chlorophyll meter (**Minolta SPAD-502, Japan**). Measurements were recorded at three distinct locations on every leaf (upper, middle, and lower regions) and the mean of these measurements was utilized to represent the chlorophyll level for each individual leaf.

Leaf Area Index (LAI): it was calculated according to Watson [19] using the following formula:

Leaf area index = (leaf area/plant) / (soil area/plant).

Growth characters and cane yield: At harvest, ten stalks from each sub-plot were randomly collected to estimate stalk diameter (cm), length (cm), and weight (kg). For determining cane yield/fed, cane stalks of each subplot were harvested, stripped, topped, and weighed before converting the weight to tons/feddan.

Juice quality characteristics: To determine the qualitative traits, the previously collected 10 stalks were crushed, and the extracted juice was analyzed.

1. Brix% (Total Soluble Solids percentage) was determined using a Brix Hydrometer according to AOAC [20].

2. Sucrose% of clarified juice was determined using an automated Saccharometer according to AOAC [20].

3. Juice purity % was calculated according to Singh and Singh [21] using the following formula:

$$\text{Juice purity \%} = \frac{\text{Sucrose Percentage}}{\text{Brix Percentage}} \times 100$$

4. Sugar recovery % was calculated according to the following formula as described by Yadav and Sharma [22].

Sugar recovery % = [Sucrose % - 0.4 (Brix % - Sucrose %)] × 0.73.

5. The recoverable sugar yield per fed (ton) was determined according to the method described by Orgeron [23] using the following equation:

Recoverable Sugar yield/fed (ton) = Cane yield/fed (ton) × Sugar recovery%

Statistical analysis

The data collected were subjected to statistical analysis as outlined by Steel [24] to compare means, and multi-range Duncan tests were enforced to Duncan [25]. The correlation coefficients were calculated among the studied traits by Steel. [26].

3. Results

3.1. Physiological Traits

The overall mean values of the evaluated sugarcane genotypes cleared that G.2003-47 showed significant superiority over G.84-47 and G.T.54-9 in leaf length. Meanwhile, the difference in this trait between G.2003-47 and G.2004-27 was not significant (Table 2). The results showed that sugarcane leaf length increased markedly by 7.07, 23.41, and 12.95 centimeters, when canes were sprayed with 0.1, 0.2 and 0.3 % of spirulina algae extract (SE), in comparison to untreated canes, successively. Concerning the interaction influence on leaf length, the results showed that G.84-47 and G.T.54-9 did not significantly differ in the leaf length when sprayed with algae extract at the rate of 0.1%. However, when the rate was rise to 0.2%, G.T.54-9 appreciably produced longer leaves than that recorded by G.84-47, in the plant cane crop. Similar findings were detected in the 1st ratoon.

Table 2. Effect of foliar application with spirulina algae extract concentrations on leaf length, leaf area index (LAI) and chlorophyll content of four sugarcane genotypes and their interactions.

Sugarcane Genotypes	Spirulina extract (%)	Leaf length (cm)		Mean	LAI		Mean	Chlorophyll content (μmol m-2)		Mean
		Plant Cane	First ratoon		Plant cane	First ratoon		Plant Cane	First ratoon	
G.2004-27	**Control**	132.00	134.33	133.17	2.14	2.30	2.22	34.20	36.07	35.14
	0.1%	145.00	147.67	146.34	2.67	2.82	2.75	40.30	41.47	40.89
	0.2%	153.00	156.33	154.67	4.09	4.25	4.17	43.40	45.00	44.20
	0.3%	150.33	152.00	151.17	3.70	3.92	3.81	40.30	41.90	41.10
Mean		145.08	147.58	**146.33**	3.15	3.33	**3.24**	39.55	41.11	**40.33**
G.84-47	**Control**	138.33	139.67	139	2.45	2.67	2.56	33.00	34.10	33.55
	0.1%	141.00	141.33	141.17	2.88	2.97	2.93	35.00	36.77	35.89
	0.2%	152.00	150.67	151.34	4.16	4.30	4.23	37.50	38.53	38.02
	0.3%	146.00	146.00	146.00	4.02	4.12	4.07	44.20	45.00	44.60
Mean		144.33	144.42	**144.37**	3.38	3.52	**3.45**	37.43	38.6	**38.01**
G.T.54-9	**Control**	133.67	130.33	132	2.91	2.97	2.94	45.20	45.80	45.5
	0.1%	141.33	138.33	139.83	3.45	3.56	3.51	48.60	49.60	49.10
	0.2%	163.00	160.00	161.50	4.73	4.79	4.76	57.3	58.70	58.00
	0.3%	145.67	143.67	144.67	3.75	3.83	3.79	52.30	53.80	53.05
Mean		145.92	143.08	**144.50**	3.71	3.79	**3.75**	50.85	51.98	**51.41**
G.2003-47	**Control**	136.67	134.00	135.34	2.99	3.11	3.05	42.10	43.47	42.79
	0.1%	142.00	139.00	140.50	3.53	3.75	3.64	42.80	43.30	43.05
	0.2%	166.00	165.33	165.67	4.81	4.91	4.86	47.10	47.90	47.50
	0.3%	151.00	148.00	149.50	3.66	3.76	3.71	46.10	48.40	47.25
Mean		148.92	146.58	**147.75**	3.75	3.89	**3.82**	44.53	45.77	**45.15**
Control		135.18	134.58	134.88	2.62	2.76	2.69	38.62	39.86	39.24
0.1%		142.33	141.58	141.95	3.13	3.27	3.20	41.68	42.78	42.23
0.2%		158.5	158.08	158.29	4.45	4.57	4.51	46.33	47.53	46.93
0.3%		148.25	147.42	147.83	3.78	3.91	3.85	45.73	47.28	46.50
LSD(0.05)	**Genotypes(A)**	3.65	2.53	3.06	0.04	0.06	0.04	0.93	0.71	1.09
	Concentration(B)	2.71	2.63	2.60	0.07	0.06	0.06	0.67	0.80	0.29

