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Effects of Foliar Amino Acid and Vitamin Applications on Heat Stress, Production and Quality of Lettuce Head Improvements

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Abstract: This study was conducted to investigate the effect of amino acid and vitamin foliar applications on improving iceberg lettuce (*Lactuca sativa* L.) production and quality during the summer. First, two hybrids (Patagonia and Bruma) were grown hydroponically in June 2018 and 2019. Then, for five consecutive weeks, plants were sprayed once a week with *Stress Free* (a commercial product comprising 0.5% vitamins [vitamin B complex/ascorbic acid] and 0.5% selenomethionine) at concentrations of 1.0, 2.0 and 3.0 g/L and *Aminomad* (20% free amino acids) at concentrations of 2.0, 3.0, and 4.0 cm^3/L. Investigations revealed that all plant growth aspects were positively improved with all foliar spray treatments than with the control. Furthermore, while mineral contents (nitrogen, phosphorus, potassium, calcium, and magnesium) showed positive responses to the applied treatments, the highest dose of amino acids showed the highest marketable and total yield effects among all foliar spray treatments with the Patagonia hybrid. However, the marketable and total yield of lettuce heads was lowest with the control treatment without spraying.

1 Introduction

Hydroponics is a technique of growing plants by submerging the roots into a nutrient solution with or without mechanical root support. Specifically, it is also called controlled environment agriculture because raising plants hydroponically requires controlling environmental factors (e.g., water temperature, light intensity and duration, humidity, pH of the solution, and mineral nutrients). Hydroponics offers advantages compared to soil-based systems because of the more efficient use of fertilizers and water, more control of the growing climate, and better pest control (Thakulla et al 2021). However, the efficiency of this plant-growing method has not been examined in some crops.

Lettuce is a popular crop in many regions of the world because of its taste and nutritional values; it contains vitamins (e.g., A, K, C, and folates) (Romani et al 2002). Lettuce is mainly consumed in its raw form and has also been proposed as a good source of vitamins and minerals (e.g., iron, calcium, and magnesium). However, as a cool-season vegetable crop, lettuce tends to bolt in response to high temperatures. Moreover, subjecting lettuce to high temperatures was observed to induce its inflorescence initiation (bolting), resulting in reduced marketability (Waycott, 1995, Simonne et al 2002). Studies also reported that the head formation process in iceberg lettuce is highly affected by the growing environment, with the latter being able to determine the final head size and quality. Therefore, high temperatures reduce maturity time while low temperatures during and around heading result in larger head weight (Wurr et al 1996, Thompson et al 1998, Choi et al 2004). Consequently, lower head weight or bolting reduces lettuce's marketability, resulting in lower economic return for the grower, which has attracted the attention of many researchers seeking the improvement of iceberg lettuce productivity and quality under heat stress. Moreover, although stem elongation in lettuce is common because of high temperature (Rader and Karlsson 2006, Fukuda et al 2012), it is also strictly cultivar dependent (Zhao and Carey 2009).

While other reports have demonstrated shading to reduce heat stress with limited or inconsistent results (Abdel-Mawgoud 1995), some treatments (e.g., amino acid application) have been tested in the production and quality of lettuce under standard production conditions (Khan et al 2019). Therefore, this study investigated the application of amino acids or vitamins to alleviate the negative effects of heat stress on the production and quality of two iceberg lettuce hybrid (Patagonia and Bruma) plants grown during the summer in Egypt within hydroponic greenhouse farms.

2 Materials and Methods

The experiment investigates the individual effects of amino acid and vitamin applications on alleviating heat stress in two hybrids (Patagonia and Bruma) of iceberg lettuce plants grown following the nutrient film technique (NFT) system conducted at a private farm located in the Abou-Ghalib district, 58 km of the Cairo–Alexandria desert road, between June (2018) and (2019).

2.1 Plant materials and growth conditions

Seedlings of two iceberg lettuce (*Lactuca sativa* L.) hybrids (i.e., Patagonia and Bruma) were transplanted into a closed-loop NFT hydroponic system between June 2018 and 2019, using plastic cups with holes for the plant roots to exit through them. The plastic cups used were 9 and 11 cm long. After the lettuce seedlings were planted in the plastic cups, they were fixed in their designated planting tube holes. Subsequently, a nutrient solution of suitable composition was also prepared by Cooper (1979) as previously recommended, and pH between 6.0 and 6.3, including electrical conductivity (Ec) between 1.5 and 2.0 mS cm^{-1} nutrient solution, was maintained regularly for optimal plant growth. Furthermore, foliar spray treatments were administered for five consecutive weeks, starting from the first week after transplanting, and plants grown in the hydroponic system comprised 840 of the two hybrids distributed equally over seven foliar spray treatments (20 plants/treatment).

