



## Supplementary Foliar Applications and Their Effect on the Agronomic Behavior of Strawberry in a Vertical System

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### Authors' contributions

This work was carried out in collaboration among all authors. Authors NCM, MPMC, AFN and PÁV designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NCM, JIGL, AFN and ARO managed the analyzes of the study and helped in the interpretation of results. Authors MPMC and XRC managed the literature searches. All authors read and approved the final manuscript.

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### ABSTRACT

**Aims:** The objective was to evaluate the agronomic behavior of the strawberry crop under supplementary foliar applications in a vertical system.

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**Study Design:** The experimental design used in each test was the completely randomized experimental model with six treatments and four repetitions each. The treatments were Control, Estimulante plus®, AeroBiot®, BasfoliarAktiv®, Basfoliar PS® and HPLS.

**Place and Duration of Study:** The research was carried out under a greenhouse in Saltillo, Coahuila, Mexico. From October 20, 2019 to February 20, 2020.

**Methodology:** The San Andreas strawberry variety was used, the vertical system consisted of 4" PVC tubes, 1.2 m long, with 5 cm diameter perforations, a mixture of peat moss and perlite was used as substrate in a ratio 70:30 %. The foliar applications were carried out every week, stimulant plus®, AeroBiot®, Basfoliar Activ® and HPLS were at a rate of 2 ml L<sup>-1</sup>, Basfoliar PS® was at a rate of 2 g L<sup>-1</sup>, the control was only distilled water.

**Results:** The foliar application of AeroBiot® statistically improved the average weight of the fruit and exceeded the control by 16.7 %, the length of the fruit was statistically similar between the applications of BasfoliarAktiv®, AeroBiot®, Basfoliar PS® and HPLS, the rest of the variables showed a similar statistical behavior.

**Conclusion:** The agronomic performance of strawberry cultivation in a vertical system was similar between supplementary foliar applications of products containing macro and microelements, amino acids and protein hydrolysates, while worm leachates such as AeroBiot® improve the average weight of the fruit.

*Keywords: Aminoacids; protein hydrolysates; vertical system; Fragaria sp.*

## 1. INTRODUCTION

In the last 25 years, strawberry exports in the world increased by 119.7%, with an export volume of more than 865,000 t in 2018, currently, strawberry cultivation is becoming increasingly important in Mexico, from 2010 to 2014 the increase in the cultivated area was 52 %, while from 2014 to 2018 it was 37.5 %, with an average annual growth of 7.5 % in the last five years. The cultivated area in 2019 was 13,710 hectares, with a production of 653, 639 tons and a production value of 13, 401 million pesos, the states that lead by production are Michoacán (72.4 %), Baja California (14 %) and Guanajuato (9 %) [1]. Strawberry exports represent 52 % of the total produced and the main export market is the US [2], with a value of 6,968 million pesos [1].

On the other hand, the roots are the main sink through which the plants take the nutrients, however, the plants can also be nourished through the leaves, and it is generally through mineral salts dissolved in water [3], that is why, in the agricultural products market, those destined for foliar applications abound, and these can be products with mineral content of macro and micronutrients, amino acids, hormones, mixtures of them [4], content of sugars or sucrose [5,6], which enter the leaves through the cuticle, stomata, ectodesmata, hydathodes [7], trichomes or lenticels [8]. Therefore, foliar nutrition has always been used to make supplements or amendments to crops, since there are reports since 1884, sometimes, nutritional programs

include programmed foliar applications, in order to avoid the minimum nutritional deficiencies in the plant [9] or reduce periods of abiotic or biotic stress by applying stimulants [10,11,12], and it is a practice that is increasingly used by producers.