AB	5.42	5.27	5.21	0.08	0.11	0.12	1.87	1.43	2.18

As for the variation among the tested sugarcane genotypes in LAI, G.2003-47 was significantly higher than G.T.54-9, G.84-47, and G.2004-27 by 1.86, 10.72 and 17.90%, respectively (Table 2). The results indicated that spraying canes with 0.2% SE resulted in the maximum mean value of LAI, followed by 0.3%, 0.1 and those left without SE. Concerning the interaction of cane genotype x SE, There was an insignificant difference between G.2004-27 and G.84-47 when they were sprayed with SE at a concentration of 2%. However, G.84-47 had a significantly higher Leaf Area Index (LAI) compared to G.2004-27 when sprayed with 3% SE in both the plant and 1st ratoon cane crops.

Data in **Table 2** revealed that leaves of G.T.54-9 genotype appreciably had the highest chlorophyll content, while G.84-47 contained the lowest value of this pigment compared with the other tested genotypes. Increasing the concentration of SE sprayed on sugarcane from 0.0 to 0.1 and 0.2 led to a substantial and gradual increase in the chlorophyll content of leaves. While, reduction in the mean value of this trait detected at 0.3 % SE. Concerning the interaction between the studied factors on chlorophyll content, data showed an insignificant difference between 0.2 and 0.3% SE in their influence on chlorophyll content in the G.2003-47 leaves. However, spraying canes with SE at 0.2 % caused an increase in mean values of this trait as compared to applying SE for G.T.54-9 and 2004-27 genotypes at 0.3%.

3.2. Growth Traits and Cane Yield

Data in **Table 3** display that G.84-47 was the taller genotype of stalk length followed by G.T.54-9, the application with 0.2% spirulina extract increased stalk length by15.34% and 20.81% in the plant cane and 1st ratoon, respectively compared to untreated plants. Concerning the interaction influence on stalk length, the results indicated that G.T.54-9 and G.84-47 did not significantly differ in stalk length when sprayed with 0.1% SE. However, when the rates rise to 0.2%, G.84-47 produced taller stalks than that recorded by G.T.54-9, in the plant cane crop.

Table 3. Effect of foliar application with spirulina algae extract concentrations on growth traits stalk length (cm), stalk diameter (cm), number of tillers/stool and cane yield/fed (ton) of four sugarcane genotypes and their interactions.