2.2 Nutrient solution

A Cooper solution formula was prepared during the experiment (Cooper 1979) for treatment following the recommendations of a previous study and the NFT. The nutrients were applied at the following concentrations in parts per million: 236 nitrogen, 60 phosphorus, 300 potassium 185 calcium, 50 magnesium, 68 sulfur, 12 iron, 0.3 boron, 2 manganese, 0.1 zinc, 0.1 copper, and 0.2 molybdenum (NFT).

2.3 Hydroponic cultivation

2.3.1 An A-shaped metal trianglar frame

An A-shaped system was constructed using an iron metal triangular frame with a 60° angle and a 130 cm top/bottom width. First, four gully holders were fixed on each side of the A-shaped triangular frame after fixing 10 cm of each side into the soil to form three levels on each side (height of 35 cm from the soil surface) to form the bottom level. Then, 25 cm from the bottom level was measured to form the middle level, and 25 cm from the middle level to form the top level. Four A-shaped triangular frames were used to construct the A-shaped system at a distance of 2 m apart with a slope of 1% toward the solution tank. The construction of an A-shaped hydroponic system is shown **(Fig 1)**.

2.3.2 Gullies

This NFT system used 110-mm gray polyvinyl chloride (PVC) tubes to form the grooves, after which 6-m holes were punched in the PVC tubing. The plastic cups used, which had a diameter of 9 cm and a length of 11 cm, also contained holes.

2.3.3 Solution tank

A 5,000-L plastic tank was used as the nutrient solution tank to supply six gullies into each A-shaped system (one nutrient solution tank for each A-shape system) and catchment tank. While the tanks were

Fig 1. Construction of an A-shaped hydroponic system

placed in front of each A-shaped system, the six gully outlets were placed inside the tank (closed system).

2.3.4 Circulated solution system

Submersible pumps (2 HP) were used (one pump for each nutrient solution tank) to thrust the nutrient solution through a polyethylene tube (18 mm) to the upper end of the six gullies in each A-shaped system. The nutrient solution returns to the solution tank (reservoir) by gravity (1% slope) and is repumped into the gullies.

Subsequently, stocks of nutrient solutions were prepared in two separate containers to avoid precipitation. The first container had calcium nitrate and iron chalets, whereas the second conducted the remaining chemicals in the nutrient solution, as previously described (El Behiary 1994).

2.4 Foliar spray treatments

Two different products (Stress Free and Aminomad 20%) were used as foliar spray applications on the plants:

- Stress Free: a commercial product comprises selenomethionine (0.5%) and vitamins (0.5%; vitamin B complex and ascorbic acid), applied at concentrations of 1.0, 2.0, and 3.0 cm^3/L.
- Aminomad 20% comprises free amino acids applied at concentrations of 2.0, 3.0, and 4.0 cm^3/L.

However, the control treatment was not sprayed with any treatment.

2.5 Data collection

Five randomly selected plants from each treatment were used for measurements of the number of leaves per head, stem length, head diameter, fresh heads, and dry weights, including total yield, component quality (marketable and unmarketable), total chlorophyll, and chemical composition (N, P, K, Ca, Mg, NO_3, and carbohydrates) measurements in leaves.

Nitrogen (N%) was determined in head tissue samples of dried lettuce according to the modified Kjeldahl's method (Horneck and Miller, 1998), and phosphorus (P%) was determined in head tissue samples of dried lettuce according to Watanabe and Olsen (1965). According to the method described by Jackson (1973), potassium was then determined using a Beckman flame photometer (Washington, DC, USA). In contrast, the nitrate content was determined in milligram per kilogram dry weight colorimetrically according to Cataldo et al (1975).