Research focused on discovering the benefits of foliar products on crops, as the results described are diverse and highly variable [13]. In foliar applications in strawberry cultivation, for example, the use of 1% urea and sucrose [14], selenite [15], hormonal such as 6BAP have been reported, AG3, AG4 + AG7 [11] and macroelements such as calcium [16]. On the other hand, it has been documented that the cultivation of strawberries in a vertical system produces higher yields and therefore higher profitability [17], and that the use of vertical and horizontal space can triple the yields per unit of surface [18]. Therefore, due to the potential benefits that the various products for foliar applications could cause to the strawberry crop, together with the imminent productive potential that the crop represents in a vertical system, it was then proposed to evaluate the agronomic behavior of the strawberry crop under supplemental foliar applications in a vertical growing system.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Experimental Site

The study was carried out from October 20, 2019 to February 20, 2020, in a medium-technology

greenhouse at the Antonio Narro Autonomous Agrarian University, Saltillo, Coahuila, Mexico. Located at 25 ° 21' 24" N and 101 ° 02' 05" W, at an altitude of 1762 meters above sea level, with an average annual rainfall of 400 mm and an average annual temperature of 12-18°C.

## 2.2 Genetic Material

To carry out the experiment, the San Andreas strawberry variety was used, which is described as a moderate day neutral variety, of excellent fruit quality, of excellent flavor, with little need for cold in winter. With resistance to diseases such as *phytophthora*, *colletotrichum*, *botrytis* and *oidio*.

## 2.3 Preparation of the Vertical Cultivation System

The vertical system consisted of six 4" PVC tubes each 1.2 m long, with holes of approximately 5 cm in diameter, the distance between holes was 20 cm and between rows of holes 8.75 cm approximately in a triangular or staggered arrangement (Fig. 1-A, B, C and D). The interconnected tubes for the drainage of the

nutrient solution and prostrated on a 20 cm high wooden base that allowed the drained nutrient solution to be collected, the PVC tubes were filled with a substrate mixture that was peat moss and perlite in a proportion 70:30 % respectively before transplantation of strawberry.

## 2.4 Establishment of Cultivation in Vertical System

The strawberry plants used were obtained from stolons of mother plants, stolons that were cut and placed in 200 cavity polystyrene trays with a mixture of peat moss and perlite substrate in a 70:30 % proportion respectively. For its rooting, the commercial product Rooting® was used at a rate of 1 ml L<sup>-1</sup>, which was applied once a week and for three consecutive weeks. When the plants were 21 days old in a tray for rooting and growth, they were transplanted the vertical system, which was made by placing a mold identical to the cavity of the tray in the perforation and inside the substrate that contained the vertical system, once made. Drilling the plants were removed from the tray and transplanted to the vertical system for the execution of the investigation.



**Fig. 1. Prepared vertical system (A), with three-week transplant strawberry plants (B). strawberry plants in full fruiting (C), strawberry plants in maturity and harvest (D)**

**Table 1. Nutrient content of foliar treatments applied as a supplement to strawberry cultivation in a vertical system**

Product content	Control	Estimulante Plus®	AeroBiot®	Basfoliar Activ®	Basfoliar PS®	HPLS
N total	-	8%	0.0061%	3%	25%	-
P (P <sub>2</sub> O <sub>5</sub> )	-	-	0.000037%	27%	10%	-
K (K <sub>2</sub> O)	-	-	0.051%	18%	17%	-
Boron	-	-	0.007%	0.01%	0.01%	-
Molybdenum	-	-	-	0.001%	0.001%	-
Copper	-	-	-	0.02%	0.02%	-
Iron	-	-	-	0.02%	0.05%	-
Zinc	-	-	0.01%	0.01%	0.02%	-
Manganese	-	-	0.01%	0.01%	0.05%	-
Magnesium	-	-	0.55%	-	0.60%	-
Sulfur	-	-	0.16%	-	2.28%	-
Calcium	-	-	2.66%	-	-	-
Sodium	-	-	0.01%	-	-	-
Chlorine	-	-	0.02%	-	-	-
Ammonium	-	-	0.16%	-	-	-
Microorganisms	-	-	0.04%	-	-	-
Aminoacids	-	24%	-	-	-	-
Protein hydrolysate	-	-	-	-	-	11%

**Table 2. Chemical nutritional composition of the nutritive solution (NS) used in irrigation for the production of strawberries in a vertical system**