Sugarcane Genotype	Spirulina extract (%)	Stalk length (cm)		Mean	Stalk weight (kg)		Mean	Stalk diameter (cm)		Mean	No. tillers		Mean	Cane yield/fed (ton)		Mean
		Plant cane	First ratoon		Plant cane	First ratoon		Plant cane	First ratoon		Plant cane	First ratoon		Plant cane	First ratoon	
G.2004-27	Control	183.00	181.67	182.34	0.96	0.95	0.96	2.40	2.10	2.25	3.00	4.00	3.50	38.40	37.00	37.70
	0.1%	209.00	209.00	209.00	1.05	1.03	1.04	2.53	2.23	2.38	4.00	4.67	4.34	40.93	41.00	40.97
	0.2%	227.70	222.23	224.97	1.27	1.21	1.24	2.80	2.13	2.47	5.70	6.33	6.02	45.33	47.97	46.65
	0.3%	204.00	203.67	203.84	1.20	1.18	1.19	2.57	2.20	2.39	4.67	5.67	5.17	44.00	45.13	44.57
Mean		205.93	204.14	**205.04**	1.12	1.09	**1.11**	2.58	2.17	**2.38**	4.34	5.17	**4.76**	42.17	42.78	**42.48**
G.84-47	Control	267.00	235.67	251.34	1.07	1.04	1.06	2.30	2.05	2.18	3.33	4.33	3.83	38.23	40.90	39.57
	0.1%	283.00	252.33	267.67	1.17	1.14	1.16	2.40	2.14	2.27	4.67	5.33	5.00	43.47	43.00	43.24
	0.2%	301.67	285.00	293.34	1.32	1.30	1.31	2.53	2.01	2.27	5.67	6.00	5.84	46.90	51.07	48.99
	0.3%	280.33	276.00	278.17	1.24	1.21	1.23	2.37	2.11	2.24	5.33	5.67	5.50	44.97	48.40	46.69
Mean		283.00	262.25	**272.63**	1.20	1.17	**1.19**	2.40	2.08	**2.24**	4.75	5.33	**5.04**	43.39	45.84	**44.62**
G.T.54-9	Control	262.00	230.00	246.00	1.17	1.11	1.14	2.10	2.27	2.19	4.00	5.00	4.50	43.57	47.03	45.30
	0.1%	280.00	262.00	271.00	1.24	1.23	1.24	2.67	2.37	2.52	4.67	5.33	5.00	47.53	52.27	49.90
	0.2%	288.87	272.33	280.60	1.59	1.55	1.57	2.97	2.57	2.77	6.67	7.67	7.17	56.13	55.57	55.85
	0.3%	272.12	263.67	267.89	1.39	1.36	1.38	2.73	2.43	2.58	5.67	6.33	6.00	55.40	54.27	54.84
Mean		275.75	257.00	**266.38**	1.35	1.31	**1.33**	2.62	2.41	**2.52**	5.25	6.08	**5.67**	50.66	52.28	**51.47**
G.2003-47	Control	183.33	177.33	180.33	1.13	1.10	1.12	2.40	2.33	2.37	3.67	4.67	4.17	42.50	45.17	43.84
	0.1%	202.00	187.67	194.84	1.21	1.18	1.20	2.53	2.43	2.48	5.00	5.00	5.00	46.20	49.93	48.07
	0.2%	215.67	216.67	216.17	1.55	1.47	1.51	2.70	2.62	2.66	6.33	6.33	6.33	54.83	53.53	54.18

	0.3%	205.67	198.00	201.84	1.37	1.32	1.35	2.60	2.53	2.57	5.33	6.00	5.67	53.07	52.20	52.64
	Mean	201.67	194.92	**198.30**	1.32	1.27	**1.30**	2.56	2.48	**2.52**	5.08	5.50	**5.29**	49.15	50.21	**49.68**
	Control	223.83	206.17	**215.00**	1.08	1.05	**1.07**	2.30	2.19	**2.25**	3.50	4.50	**4.00**	40.68	42.53	**41.61**
	0.1%	243.50	227.75	**235.63**	1.17	1.14	**1.16**	2.53	2.29	**2.41**	4.58	5.08	**4.83**	44.53	46.55	**45.54**
	0.2%	258.17	249.08	**253.63**	1.43	1.38	**1.41**	2.75	2.33	**2.54**	6.08	6.58	**6.33**	50.80	52.03	**51.42**
	0.3%	240.58	235.33	**237.96**	1.30	1.27	**1.29**	2.57	2.31	**2.44**	5.25	5.92	**5.59**	49.36	50.00	**49.68**
LSD 0.05	**Genotype (A)**	4.16	6.77	4.23	0.02	0.02	0.02	0.12	0.08	0.09	0.33	0.38	0.26	0.79	0.62	0.48
	Spirulina extract (B)	6.17	7.29	6.47	0.04	0.03	0.04	0.13	0.13	0.08	0.30	0.28	0.22	0.91	0.38	0.77
	(A × B)	8.69	14.59	12.93	0.04	0.04	0.07	0.23	0.17	0.16	ns	ns	0.16	1.82	1.14	1.54