Furthermore, while total phosphorus was determined colorimetrically in milligrams/100 g dry weight using the hydroquinone and sodium sulfite method (AOAC 2005), total carbohydrates were quantitatively determined in lettuce by the Anthron method according to Mahadevan and Sridhar (1982) as follows: First, the extraction was conducted by grinding dry matter in a Mahadevan buffer (sodium citrate buffer, pH 6.8). Then, extracts were homogenized for 3 min and centrifuged at 4,000 rpm for 15 min. The supernatant was subsequently used to determine the total carbohydrates. Finally, according to the method Jackson (1973) described, calcium and magnesium were determined using a Beckman flame photometer.

2.6 Experimental design and statistical analysis

The experiment adopted the split-plot design, with hybrids and foliar spray in the main and submain plots, respectively. Specifically, each submain treatment plot comprised 20 plants, comprising the two total experimental hybrids as the main plots. However, seven foliar spray applications were made on subplots. Notably, three replicate applications were conducted for each treatment.

The collected data were subjected to analysis of variance, after which the least significant difference (5%) was calculated to differentiate the means (Snedecor and Cochran, 1980).

3 Results and Discussions

3.1 Effect of hybrids

Table 1 shows the effect of different treatments on the number of leaves per head. Results showed that Patagonia was superior to the Bruma hybrid, with the difference between the two hybrids being considerable. Moreover, while the stem length differed between the two hybrids, this difference was not significantly affected and was inconsistent during the two successful seasons.

However, hybrids positively and significantly influenced fresh and dry head weights. Specifically, Patagonia was observed to be superior in fresh weight in both seasons and for dry weight only in the 2018 season compared to Bruma. Meanwhile, the two hybrids were not significantly different regarding dry weight in the 2019 season **(Table 2)**.

Furthermore, while the head diameter **(Table 3)** did not show significant differences between hybrids, chlorophyll content increased significantly in Patagonia compared with Bruma in both seasons. Moreover, no significant differences were observed between the two hybrids, based on yield and their components (marketable and unmarketable; **Table 4**).

Results also showed that while N% was significantly higher in Patagonia than in the Bruma hybrid, the P% content did not differ significantly between the two hybrids in both growing seasons **(Table 5)**. Likewise, while potassium did not show significant differences between the two hybrids **(Table 6)**, Ca% content was significantly higher in Patagonia than in Bruma **(Table 6)**.

Additionally, although a higher Mg content was noted in Patagonia than in Bruma, it was only significant in the 2019 season **(Table 7)**. Meanwhile, the carbohydrate content did not significantly differ between the two hybrids in both seasons. Moreover, Patagonia recorded lower nitrate content than Bruma **(Table 8)**.

3.2 Effects of foliar treatment

Table 1 shows that all applied treatments significantly increased the number of leaves per head compared with the control treatment in both seasons. Specifically, while all treatments of amino acids had a significant effect compared to antioxidant treatments, only the highest dose of each product significantly affected stem length.

All treatments also positively affected the fresh and dry weights of heads compared to the control in both seasons **(Table 2)**. Results showed that while amino acids recorded higher effects than vitamin treatments, these amino acids (3.0 cm/L) showed insignificant differences from those of antioxidants (2.0 cm/L) on the dry weight.

In contrast, the head diameters **(Table 3)** responded positively and significantly to all foliar spray treatments compared with the control. The highest dose of amino acid application was observed to record the largest head diameter among other foliar treatments. Similarly, all foliar spray applications increased chlorophyll contents significantly more than the control **(Table 3)**. Again, the highest dose of amino acid application showed the highest positive effect of all other treatments.

Furthermore, total yield responded positively to all foliar treatments compared with the control treatment **(Table 4)**. While the foliar doses of each product were observed to increase, the total yield also increased significantly. However, while amino acid treatments had superior effects to vitamin treatments, all yields from the control treatment were nonmarketable. Therefore, all foliar spray treatments significantly increased marketable yield.

All foliar spray treatments increased N% and P% contents significantly in the growing plants than in the control treatment **(Table 5)**. The highest dose of amino acid treatments showed the most significant effect, whereas the lowest dose of antioxidants showed the least significant effect on that parameter. Based on the P% content, the effects of lowest and medium doses of amino acids were not significantly different from the vitamins' comparable levels. Therefore, only the highest dose of amino acids was significantly higher than the highest of vitamins.

