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Effect of Fertilization and Planting Date on the Production and Shelf Life of Tuberose

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Abstract: The tuberose, *Agave amica*, is an ornamental plant appreciated for its oils. The objective of this study was to evaluate the effect of planting dates (April, May and June), dose of NPK (N_{80}-P_{60}-K_{40}, N_{300}-P_{200}-K_{200}, N_{100}-P_{50}-K_{50} and N_{00}-P_{00}-K_{00}), and fertilizer sources (chemical, organic, combined and control) on tuberose production, flower quality and postharvest shelf life. The physiological variables spike characteristics, leaf color, biomass, and postharvest flower quality were evaluated. The results show that the best planting date is in June; plants planted in June flowered earlier (156 days) and had better flower quality. The fertilization formula N_{300}-P_{200}-K_{200} produced a higher number of spikes (1.32) and flowers (38.93), a larger stem diameter (0.9 cm), and promoted fewer days to flowering (188d). Plants fertilized with chemical fertilizer had fewer yellow leaves, a larger number of spikes (1.41), a longer spike length (26.89 cm), and a higher number of flowers/spikes (39.28), corms/plants (31.03), and open flowers on the ninth day in vase (13.14) and heavier stems with spikes (134.80 g). In conclusion, the dose of N_{300}-P_{200}-K_{200} from chemical source and planting in June produced the best flower quality and the shortest production cycle.

Keywords: leaf color; photosynthesis; flower quality; vase life

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1. Introduction

The genus *Polianthes* is endemic to Mexico. It belongs to the Asparagaceae family and is important for the fragrance of its flowers [1], owing to the presence of geraniol, nerol, benzyl alcohol, eugenol, and methyl anthranilate [2]. Its essential oil is of interest for the pharmaceutical and cosmetic industry [1,3] because it has antibacterial, antifungal, insecticidal, herbicidal and healing properties [4]. This genus comprises 15 species, but only one, *Polianthes tuberosa*, is grown commercially; the rest of the species are wild [2].

Polianthes tuberosa, recently referred to as *Agave amica*, commonly known as tuberose (nardo in Mexico) [5], has been cultivated by the Aztecs in Mexico as an ornamental plant since before the arrival of the Spanish colonizers [6]. It was used as a substitute for soap because of the high sapogenin concentration in its roots [3], and was, thus, called "amole", meaning soap, or "omixochitl" (bone flower) in Nahuatl [6]. It has also been reported that this species has considerable capacity to absorb heavy metals such as chrome [4]. Other uses are found in the industry of beverages and food. Additionally, the ground dried bulbs are used as a remedy for gonorrhea, and the fragrance of the flowers calms nerves. The flowers are also used in preparing vegetable juices [2]. Commercially, the tuberose is propagated vegetatively by dividing the bulbs [2]. However, production is faced with several difficulties that can reduce quality and quantity of flowers [7]. The factors that can affect production, quality, and postharvest life of the tuberose flower range from environmental factors, cultural practices, irrigation, crop genetics [8], temperature and solar radiation [9], plant density, soil, and planting season [10] to nutrition [2,11,12] and bulb size [2,12]. In terms of the planting season, tuberose can be established in any season of the year (in subtropical regions). It is generally recommended to be planted in the spring [10]. Regarding nutrition, there are several studies on different dosages of N-P-K in kg/ha that have obtained good results in flower yield and quality. They have recommended different ideal doses, such as N_{120}-P_{60}-K_{80} [2], N_{300}-P_{200}-K_{200} [13], N_{200}-P_{200}-K_{400} [14], N_{100}-P_{50}-K_{50} [15], N_{100}-P_{75}-$K_{62.5}$ [16]. Other studies have found that the application of organic fertilizers, such as chicken manure, promotes more biomass growth and a higher number of flowers [17]. Still, others have found that soil amended with humic acid exhibits a higher plant height (43.08 cm), number of florets/spikes (22.79), number of bulblets produced/plants (22.03) and number of leaves/plants (22.17) [12]. Babarabie (2020) also reports an increase in the chlorophyll content and N-P-K content in leaves, as well as an increase in the spike and stem length, number of flowers and bulbs, leaf area and root depth with the application of 150 mg L^{-1} humic acids [18]. Similarly, other authors have reported a higher plant height, growth, number of leaves/plants, spike length, rachis length and tuberosa spikes yield with 10 t vermicompost plus 50% recommended dose of fertilizer (N_{150} P_{30} K_{100} S_{20} B_1 Zn_1 kg/ha) [11]. Therefore, well-managed non-nutritional and nutritional factors can facilitate the achievement of quality and productivity, a reduction in pollution and lower production costs [19]. Our objective was to evaluate the effect of planting dates (April, May, and June), NPK formulas (N_{80}-P_{60}-K_{40}, N_{300}-P_{200}-K_{200}, N_{100}-P_{50}-K_{50} and N_{00}-P_{00}-K_{00}), and fertilizer sources (chemical, organic, combined, and control) on the production and quality of tuberose flowers.