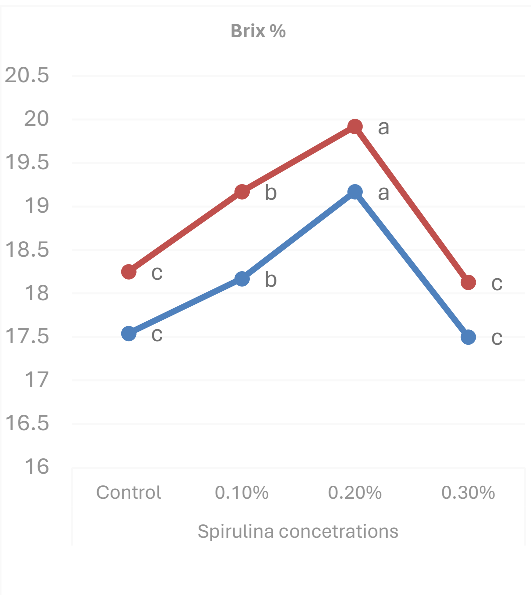
ns = not significant at 0.05 levels.

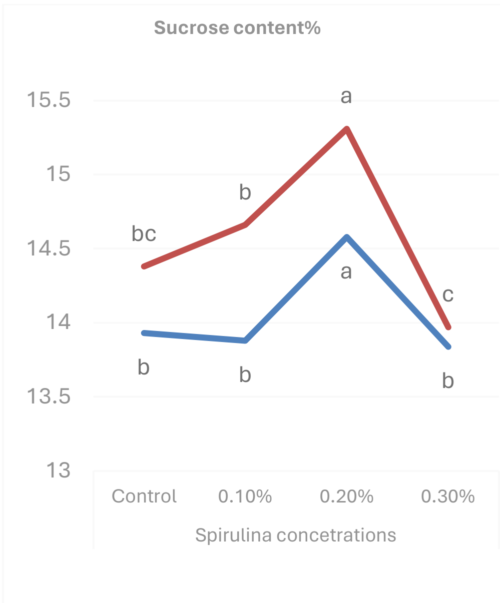
Overall, G.T.54-9 had greater stalk weight than those observed in other genotypes. Spirulina treatments (0.1, 0.2, and 0.3%) increased the stalk weight by 8.41, 31.78, and 20.56%, respectively, compared with the control. According to the interaction consequence on stalk weight, data showed an insignificant difference between G.T.54-9 and G.2003-47 of control plants, while when sugarcane plants foliar spring with 0.1 and 0.2% spirulina extract G.T.54-9 gave heavier stalks than that recorded by G.2003-47, in the 1st ratoon (Table 3).

Comparing genotypic averages, G.T.54-9 had the highest cane yield, while G.2004-27 was the lowest one. The application of SE spray led to a significant enhancement in sugarcane yield. More precisely, the productivity of sugarcane treated with a 0.2% concentration of SE increased by 24.88% and 22.34% in the plant cane and 1st ratoon, respectively, when compared to the control group, the study revealed that there was no substantial disparity in cane production between the control plants of G.2004-27 and G.84-47. Nevertheless, the application of a 0.1% concentration of SE resulted in a higher cane yield for G.84-47 as compared to G.2004-27 in the plant cane crop (Table 3).

3.3. Juice Quality and Recoverable Sugar Yield

Higher Brix% was found in G.T.54-9 which did not significantly different for G.2003-47 while G.84-47 had the lowest Brix% (Table 4). Compared with the control, brix% of 0.2% spirulina extract treatment was significantly increased by 9.29 and 9.15%, and 0.1% SE increased brix % by 3.59 and 5.04 at plant cane and first ratoon, respectively (Figure 2). Data in **Table 4** indicated the interaction of cane genotype x SE, there was an insignificant variance between G.T.54-9 and G.2003-47 of control plants and the plants treated with 0.1%SE, while G.T.54-9 recorded a higher and significant value of Brix% than that recorded by G.2003-47 at 0.2% SE in the plant cane.