Table 1. Effects of hybrid and foliar interactions on the number of leaves per head and stem length (cm) in lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Number of leaves per head		Stem length (cm)	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	27.00	28.00	12.00	10.00
	Amino acids (3 cm^3/L)	29.00	30.00	13.00	12.00
	Amino acids (4 cm^3/L)	31.00	32.00	15.00	14.00
	Vitamins (1g/L)	26.00	25.00	10.00	11.00
	Vitamins (2 g/L)	28.00	29.00	12.00	11.00
	Vitamins (3 g/L)	30.00	31.00	14.00	14.00
	Control	16.00	15.00	9.00	8.00
Mean		26.71	27.14	12.14	11.42
Bruma	Amino acids (2 cm^3/L)	25.00	26.00	10.00	11.00
	Amino acids (3 cm^3L)	27.00	28.00	12.00	13.00
	Amino acids (4 cm^3/L)	29.00	30.00	14.00	15.00
	Vitamins (1 g/L)	24.00	25.00	11.00	12.00
	Vitamins (2 g/L)	26.00	27.00	11.00	13.00
	Vitamins (3 g/L)	28.00	28.00	14.00	14.00
	Control	15.00	14.00	8.00	7.00
Mean		24.85	25.42	11.42	12.14
Treatment means	Amino acids (2 cm^3/L)	26.00	27.00	11.00	10.50
	Amino acids (3 cm^3/L)	28.00	29.00	12.50	12.50
	Amino acids (4 cm^3/L)	30.00	31.00	14.50	14.50
	Vitamins (1 g/L)	25.00	25.00	10.50	11.50
	Vitamins (2 g/L)	27.00	28.00	11.50	12.00
	Vitamins (3 g/L)	29.00	29.50	14.00	14.00
	Control	15.50	14.50	8.50	7.50
L.S.D. at 5%	Hybrids	0.87	0.89	1.09	1.21
	Treatments	1.07	1.10	1.89	1.43
	Interactions	1.51	1.64	1.92	2.04

Table 2. Effects of hybrid and foliar interactions on the fresh head weight (in grams per plant) and head dry weight (in grams per plant) in lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Head fresh weight (g/plant)		Head dry weight (g/plant)	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	218.00	210.00	11.00	12.00
	Amino acids (3 cm^3/L)	235.00	222.00	13.00	13.00
	Amino acids (4 cm^3/L)	285.00	298.00	16.00	17.00
	Vitamins (1g/L)	192.00	185.00	9.00	10.00
	Vitamins (2 g/L)	223.00	217.00	12.00	12.00
	Vitamins (3 g/L)	278.00	264.00	15.00	14.00
	Control	155.00	138.00	6.00	5.00
Mean		226.57	219.14	11.00	11.85
Bruma	Amino acids (2 cm^3/L)	214.00	215.00	11.00	9.00
	Amino acids (3 cm^3L)	229.00	225.00	12.00	12.00
	Amino acids (4 cm^3/L)	302.00	275.00	17.00	15.00
	Vitamins (1 g/L)	175.00	198.00	10.00	11.00
	Vitamins (2 g/L)	222.00	218.00	12.00	13.00
	Vitamins (3 g/L)	256.00	255.00	14.00	11.000
	Control	122.00	115.00	8.00	7.00
Mean		217.14	214.42	12.00	11.14
Treatment means	Amino acids (2 cm^3/L)	216.00	212.50	11.00	10.50
	Amino acids (3 cm^3/L)	232.00	223.50	12.50	12.50
	Amino acids (4 cm^3/L)	293.00	286.50	16.50	16.00
	Vitamins (1 g/L)	183.50	191.50	9.50	10.50
	Vitamins (2 g/L)	222.50	236.00	12.00	12.50
	Vitamins (3 g/L)	267.00	267.50	14.50	12.50
	Control	138.50	126.50	7.00	6.00
L.S.D. at 5%	Hybrids	2.74	2.52	0.81	0.73
	Treatments	3.65	3.22	0.92	0.84
	Interactions	4.12	3.74	1.01	0.99