2. Materials and Methods

The study was conducted in Ciudad Guzmán, Jalisco, Mexico, in a greenhouse. Tuberose bulbs (cv Mexican Double) were planted at a depth of 5 cm in a substrate of soil and peat moss (BM, 2, Berger) (3:1) in 10 L pots. Soil characteristics were as follows. Soil texture (Bouyoucos): sand 54.91%, clay 20.58%, silt 17%; pH 5.95 in water; water holding capacity, 17%; organic matter content (Walkey–Black), 0.55%; electrical conductivity 0.25 milli-mhos/cm at 25 °C; nitric nitrogen (Morgan) at 2.05 ppm, ammoniacal nitrogen (Morgan) at 12 ppm, phosphorus (Morgan) at 30 ppm, and potassium (Morgan) at 60 ppm. Three planting dates were established (1 April, 1 May, and 1 June 2020). The plants of each planting date were fertilized four times with intervals of 15 days between applications; the first was applied 15 days after leaves appeared. The fertilizers used as chemical sources were the following: Hakaphos Base, N_7-P_{12}-K_{40}, (Compo Expert); DAP N_{18}-P_{46}-K_{00}, (FERTIMAX); NovaTec Solub 45%, N_{45}-P_{00}-K_{00}, (Compo Expert). The fertilizers used as organic source were bioactive, organic plant stimulant, $N_{1.43}$-$P_{2.16}$-$K_{1.44}$ (BioStar, Mexico); solid humus from the gulf (vermicompost), $N_{2.20}$-$P_{1.37}$-$K_{1.19}$ (Siempre Terra); phosphoric rock, N_{00}-P_{24}-K_{00} (Fosforita de México, S. A. de C.V); bio-humus, N_{00}-P_{00}-K_6- (BioStar, Mexico); and Algacell nitrogen, N_{16}-P_{00}-K_{00} (BioMex). For the calculations, we used a population density of 6 plant/m^2. The following formula was used: Fertilizer application rate = required nutrient application rate X 100/% of the nutrient in the fertilizer. The evaluated fertilizer doses, applied products, and sources are shown in (Figure 1).

2.1. Physiological Variables

Three months after establishment, the physiological variables were measured: transpiration rate (TR, mmol m^{-2} s^{-1}), stomatic conductance (SC, mol m^{-2} s^{-1}), photosynthetic rate (PR, µmol m^{-2} s^{-1}), and incident photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}) in a leaf chamber, and leaf chamber temperature (LChT, °C) using a portable photosynthesis analyzer LCi-SD (ADC Bioscientific Ltd., Hoddesdon, UK).