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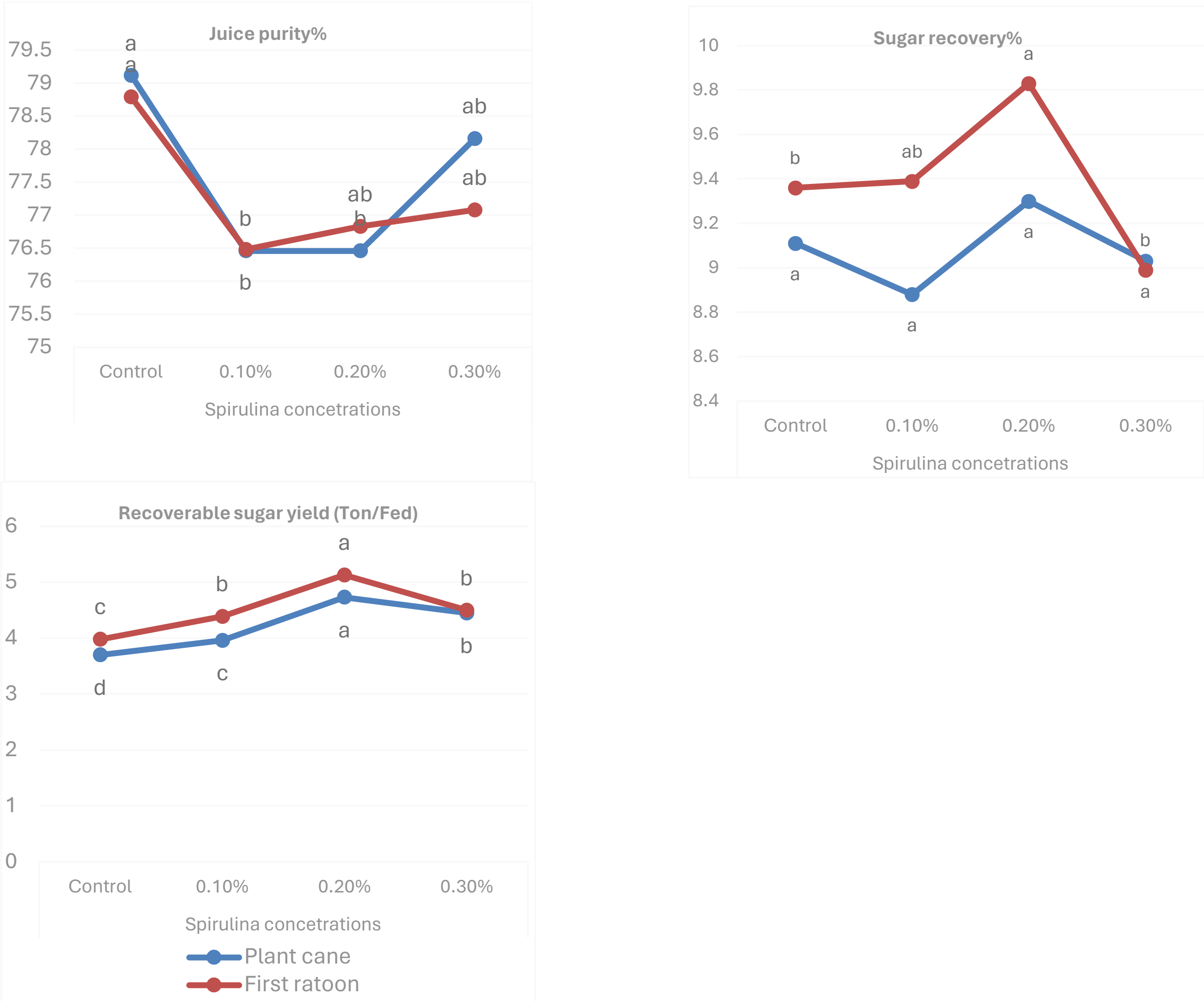

Figure 2. Effects of foliar application with different concentrations of spirulina extract on the sugarcane quality traits at plant cane and first ratoon.

Table 4. Effect of interaction between sugarcane genotypes and spirulina treatments on sugarcane juice quality at plant crop and first ratoon.

Genotypes	Spirulina concentration	Brix %			Sucrose content%			Sugar recovery%			Recoverable sugar yield (ton/fed)		
		Plant cane	First ratoon	Mean	Plant cane	First ratoon	Mean	Plant cane	First ratoon	Mean	Plant cane	First ratoon	Mean
G2004-27	**Control**	16.95	18.65	17.80	13.91	14.42	14.16	9.25	9.28	9.26	3.55	3.43	3.49
	0.1%	17.82	18.96	18.39	13.16	14.18	13.67	8.25	8.94	8.59	3.37	3.67	3.52
	0.2%	18.84	19.79	19.31	13.76	14.35	14.05	8.56	8.98	8.77	3.88	4.31	4.09
	0.3%	17.45	18.66	18.05	13.89	14.36	14.12	9.09	9.22	**9.15**	3.99	4.16	4.07
	Mean	17.76	19.01	**18.38b**	13.68	14.32	**14.00c**	8.78	9.11	**8.95 b**	3.69	3.89	**3.80c**
G84-47	**Control**	17.17	17.33	17.25	13.97	13.93	13.95	9.27	9.18	9.22	3.54	3.75	3.64
	0.1%	17.50	19.00	18.25	13.61	14.29	13.95	8.80	9.06	8.93	3.82	3.90	3.86
	0.2%	18.83	19.33	19.08	14.77	14.93	14.85	9.59	9.62	9.60	4.49	4.92	4.70