Table 3. Effects of hybrid and foliar interactions on the head diameter (cm) and total chlorophyll parameter of lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Head diameter (cm)		Total chlorophyll	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	9.21	8.01	31.12	29.36
	Amino acids (3 cm^3/L)	11.22	12.36	39.02	38.59
	Amino acids (4 cm^3/L)	13.02	14.81	43.32	44.45
	Vitamins (1g/L)	8.26	7.09	28.23	26.90
	Vitamins (2 g/L)	10.34	11.14	34.01	35.47
	Vitamins (3 g/L)	12.34	13.48	40.03	41.06
	Control	6.25	6.51	21.30	19.05
Mean		10.09	10.48	33.86	33.55
Bruma	Amino acids (2 cm^3/L)	8.08	8.50	29.09	27.02
	Amino acids (3 cm^3L)	12.23	10.61	35.23	33.04
	Amino acids (4 cm^3/L)	14.14	15.36	41.17	43.10
	Vitamins (1 g/L)	7.12	8.41	26.03	24.03
	Vitamins (2 g/L)	11.13	11.50	31.14	30.16
	Vitamins (3 g/L)	13.56	13.32	38.08	37.19
	Control	6.56	5.53	17.13	18.13
Mean		10.40	10.46	31.12	30.38
Treatment means	Amino acids (2 cm^3/L)	8.65	8.26	30.15	28.19
	Amino acids (3 cm^3/L)	11.73	11.48	37.12	35.85
	Amino acids (4 cm^3/L)	13.58	15.08	42.25	43.77
	Vitamins (1 g/L)	7.69	7.75	27.13	25.46
	Vitamins (2 g/L)	10.74	11.32	32.57	32.81
	Vitamins (3 g/L)	12.95	13.40	39.05	39.12
	Control	6.41	6.02	19.21	18.59
L.S.D. at 5%	Hybrids	0.70	0.66	1.10	1.20
	Treatments	0.85	0.76	1.71	1.83
	Interactions	0.92	0.89	2.02	1.99

Table 4. Effects of hybrid and foliar interactions on yield (in grams per square meter), marketable yield (in grams per square meter), and unmarketable yield (in grams per square meter) of lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Yield (g/m^2)		Marketable yield (g/m^2)		Unmarketable yield (g/m^2)	
		2018 Season	2019 Season	2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	6,100	6,020	5,620	5,510	480	510
	Amino acids (3 cm^3/L)	6,840	6,780	6,540	6,430	300	350
	Amino acids (4 cm^3/L)	7,850	7,715	7,620	7,450	230	265
	Vitamins (1g/L)	4,885	4,820	4,350	4,290	535	530
	Vitamins (2 g/L)	6,495	6,415	6,180	6,080	315	335
	Vitamins (3 g/L)	7,710	7,795	7,350	7,420	360	375
	Control	650	680	0.00	0.00	650	680
Mean		5,790	5,746.42	5,380	5,311	410	435
Bruma	Amino acids (2 cm^3/L)	6,080	5,995	5,620	5,510	460	485
	Amino acids (3 cm^3L)	6,685	6,510	6,345	6,160	340	350
	Amino acids (4 cm^3/L)	7,740	7,590	7,530	7,355	210	235
	Vitamins (1 g/L)	5,285	5,220	4,750	4,690	535	530
	Vitamins (2 g/L)	6,555	6,465	6,180	6,080	375	385
	Vitamins (3 g/L)	7,630	7,605	7,310	7,290	320	315
	Control	590	615	0.00	0.00	590	615
Mean		Mean	5,714.28	5,390.7	5,297.8	404.28	416.42
Treatment means	Amino acids (2 cm^3/L)	6,090	6,007.5	5,620	5,510	470	497.5
	Amino acids (3 cm^3/L)	6,762.5	6,645	6,442.5	6,295	320	350
	Amino acids (4 cm^3/L)	7,795	7,652.5	7,575	7,402.5	220	250
	Vitamins (1 g/L)	5,085	5,020	4,550	4,490	535	530
	Vitamins (2 g/L)	6,525	6,440	6,180	6,080	345	360
	Vitamins (3 g/L)	7,670	7,700	7,330	7,355	340	345
	Control	620	647.5	0.00	0.00	620	647.5
L.S.D. at 5%	Hybrids	37.12	35.36	33.21	29.32	23.22	20.13
	Treatments	41.20	38.55	38.65	30.23	25.90	22.56
	Interactions	46.35	42.75	41.34	32.11	29.76	23.56