Macroelements							
NS (%)	NO <sub>3</sub> <sup>-</sup>	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup> y CO <sub>3</sub> <sup>2-</sup>	K <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>
	Miliequivalents L <sup>-1</sup>						
100	7	1	6	1	5	3	6
75	4.88	0.75	4.5	1	3.75	2.25	4.5
Microelements							
SN (%)	Fe <sup>3+</sup>	Mn <sup>2+</sup>	H <sub>3</sub> BO <sub>3</sub>	Zn <sup>2+</sup>	Cu <sup>+</sup>	MoO <sub>4</sub> <sup>2-</sup>	
	Parts per million (ppm)						
100	3	1.48	0.28	0.24	0.12	0.08	
75	2.25	1.11	0.21	0.18	0.09	0.06	

A completely randomized experimental arrangement was used with six supplementary foliar treatments that were; the Control, Stimulant plus® from MANVERT, AeroBiot® (Worm Leachate) from FERTILOM, BasfoliarAktiv® and Basfoliar PS® from COMPO EXPERT, HPLS (*experimental milk whey protein hydrolysate*) (Table 1) and four repetitions each, where each PVC tube with 20 plants represents a treatment and a total of five plants for each repetition, the foliar applications were made every week and distilled water was used for its application, for stimulant plus®, AeroBiot®, Basfoliar Aktiv® and HPLS were at a rate of 2 ml L<sup>-1</sup>, while Basfoliar PS® was at a rate of 2 g L<sup>-1</sup>. The control was only distilled water.

The composition of the nutritive solutions used as a base to nourish the plants via the roots are shown in Table 2. The CO<sub>3</sub><sup>-</sup> and HCO<sub>3</sub><sup>-</sup> were

neutralized with phosphoric and nitric acid in such a way that in the irrigation water they contributed 1 mEq L<sup>-1</sup> of HCO<sub>3</sub><sup>-</sup> which represents the alkalinity of the water with 6.2 pH, the nutrient solution was supplied as a percentage in two stages of growth of the crop, 75 % five after transplanted, once flowering started, 100 % was supplied (Table 2), the which was maintained until the end of the experiment, 10 % drainage was used. For the control of red spider (*Tetranychus urticae*) weekly applications of abamectin 1.8%, deltamethrin 1.01% + Imidacloprid 7.6% were made at a rate of 1 ml L<sup>-1</sup>.

## 2.5 Determination of Evaluated Variables

To determine the yield variables, six harvests were carried out at weekly intervals, the first was on January 10, 2020 and the last on February 14, 2020. The yield in grams per plant was

estimated by harvesting all the ripe fruits (more than 50 % red coloration) of each plant, in each harvest, which were weighed on a precision digital scale SARTORIUS model TS 1352Q37, the number of fruits that were harvested from each plant, the average fruit weight was also counted. It was calculated dividing the total weight of fruits harvested by the total number of fruits per plant, while the equatorial diameter of the fruit (EDF) and length of the fruit was estimated at five fruits for each repetition and in each harvest carried out and a digital vernier was used Autotec® brand. Leaflet length (LL), leaflet width (LW) was quantified in five leaflets of each repetition, length of fruit bunch (LFB) and leaf petiole length (LPL), were determined in five leaflets for each repetition and it was measured with a measuring tape graduated in cm, to quantify the fresh and dry weight of leaves (FWL and DWL) the same precision balance was used with which yield was determined.

## 2.6 Determination of Fruit Quality

Total soluble solids were determined with an Atago® brand digital refractometer and the data obtained in degrees brix was recorded. The firmness of the fruit was quantified with a Fruit Pressure Tester penetrometer, model FT-327 of 13 kg, with a 3 mm tip. For both variables, the same fruits were used, whose length and equatorial diameter were quantified.

## 2.7 Statistic Analysis

Statistical analysis was performed with the SAS version 9.1 program. The experimental model was completely randomized with six treatments and four repetitions each and significance of  $P = .05$ , with comparison of LSD Fisher means ( $LSD \leq .05$ ).