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	0.3%	16.5	16.83	16.66	13.80	13.05	13.43	9.29	8.42	8.85	4.17	4.08	4.12
	Mean	17.5	18.12	**17.81c**	14.04	14.05	**14.05b**	9.23	9.07	**9.15ab**	4.00	4.16	**4.08b**
GT54-9	**Control**	17.95	17.95	17.95	13.45	14.06	13.75	8.50	9.13	8.81	3.70	4.29	3.99
	0.1%	18.95	19.14	19.04	14.84	14.91	14.87	9.63	9.65	9.64	4.57	5.04	4.80
	0.2%	19.95	20.31	20.13	15.91	16.20	16.06	9.46	10.63	10.04	5.31	5.90	5.60
	0.3%	18.81	18.95	18.88	13.66	14.06	13.86	8.64	9.60	9.12	4.79	5.21	5.00
	Mean	18.91	19.08	**18.99a**	14.46	14.80	**14.63a**	9.05	9.75	**9.41a**	4.59	5.11	**4.85a**
G2003-47	**Control**	18.00	19.00	18.5	14.36	15.08	14.72	9.42	9.86	9.64	4.00	4.46	4.23
	0.1%	18.33	19.50	18.91	13.91	15.27	14.59	8.86	9.91	9.38	4.08	4.95	4.51
	0.2%	19.00	20.50	19.75	14.80	15.74	15.27	9.58	10.10	9.84	5.25	5.41	5.33
	0.3%	17.67	18.00	17.83	13.96	13.66	13.81	9.11	8.70	8.90	4.84	4.54	4.69
	Mean	18.25	19.25	**18.75a**	14.25	14.94	**14.60a**	9.24	9.64	**9.44a**	4.54	4.84	**4.69a**
LSD0.05		0.87	0.78	0.80	ns	1.01	0.85	ns	0.92	ns	0.52	0.49	0.43

ns = not significant at 0.05 levels.

Data from **Table 4** showed an insignificant variance between G.T.54-9 and G.2003-47 for Sucrose content %. The sucrose content % of sugarcane in the 0.2% SE was significantly higher than that of the control by 4.67%. There were insignificant differences between 0.1%, 0.3% SE, and the control at plant cane crop; moreover 0.1% and 0.2% SE were higher than that of the control by 1.94% and 6.47%, respectively at first ratoon (Figure 2). Regarding the interaction influence on sucrose content %, the results showed that the plants without SE insignificantly differ in sucrose content % of G.84-47 and G.T.54-9, while when they were sprayed with 0.2% SE G.T.54-9 produced higher sucrose content % than G.84-47, in the 1st ratoon.

These were insignificant differences between G.84-47, GT54-9 and G2003-47 for sugar recovery % (Table 4). The sugar recovery % of sugarcane sprayed with spirulina extract was insignificantly different from the control at plant cane. However, sugar recovery % increased significantly by 5.02% for 0.2% compared with those of the control and there was insignificant difference in sugar recovery% between 0.1% and 0.3% treatments and those without spirulina treatment for the first ratoon (Figure 2).

Higher recoverable sugar yield (ton/fed) were found in G.T.54-9 and G.2003-47, while G.2004-27 had the lowest recoverable sugar yield (Table 4). Recoverable sugar yield (ton/fed) was significantly higher than that in non-spirulina treatments and 0.2% spirulina extract was significantly higher than all other treatments in every year (Figure 2). According to the interaction consequence on recoverable sugar yield, data display the insignificant difference between G.2004-27 and G.84-47 of control plants while when sugarcane plants foliar spraying with 0.1 and 0.2% spirulina extract G.84-47 gave higher recoverable sugar yield than that recorded by G.2004-27 in the plant cane crop (Table 4).

3.4. Correlation Coefficients between Studied Traits

Data in **Table 5** revealed that cane yield had a positive and significant correlation with all agronomic and juice quality traits except that with the purity % negative and non-significant correlation coefficient. Similarly, Recoverable sugar yield showed a positive and significant correlation with agronomic and juice quality traits.