Table 5. Hybrid and foliar interaction effects on nitrogen and phosphorus percentages of lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	N (%)		P (%)	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	3.82	3.52	0.40	0.39
	Amino acids (3 cm^3/L)	4.21	4.21	0.42	0.43
	Amino acids (4 cm^3/L)	4.95	4.89	0.49	0.48
	Vitamins (1g/L)	3.52	3.23	0.39	0.38
	Vitamins (2 g/L)	4.10	4.18	0.41	0.40
	Vitamins (3 g/L)	4.61	4.38	0.45	0.44
	Control	3.26	3.31	0.31	0.30
Mean		4.07	3.96	0.41	0.40
Bruma	Amino acids (2 cm^3/L)	3.56	3.12	0.38	0.37
	Amino acids (3 cm^3L)	4.22	4.03	0.44	0.43
	Amino acids (4 cm^3/L)	4.41	4.00	0.49	0.47
	Vitamins (1 g/L)	3.26	3.96	0.38	0.37
	Vitamins (2 g/L)	4.10	4.05	0.41	0.42
	Vitamins (3 g/L)	4.29	4.10	0.43	0.41
	Control	3.00	2.99	0.30	0.29
Mean		3.83	3.75	0.40	0.39
Treatment means	Amino acids (2 cm^3/L)	3.69	3.32	0.39	0.38
	Amino acids (3 cm^3/L)	4.21	4.12	0.43	0.43
	Amino acids (4 cm^3/L)	4.68	4.45	0.49	0.47
	Vitamins (1 g/L)	3.39	3.59	0.38	0.37
	Vitamins (2 g/L)	4.10	4.11	0.41	0.41
	Vitamins (3 g/L)	4.45	4.24	0.44	0.42
	Control	3.13	3.15	0.30	0.29
L.S.D. at 5%	Hybrids	0.16	0.18	0.07	0.05
	Treatments	0.28	0.29	0.04	0.02
	Interactions	0.39	0.41	0.07	0.03

Investigations also revealed that K% and Ca% responded significantly to all foliar spray treatments. The highest effect was recorded under the highest dose of amino acids, followed by the highest dose of vitamins **(Table 6)**. However, Mg% and carbohydrates% **(Table 7)** responded significantly to all foliar spray treatments. These responses increased as the dose of the application increased. Again, the highest effects were recorded in response to amino acids (4.0 cm^3/L).

Contrastively, only the nitrate content negatively responded to the foliar spray treatments **(Table 8)**. All foliar spray treatments were observed to reduce the nitrate content more than the control treatment, with the highest reduction at 4 cm^3/L amino acids. These results were recorded in both study seasons.

3.3 Effects of interaction

Compared to the stem length, an association was noted between hybrids and the respective treatments based on the number of leaves per head **(Table 1)**. Specifically, while Patagonia under amino acid treatments showed significant responses than Bruma under vitamin treatments, all treatments were significantly higher than the control treatment.

An interaction (*p* value) between hybrids and amino acid doses was also observed based on fresh and dry weights in both seasons. Results showed that Patagonia treated with the highest dose of amino acids had the highest positive effect **(Table 2)**.

Alternatively, the head diameter was affected by foliar application treatments **(Table 3)**. The highest dose for amino acids (4 cm/L) was observed to lead to the highest head diameter value than the control. Moreover, all foliar spray treatments increased chlorophyll content more in Patagonia than in Bruma. Specifically, Patagonia, with the highest concentration of amino acid treatment, recorded the highest chlorophyll content of all other treatments.

Since hybrids had no significant yield difference, the significant responses observed in this parameter were more similar to those recorded under foliar spray treatments **(Table 4)**. Specifically, both hybrids showed the highest response to amino acids (4.0 cm/L) and the lowest positive response to vitamins (1.0 cm/L). Marketable yield was observed to significantly improve, following the same trend observed under the foliar spray treatments. Hence, Patagonia had the highest concentration of amino acid treatments and recorded the highest yield compared with all other treatments.

Investigations also revealed that while the highest concentration of amino acid and vitamin treatments within each hybrid significantly differed regarding N% content, all foliar treatments increased the P% content significantly in both hybrids than the control **(Table 5)**.

Moreover, an interaction (*p* value) between foliar applications and hybrids on the K and Ca content was observed. Therefore, the highest dose of amino acids significantly affected both hybrids for both K and Ca contents than all other treatments **(Table 6)**.