Sources	Doses (kg/ha)	Applied products	1st	2nd	3rd	4th	Total
Chemical	N_{80}-P_{60}-K_{40}	N_{7}-P_{12}-K_{40} (g)	0.41	0.41	0.41	0.41	1.66
		N_{18}-P_{46}-K_{00} (g)	0.43	0.43	0.43	0.43	1.739
		N_{45}-P_{00}-K_{00} (g)	0.50	0.50	0.50	0.50	2.0
	N_{300}-P_{200}-K_{200}	N_{7}-P_{12}-K_{40} (g)	2.08	2.08	2.08	2.08	8.33
		N_{18}-P_{46}-K_{00} (g)	1.26	1.26	1.26	1.26	5.07
		N_{45}-P_{00}-K_{00} (g)	1.94	1.94	1.94	1.94	7.78
	N_{100}-P_{50}-K_{50}	N_{7}-P_{12}-K_{40} (g)	0.52	0.52	0.52	0.52	2.08
		N_{18}-P_{46}-K_{00} (g)	0.31	0.31	0.31	0.31	1.268
		N_{45}-P_{00}-K_{00} (g)	0.71	0.71	0.71	0.71	2.87
Organic	N_{80}-P_{60}-K_{40}	Bioactive (mL)	0.0	5	5	5	15.0
		Solid h (g)	9.5	9.5	9.5	9.5	37.9
		Phosphoric rock (g)	0.0	0.0	0.66	0.0	0.66
		Algacell nitrogen (g)	1.78	0.0	0.0	0.0	1.78
	N_{300}-P_{200}-K_{200}	Bioactive (mL)	0.0	10	11	10	30.9
		Solid humus (g)	30.4	30.4	30.4	30.4	121.6
		Phosphoric rock (g)	0.0	0.0	2.1	2.1	4.2
		Algacel nitrogen (g)	2.94	2.94	2.94	2.94	11.77
		Bio-humus (g)	3	3	0.0	0.0	6.0
	N_{100}-P_{50}-K_{50}	Bioactive (mL)	0.0	0.0	4	4	7.7
		Solid humus (g)	12.2	12.2	12.2	12.2	48.7
		Algacell nitrogen (g)	3.0	0.0	0.0	0.0	3.0
		Bio-humus (g)	0.0	2.4	0.0	0.0	2.4
Combined	N_{80}-P_{60}-K_{40}	Bioactive (mL)	0.0	2.5	2.5	2.5	7.50
		Solid-humus (g)	4.7	4.7	4.7	4.7	18.9
		Phosphoric rock (g)	0.0	0.0	0.32	0.0	0.32
		Algacell nitrogen (g)	0.89	0.0	0.41	0.0	0.41
		N_{7}-P_{12}-K_{40} (g)	0.21	0.21	0.21	0.21	0.84
		N_{18}-P_{46}-K_{00} (g)	0.22	0.22	0.22	0.22	0.88
		N_{45}-P_{00}-K_{00} (g)	0.25	0.25	0.25	0.25	1.00
	N_{300}-P_{200}-K_{200}	Bioactive (mL)	0.0	5	5.5	5.0	15.5
		Solid humus (g)	15.2	15.2	15.2	15.2	60.8
		Phosphoric rock (g)	0.0	0.0	1.05	1.05	2.10
		Algacell nitrogen (g)	1.5	1.5	1.5	1.5	5.9
		Bio-humus (g)	1.5	1.5	0.0	0.0	3.0
		N_{7}-P_{12}-K_{40} (g)	1.04	1.04	1.04	1.04	4.16
		N_{18}-P_{46}-K_{00} (g)	0.63	0.63	0.63	0.63	2.54
		N_{45}-P_{00}-K_{00} (g)	0.97	0.97	0.97	0.97	3.89
	N_{100}-P_{50}-K_{50}	Bioactive (mL)	0.0	0.0	2.0	2.0	3.9
		Solid humus (g)	6.0	6.0	6.0	6.0	24.3
		Algacell nitrogen (g)	1.52	0.0	0.0	0.0	1.52
		Bio-humus (g)	0.0	1.2	0.0	0.0	1.2
		N_{7}-P_{12}-K_{40} (g)	0.26	0.26	0.26	0.26	1.04
		N_{18}-P_{46}-K_{00} (g)	0.15	0.15	0.15	0.15	0.60
		N_{45}-P_{00}-K_{00} (g)	0.35	0.35	0.35	0.35	1.40
Control	N_{0}-P_{0}-K_{0}	-------------	0	0	0	0	0.0

Figure 1. Treatments established for different fertilizer sources (chemical, organic, combined, and control), doses in tuberose, and applied products for four runs of each experiment.

2.2. Leaf Color

In addition, leaf color was determined with twelve readings on the middle part of six leaves per treatment, using a Konica colorimeter Minolta CR-400. The color readings were expressed in units "L*" = luminosity, from completely opaque (0) to totally transparent (100); "a*" = red coordinates (positive values), green (negative values); and "b*" = yellow coordinates (positive values), blue (negative values). Hue is the tone or shade of a color, and chroma is the intensity of the hue.