In this study, cane yield was significantly correlated with stalk weight (r =0.88) followed by leaf area index (r = 0.82), chlorophyll content (r = 0.82), stalk length (r =0.76) and number of tiller (r = 0.73). These indicated that selection through the above traits would lead to an increase in cane yield.

These have consequences for choosing which varieties to use as parents in hybrids. According to the data shown above, many characters affected cane yield; however, the effect varied from one character to another, depending on how strongly we associate each character with cane yield. Regarding this situation, selecting the character of stalk weight would result in the highest yield compared to all other characters. Concerning the biochemical traits in the present study, recoverable sugar yield is strongly correlated (P < 0.01) with sugar content% (r = 0.76). These indicated that selection through sugar content would produce varieties with high levels of recoverable sugar yield.

Table 5. Pearson's correlation coefficients for studied traits in four sugarcane genotypes treated with different concentrations of spirulina extract over two sequential seasons. Traits include Stalk length (SL), Stalk weight (SW), Stalk diameter (SD), number of tiller (NOT), Leaf length (LL), Leaf width (LW), Leaf area index (LAI), Chlorophyll content (CH), Cane yield (CY), Brix % (Brix), Sugar content% (SC), Sugar recovery (SR), Recoverable sugar yield (RSY) and Purity% (PUR).

	SL	SW	SD	NOT	LL	LW	LAI	CH	CY	Brix	SC	RS	RSY	PUR
SL	**1**	**0.71** ***	**0.49** ***	**0.42** ***	0.35 ***	0.04 ns	**0.54** ***	**0.80** ***	**0.76** ***	**0.47** **	0.34 ***	0.23 *	0.68 ***	-0.14 ns
SW		1	**0.56** ***	**0.79** ***	**0.72** ***	**0.51** ***	**0.88** ***	**0.75** ***	**0.88** **	**0.50** ***	0.39 ***	0.28 ***	**0.79** ***	-0.10 ns
SD			1	0.22 *	**0.45** ***	0.36 ***	**0.43** ***	**0.41** ***	**0.46** ***	0.12 ns	0.10 ns	0.07 ns	0.37 ***	-0.02 ns
NOT				1	**0.60** ***	**0.55** ***	**0.80** ***	**0.63** ***	**0.73** ***	**0.54** ***	0.36 ***	0.23 *	**0.66** ***	-0.19 ns
LL					1	**0.68** ***	**0.80** ***	**0.43** ***	**0.57** ***	**0.43** ***	0.26 **	0.15 ns	**0.51** ***	-0.18 ns
LW						1	**0.57** **	0.22 *	0.36 ***	0.23 *	0.12 ns	0.05 ns	0.30 **	-0.12 ns
LAI							1	**0.65** ***	0.82 ***	**0.51** ***	0.40 ***	0.28 **	**0.75** ***	-0.11 ns
CH								1	**0.82** ***	**0.48** ***	0.33 **	0.21 *	**0.72** ***	-0.17 ns
CY									1	**0.49** **	0.36 ***	0.24 *	**0.87** ***	-0.14 ns
Brix										1	**0.71** ***	**0.46** ***	**0.61** **	-0.31 **
SC											1	**0.93** ***	**0.76** ***	**0.45** ***
SR												1	**0.69** ***	**0.70** ***
RSY													1	0.25 *
PUR														1

* significant at 5 percent level (p≤0.05) **significant at 1 percent level (p≤0.01) *** significant at 0.1 percent level (p≤0.001), ns non-significant at 0.05 levels.

4. Discussion

The results of this investigation showed significant increases in stalk length/cm, weight/kg, diameter/cm, number of tillers/stool and cane yield (ton/fed) by increasing the concentration of spirulina to 0.02% in both studied seasons. They are consistent with the results reported by Ali et al. [27], He said that because seaweed has unique bioactive components and effects, its bioproducts are

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becoming more and more common in crop production systems. They increase growth and yield metrics in a number of important crop plants because of their phytostimulatory properties.