# 3. RESULTS AND DISCUSSION

## 3.1 Agronomic Performance Indicators

According to the ANOVA ( $P = .05$ ) performed and the  $LSD \leq .05$  mean test performed, no statistical significance was detected between applied foliar treatments (Table 3), in the response variables of equatorial diameter of fruit (EDF), length of leaflet (LL), leaflet width (LW), fresh weight of leaves (FWL), dry weight of leaves (DWL) and length of fruit bunch (LFB), so it is inferred that supplementary foliar applications with Products of different origin and content do not necessarily generate positive effects on these variables, as long as root nutrition is adequately provided [19], since the nutritional status of the plant is determined by

absorption of nutrients, which determines the assimilation of these nutrients [8]. While in the variable of leaf petiole length (LPL) the foliar applications with AeroBiot®, BasfoliarAktiv®, HPLS and Control had a similar statistical behavior, with the exception of Basfoliar PS® and stimulant plus® that presented lower results than before cited.

## 3.2 Yield and Yield Components

The foliar application of the AeroBiot® product, which is a product derived from earthworm leachate, statistically improved the average weight of the fruit with 17.11 g (Fig. 2), higher than the control by 16.7 %, which was probably due to, to the proportion of some macroelements, microelements and the ammonium that it contributed, since due to its content, the worm leachates increase the production of photoassimilates [20], which translates into an increase in yield and some of its components, and in high doses (30 ml.L-1) the best results are observed [21], in addition, earthworm leachates represent a sustainable alternative to increase quality and yields [22], since it can be used as a growth promoter [23], the rest of the treatments showed a similar statistical performance. Meanwhile, in the fruit length variable, a similar statistical behavior was observed between the foliar applications of BasfoliarAktiv®, AeroBiot®, Basfoliar PS® and HPLS with 42.24, 41.09, 39.71 and 39.47 mm respectively, which could be explained due to the supply of macro and micronutrients provided by said products and the free amino acids and peptides provided by HPLS, while the Control and Stimulant plus® were lower than those mentioned above. The amino acid content of Estimulante plus® probably did not reflect a good performance of the crop, since apparently the plants did not suffer any type of stress, since amino acids are generally used to counteract the effect of biotic and abiotic stress [24,10,25].

In the yield variable ( $\text{g plant}^{-1}$ ), no statistical significance was found between applied foliar treatments (Fig. 3), similar results were found when applying selenite [15], 1% urea and sucrose [14], however, the treatment that was percentage superior to the others, was HPLS with 391.5 g per harvested plant, and exceeded the Control in 15.7 %, similar effects could be observed in number of fruits per plant, since HPLS exceeded the Control by 17.3 %, which could be explained in that said product contains mainly free amino acids and soluble peptides, which are immediately incorporated into

enzymatic reactions that activate the synthesis of phytohormones or as a direct nutrient [26,12], they are also easily absorbed and assimilated both via foliar and root and are quickly transported to the organs of greatest demand [27], where rapidly incorporate into cellular metabolism, saving energy for plants [12], improving crop yield and quality [28]. Basfoliar PS® and Basfoliar Activ® products also showed slight percentage increases in both variables.

### 3.3 Fruit Quality

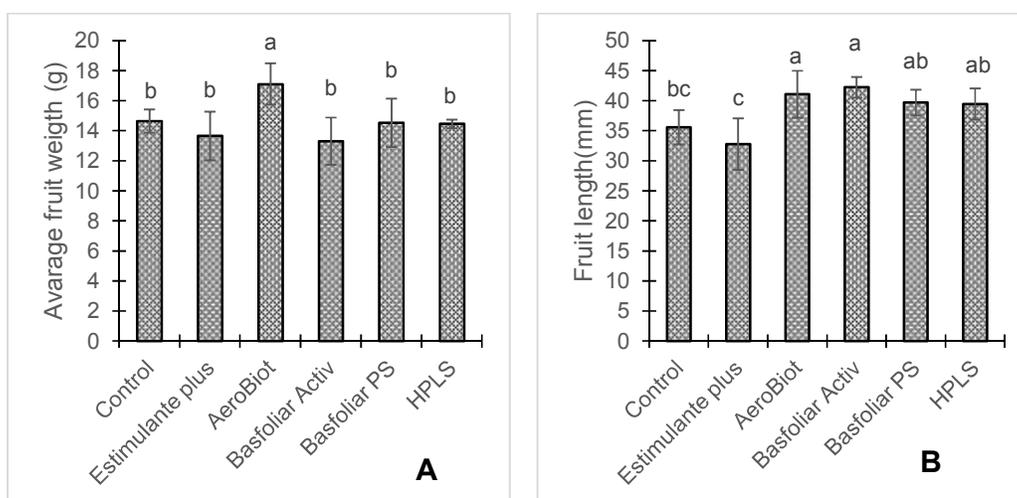
In the fruit quality variables such as firmness and total soluble solids, statistical significance