Additionally, although the Mg% and carbohydrate% contents **(Table 7)** responded positively to the interaction effects between amino acids and hybrids, amino acid treatments on Patagonia recorded the lowest nitrate content of all other treatments **(Table 8)**.

A temperature range between 4°C and 27°C was previously reported to be optimum for lettuce, tolerating up to 30°C. The findings of the current study agree with these statements, where high temperature significantly reduces the marketable lettuce of Patagonia and Bruma hybrids to null. However, while it is the main challenge for originally mild climate species to develop heat-tolerant genotypes, no effect of the hybrids on this parameter was observed (Queiroz et al 2014). Furthermore, foliar sprays of amino acids and vitamins improved all plant growth aspects and quality than the control. The positive effect of amino acid applications has been reported in other crops grown under stress conditions (Kowalczyk et al 2008, Tantawy et al 2009,). These positive effects of amino acids may be because they are biostimulants (Rouphael and Colla 2018, Rouphael et al 2018), mitigating abiotic stress injuries (Kowalczyk et al 2008) and serving as hormone precursors (Kowalczyk et al 2008, Calvo et al 2014, Rouphael and Colla 2018). Therefore, these factors were proposed to contribute to this study's positive plant performance. Moreover, the possible effect of amino acids on root development (Walch-Liu et al 2007, Calvo et al 2014, Halpern et al 2015) and function (Hildebrandt et al 2015, Weiland et al 2016) can be the reason for improved nutrient content in plant tissue, which was reflected in the total plant production and quality in the current study.

Alternatively, stress conditions (including heat stress) can interrupt essential compounds' metabolic processes by harming growing plants. For example, Hanson et al (2016) mentioned that abiotic stresses

Table 6. Hybrid and foliar interaction effects on potassium and calcium percentages of lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	K (%)		Ca (%)	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	5.20	5.39	0.96	0.94
	Amino acids (3 cm^3/L)	6.25	6.12	1.20	1.10
	Amino acids (4 cm^3/L)	7.12	7.05	1.62	1.65
	Vitamins (1g/L)	4.95	4.85	0.92	0.94
	Vitamins (2 g/L)	5.76	5.45	1.00	1.01
	Vitamins (3 g/L)	6.54	6.42	1.40	1.20
	Control	4.35	4.21	0.83	0.80
	Mean	5.73	5.64	1.13	1.09
Bruma	Amino acids (2 cm^3/L)	5.31	5.16	0.91	0.94
	Amino acids (3 cm^3L)	6.13	5.99	1.01	1.00
	Amino acids (4 cm^3/L)	7.00	6.95	1.63	1.48
	Vitamins (1 g/L)	4.42	4.35	0.90	0.89
	Vitamins (2 g/L)	5.93	5.87	1.00	1.01
	Vitamins (3 g/L)	6.42	6.15	1.12	1.18
	Control	4.38	4.18	0.81	0.82
	Mean	5.65	5.52	1.05	1.04
Treatment means	Amino acids (2 cm^3/L)	5.25	5.27	0.93	0.94
	Amino acids (3 cm^3/L)	6.19	6.05	1.10	1.05
	Amino acids (4 cm^3/L)	7.06	7.00	1.62	1.56
	Vitamins (1 g/L)	4.68	4.60	0.91	0.91
	Vitamins (2 g/L)	5.84	5.66	1.00	1.01
	Vitamins (3 g/L)	6.48	6.28	1.26	1.19
	Control	4.36	4.19	0.82	0.81
L.S.D. at 5%	Hybrids	0.24	0.20	0.02	0.01
	Treatments	0.36	0.31	0.03	0.02
	Interactions	0.42	0.39	0.07	0.06