The obtained results reflected that there were significant increases in cane yield (ton/fed) compared with control in both studied seasons. Furthermore, Deshmukh and Phonde [8] demonstrated that applying SEs to sugarcane leaves increased yield by 14.1%, and Karthikeyan and Shanmugan [9] confirmed that spraying sugarcane three times with SEs could increase yield by 20.47 to 28.79 %. Additionally, this study's' findings concur with those of studies conducted on various crops, such as tomatoes, maize, and strawberries[28–30]. Arioli et al. [14] discovered that seaweed extracts enhanced plant growth, which was attributed to a combination of active compounds. These substances can either have a direct effect on the plant or influence the regulation of genes. Upon the application of SEs, the expression levels of the PinII and ETR-1 marker genes exhibited a significant increase compared to the control group. The gene transcripts for auxin (IAA), gibberellin (Ga2Ox), and cytokinin (IPT) were all simultaneously, suggesting that somatic embryogenesis (SEs) may enhance plant growth [31]. Foliar application with spirulina extract concentration (0.2%) of studied sugarcane genotypes scored the highest values of all measured physiological traits in plant cane and 1st ratoon. These results are consistent with those reported by Shedeed et al. [32], they found that, after applying 0.25% spirulina extract topically to *Lupinus luteus*, the highest values of growth and yield components were obtained, as compared to higher doses (0.5% and 1.0%). At the greater concentration (1.0%), however, the growth was markedly impeded, resulting in lower measured character values than the control. Consequently, according to Bokil et al. [33], even at very low concentrations (diluted as 1:1000 or more), seaweed extracts can have bioactive effects. Some micronutrients and growth-promoting substances found in seaweed extracts, such as auxins, gibberellins, and phenyl acetic acid, may explain why even at low concentrations, germination and seedling vigor are improved [34,35]. Micronutrients, vitamins, amino acids, growth-promoting substances like IAA and IBA Gibberlins (A & B), and other micronutrients have a significant impact on crop germination at lower concentrations, whereas excessive hormones or a high mineral concentration at higher concentrations can retard growth [36].

The Brix, sucrose content, sugar recovery percentages, and recoverable sugar yield (ton/fed) showed an increase with a higher concentration of spirulina extract. The highest value was obtained for a concentration of 0.2% in both years of the study. These results agree with Chen et al. [37] who stated that the application of sugarcane with Seaweed extracts (SEs) increased the sucrose accumulation in sugarcane stems. Oliveira et al. [38] found that using marine algae extract to boost sugarcane photosynthetic and metabolic efficiency improved industrial quality and productivity. Our results were consistent with their findings. Thus, Jacomassi et al. [39] discovered that applying seaweed extract (SWE) topically to sugarcane plants led to a rise in the accumulation of stalk sucrose, which in turn raised the industrial grade of the raw materials and enhanced sugar yield.

The results found correlation of cane yield with stalk length, weight and number of tiller was very strong ($r = 0.76^{***}$, $r = 0.88^{**}$ and $r = 0.73^{***}$, respectively). Those findings are in line with those of Tyagi and Lal. [40], who found a positive and statistically significant relationship between cane yield and variables like stalk height, number of millable canes, and weight of individual canes. Also Brown et al. [41]; Punia et al. [42] discovered a strong and favorable relationship between cane yield and its constituents, including the weight of individual canes, the length of the stalk, and the production of millable cane numbers.

In this study, there was a strong correlation between cane yield and stalk weight ($r = 0.88$) followed by leaf area index ($r = 0.82$), chlorophyll content ($r = 0.82$), stalk length ($r = 0.76$) and number of tiller ($r = 0.73$). These results disagree with Hogarth [43] and James [44] who found that cane yield was more closely correlated with stalk number than weight per stalk or stalk diameter. [45]. Millable cane numbers were highlighted by Brown et al. [41] as an important factor in selecting for higher cane yield.

Esayas et al. [46] highlighted the significance of understanding the interrelationships among various traits, suggesting that selecting for one characteristic will inherently influence other attributes. Thus, in order to execute a successful breeding program, it is essential to comprehend the interrelationships among the component details. Any two characters' association is based on their inheritance. If they are inherited simultaneously, their relationship can be observed. The correlation between phenotypic and genotypic characteristics is due to the mean value of the genes regulating multiple traits. This can be accounted for by the genes being located on the same chromosome or by the fact that they regulate a limited number of traits, such as one or two.

5. Conclusions

The investigation's' findings demonstrated:

1. Significant increases in cane yield (ton/fed), weight/kg, diameter/cm, number of tillers/stool, and stalk length/cm were obtained when the concentration of spirulina extract was raised to 0.2% in both of the seasons under study.

2. Foliar application with spirulina extract concentration (0.2%) of studied sugarcane genotypes scored the highest value of all measured physiological traits in plant cane and 1st ratoon.

3. The Brix level, sucrose content, sugar recovery percentages, and recoverable sugar yield (ton/fed) all demonstrated an increase with a higher concentration of spirulina extract. The highest value was achieved at a concentration of 0.2% in both years of the study.

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