2.3. Spike Characteristics and Biomass

Characteristics of the spike (sampled during flowering 157–185 days after planting) were evaluated: number of spikes/plants (NSp), length of the floral stem (SL, cm) from the stem base to the tip of the spike, spike length (SpL, cm) from the base of the spike to the tip, number of florets or flowers/spikes (NFSp), stem diameter at the middle (SD, cm), days to appearance of the spike (APSp, d), days to pre-flowering (PRE, d) when the spike was pink, and days to flowering (FLO, d) when the plant had two open flowers. To measure plant biomass, a destructive sampling was conducted at the end of the experiment with four plants from each treatment, and the length of the longest leaf (LL, cm), root length (RL, cm), aerial biomass (AB, g), number of corms/plants (NC), and corm diameter (CD, cm) were recorded. Weights were measured with an electronic balance (Santorius Te2145), and the length was obtained with a tape measure.

2.4. Postharvest

Postharvest, or vase, life was evaluated over 9 days. Nine floral stems were used per treatment in each experiment. The variables evaluated were the number of open flowers (OF), fresh weight of floral stems with spikes (FW, g), senescent flowers (SF), and water uptake (WU, mL). After 9 days in the vase, the spike was separated from the stem and placed in a drying oven (Binder® series FD) for three days at a temperature of 60 °C, and spike dry weight (SpDW, g), floral stem dry weight (SDW, g), and dry weight of spike plus stem (DWSSp, g) were determined.

2.5. Greenhouse Temperature

The temperatures registered in the greenhouse during the crop cycle varied. Minimum, mean, and maximum temperatures for April were 8, 21, and 40 °C, for May they were 10, 25 and 45 °C, and for June they were 11, 23, and 41 °C, respectively. There was no temperature control because the facilities were not automated (Figure 2).

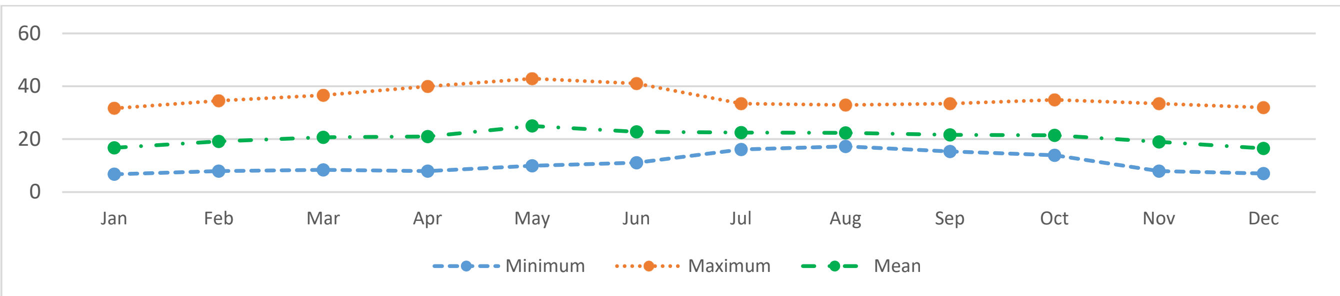

Figure 2. Minimum, maximum, and mean temperatures registered in the greenhouse.

The experimental design was completely random blocks with four replications. The experimental unit was three plants, and one bulb (40–50 mm diameter) was established per pot. Data analysis was a 3 × 4 × 4 factorial, in which the first factor was the planting date (1 April, 1 May and 1 June), the second factor was fertilization dose (N_{80}-P_{60}-K_{40}, N_{300}-P_{200}-K_{200}, N_{100}-P_{50}-K_{50} and N_{00}-P_{00}-K_{00}), and the third factor was fertilizer source [chemical, organic, combined (chemical and organic), and the control]. For the statistical analysis, an analysis of variance was performed, then means were compared with Tukey ($\alpha = 0.05$) using the software Statistical Analysis System version 9.1.3 [20].

3. Results

3.1. Analysis of Planting Dates

3.1.1. Effect of Planting Date on Physiological Variables

The factorial analysis of the three planting dates revealed that the treatments set up in June had a temperature and transpiration rate that were higher than those of April and May. There were no significant differences in the photosynthetic rate; the recorded values were between 2.966 and 3.26 µmol $m^{-2}s^{-1}$. The plants established in May received the highest value of photosynthetically active radiation (PAR), 130.4 µmol m^{-2} s^{-1}. The incident temperature in the leaf chamber (LChT) and the transpiration rate were lower in those plants established in April compared to those planted in May and June (Table 1). The transpiration rate is closely related to PAR and LChT since when radiation and temperature are low, the transpiration rate is also low, as did occur in April.