Table 7. Effects of hybrid and foliar interactions on magnesium and carbohydrate percentages in lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Mg (%)		Carbohydrate (%)	
		2018 Season	2019 Season	2018 Season	2019 Season
Patagonia	Amino acids (2 cm^3/L)	0.41	0.42	12.10	12.36
	Amino acids (3 cm^3/L)	0.51	0.53	14.00	14.22
	Amino acids (4 cm^3/L)	0.61	0.63	15.85	15.74
	Vitamins (1g/L)	0.38	0.39	12.80	12.75
	Vitamins (2 g/L)	0.46	0.47	13.70	13.42
	Vitamins (3 g/L)	0.53	0.55	15.30	15.38
	Control	0.35	0.34	9.50	8.90
Mean		0.46	0.47	13.32	13.25
Bruma	Amino acids (2 cm^3/L)	0.39	0.38	12.86	12.62
	Amino acids (3 cm^3L)	0.50	0.51	14.62	14.30
	Amino acids (4 cm^3/L)	0.60	0.59	15.92	15.79
	Vitamins (1 g/L)	0.36	0.35	12.71	12.64
	Vitamins (2 g/L)	0.43	0.41	13.32	13.55
	Vitamins (3 g/L)	0.51	0.49	15.48	15.36
	Control	0.30	0.31	8.80	9.10
Mean		0.44	0.43	13.38	13.33
Treatment means	Amino acids (2 cm^3/L)	0.40	0.40	12.48	12.49
	Amino acids (3 cm^3/L)	0.50	0.52	14.31	14.26
	Amino acids (4 cm^3/L)	0.60	0.61	15.88	15.76
	Vitamins (1 g/L)	0.37	0.37	12.75	12.69
	Vitamins (2 g/L)	0.44	0.44	13.51	13.48
	Vitamins (3 g/L)	0.52	0.52	15.39	15.37
	Control	0.32	0.33	9.15	9.00
L.S.D. at 5%	Hybrids	0.02	0.01	0.51	0.48
	Treatments	0.04	0.03	0.67	0.53
	Interactions	0.05	0.04	0.69	0.58

Table 8. Effects of hybrid and foliar interactions on the nitrate content of lettuce plants during the 2018 and 2019 seasons

Hybrids	Treatments	Total nitrate (mg/kg) d.w.	
		2018 Season	**2019 Season**
Patagonia	Amino acids (2 cm^3/L)	103.11	100.68
	Amino acids (3 cm^3/L)	97.72	96.17
	Amino acids (4 cm^3/L)	92.13	93.44
	Vitamins (1g/L)	111.55	106.32
	Vitamins (2 g/L)	104.20	103.47
	Vitamins (3 g/L)	94.33	92.10
	Control	208.31	205.43
Mean		115.90	113.94
Bruma	Amino acids (2 cm^3/L)	109.36	105.14
	Amino acids (3 cm^3L)	104.91	100.32
	Amino acids (4 cm^3/L)	99.03	95.89
	Vitamins (1 g/L)	112.50	108.44
	Vitamins (2 g/L)	107.12	103.13
	Vitamins (3 g/L)	102.01	98.23
	Control	210.32	206.46
Mean		120.75	116.80
Treatment means	Amino acids (2 cm^3/L)	106.23	102.91
	Amino acids (3 cm^3/L)	101.31	98.24
	Amino acids (4 cm^3/L)	95.58	94.66
	Vitamins (1 g/L)	112.02	107.38
	Vitamins (2 g/L)	105.66	103.30
	Vitamins (3 g/L)	98.17	95.16
	Control	209.31	205.94
L.S.D. at 5%	Hybrids	3.12	3.05
	Treatments	4.17	4.07
	Interactions	5.32	5.11

cause vitamin and cofactor deficiencies, degrading plant performance. They concluded that supplementing stressed plants with deficient vitamin(s) improves their performance. This finding explains the observed positive effects of applying vitamins (vitamin mix) in this study. In previous studies, applying B vitamins to stressed crop species has also been reported to have beneficial effects on plants under salinity stress, e.g., wheat, sunflower, and corn (Al-Hakimi and Hamada 2001, Sayed and Gadallah 2002, Kaya et al 2015). However, Asensi-Fabado and Munné-Bosch (2010) argued that whether the observed protection is due to direct the vitamin's effects is unclear. Nevertheless, differences between hybrids due to genetic hybrid differences are proposed to affect the results in this investigation.

4 Conclusions

The investigations of the current study established that applying amino acids and vitamins (e.g., vitamin mix) could improve lettuce production and quality under hydroponic systems. While the highest dose of amino acids and vitamins showed the highest effects, especially with the Patagonia hybrid, the lowest lettuce production and quality values were in the control treatment (without spraying). Therefore, based on the background created by this study, future work may include investigating the mixed application of two compounds to examine their positive cumulative effects.

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