was not found between applied foliar treatments (Fig. 4), which indicates that the composition of the applied foliar products did not influence the significant modification of these variables of quality, so its use could be omitted if the objective is to improve these variables. The results of total soluble solids agree with the values reported in strawberries treated with selenium [15] and in strawberries treated with gibberellins and cytokinins [11]. For its part, the firmness of the fruit also corresponds to those discovered by [11], while foliar applications of calcium help to improve this fruit quality variable [16].

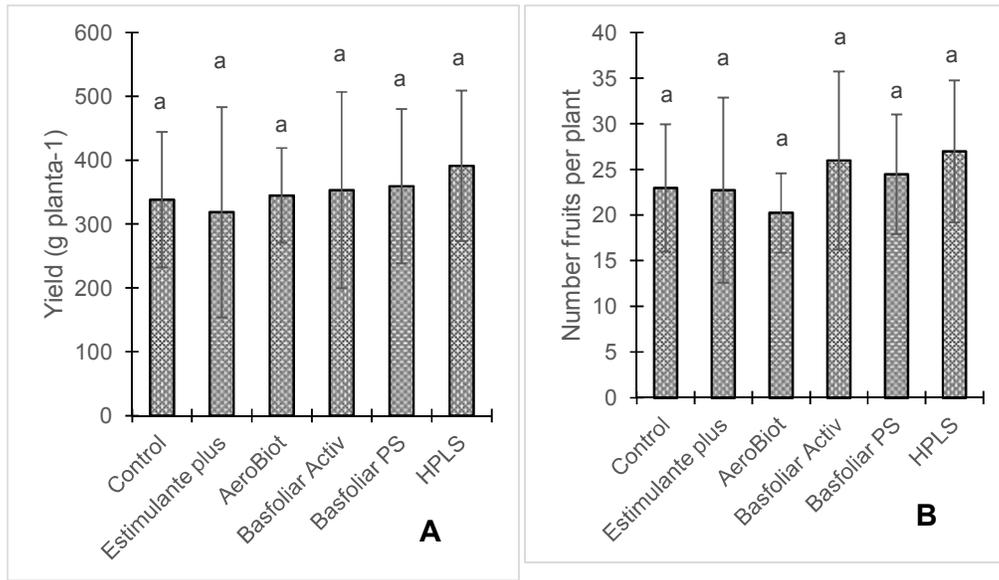
**Table 3. Analysis of variance and LSD Fisher test of means ( $LSD \leq .05$ ) of agronomic variables of strawberry treated with different supplementary foliar products**

Treatments	EDF (mm)	LL (cm)	LW (cm)	FWL (g)	DWL (g)	LFB (cm)	LPL (cm)
Control	32.79 a <sup>*</sup>	5.39 a	5.08 a	56.35 a	16.35 a	11.51 a	11.99 ab
Estimulante plus®	30.72 a	5.45 a	5.26 a	54.03 a	15.60 a	11.09 a	10.87 b
AeroBiot®	35.98 a	5.82 a	5.67 a	58.38 a	16.30 a	12.33 a	12.68 a
Basfoliar Activ®	35.20 a	5.39 a	5.35 a	55.93 a	16.05 a	11.47 a	12.05 ab
Basfoliar PS®	32.69 a	5.56 a	5.26 a	56.90 a	16.18 a	11.61 a	10.63 b
HPLS	34.33 a	5.30 a	5.12 a	50.53 a	14.65 a	10.63 a	11.45 ab
MSD	4.43	0.6	0.62	22.81	6.55	1.22	1.52
ANOVA ( $P = .05$ )	0.1983	0.5555	0.4323	0.9839	0.9963	0.1460	0.0904
Coefficient of variation (%)	8.87	7.42	7.94	27.74	27.75	7.2	8.84

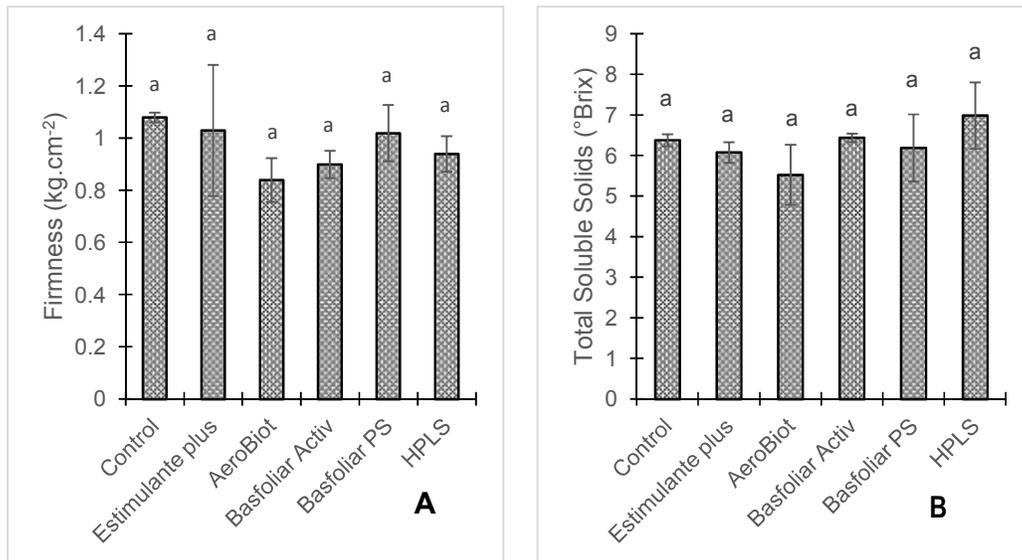
<sup>\*</sup> & = average followed by the same letter in the columns are statistically equal LSD Fisher ( $LSD \leq .05$ ), DEF = equatorial diameter of fruit, LL = length of leaflet, LW = leaflet width, FWL = fresh weight of leaf, DWL = dry weight of leaves, LRF = length of fruit bunch, LPL = leaf petiole length, MSD = minimum significant difference



**Fig. 2. Average fruit weight (A) and fruit length (B) of strawberry treated with different supplementary foliar products. ANOVA  $P = .05$ , LSD Fisher mean test ( $LSD \leq .05$ ). Vertical bars correspond to standard deviation**



**Fig. 3.** Yield in g plant<sup>-1</sup> (A) and number of fruits per plant (B) in strawberry plants treated with different supplementary foliar products. ANOVA  $P = .05$ , LSD Fisher mean test ( $LSD \leq .05$ ). Vertical bars correspond to standard deviation



**Fig. 4.** Firmness (A) and total soluble solids (B) in strawberry plants treated with different supplementary foliar products. ANOVA  $P = .05$ , LSD Fisher mean test ( $LSD \leq .05$ ). Vertical bars correspond to standard deviation

#### 4. CONCLUSION

The agronomic performance of the strawberry crop in a vertical system was similar between supplementary foliar applications of products with macro and microelements, amino acids and protein hydrolysates. Foliar derived from worm

leachate such as AeroBiot® improve the average weight of strawberry fruit. The agronomic variables and fruit quality is not affected by foliar applications. Therefore, it is inferred that the similar response between treatments is the result of an appropriate nutrient supply through the nutrient solution.

## DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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