Table 1. Photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}), temperature (LChT, °C), transpiration rate (TR, mmol m^{-2} s^{-1}), stomatic conductance (SC, mol m^{-2} s^{-1}), and photosynthetic rate (PR, µmol m^{-2} s^{-1}) in tuberose established on three planting dates.

Date	PAR µmol $m^{-2}s^{-1}$	LChT °C	TR mmol $m^{-2}s^{-1}$	SC mol $m^{-2}s^{-1}$	PR µmol $m^{-2}s^{-1}$
April	91.8 ^{c}	25.73 ^{c}	1.339 ^{c}	0.097 ^{a}	2.966 ^{a}
May	130.4 ^{a}	28.70 ^{b}	1.545 ^{b}	0.085 ^{b}	3.260 ^{a}
June	113.1 ^{b}	30.01 ^{a}	1.836 ^{a}	0.091 ^{ab}	3.029 ^{a}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.1.2. Effect of Planting Date on Leaf Color

Leaf luminosity ("L*"), which defines brightness from completely opaque (0) to totally transparent (100), had values from 50.11 to 52.39. We observed that in plants established in April, the luminosity was higher (52.39) than in those planted in May and June, which had values of 50.11 and 51.41, respectively. The "a*" value identifies the red coordinates for positive values and green in negative values. We observed that plants established in April had a greener value, the lowest negative value, while May and June plants were statistically equal. Regarding "b*", where the yellow coordinates define positive values and the blue negative values, we observed that it inclined toward yellow, and the plants established in April were yellower, indicating that these plants had less chlorophyll and, thus, a lower photosynthetic rate (Table 1). Hue is the tone or shade of a color, and chroma (CH) is the intensity of that color. The plants established in May and June had a more intense color (Table 2).

Table 2. L*, a*, b*, hue, and chroma in tuberose leaves established in April, May, and June.

Date	L*	a*	b*	HueR	HueG	CH
April	52.39 ^{a}	−12.42 ^{b}	16.68 ^{a}	−0.931 ^{b}	53.34 ^{a}	20.81 ^{a}
May	50.11 ^{c}	−11.34 ^{a}	14.67 ^{b}	−0.908 ^{a}	52.03 ^{b}	18.55 ^{b}
June	51.41 ^{b}	−11.57 ^{a}	15.10 ^{b}	−0.914 ^{a}	52.36 ^{b}	19.03 ^{b}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.1.3. Effect of Planting Date on Spike Characteristics and Biomass

Spike characteristics determine flower quality. Plants established in June had the highest quality, expressed in a larger number of flowers/spikes (33.70) and stem diameter (0.83 cm). Moreover, they had longer stems and spikes, although they were not statistically different. Those planted in May had a heavier stem dry weight (11.03 g) and total (stem plus spike) dry weight (14.25 g) than those planted in April (9.26 g and 14.25 g, respectively) and June (9.12 g and 12.54 g, respectively). Leaf length of the plants established in May was statistically equal to those of June plants (57.65 and 55.93 cm, respectively) and statistically superior to that of April plants (51.96 cm). Root length was statistically equal in plants established in April (32.79 cm) and in June (31.91 cm), and was statistically superior to that of May plants. Statistically equal values were obtained for the variable aerial biomass for plants established in June (131.62 g) and April (120.71). May plants formed a larger number of corms/plants, obtaining the highest value (30.25). In the average corm diameter/plant, there were no significant differences between treatments; the range was 1.29 to 1.34 cm (Table 3).

Table 3. Characteristics of spike and leaf stem and days to flowering of plants established on three dates in April, May, and June.

Variables/Month	April	May	June
Number of spikes (NSp)	1.34 ^{a}	1.21 ^{ab}	1.16 ^{b}
Stem length (SL, cm)	79.14 ^{a}	81.71 ^{a}	82.45 ^{a}
Spike length (SpL, cm)	22.48 ^{a}	21.23 ^{a}	22.83 ^{a}
Number of flowers/spikes (NFSp)	32.86 ^{a}	30.22 ^{b}	33.71 ^{a}
Stem diameter (SD, cm)	0.802 ^{b}	0.785 ^{b}	0.831 ^{a}
Stem dry weight (SDW, g)	9.26 ^{b}	11.03 ^{a}	9.12 ^{b}
Spike dry weight (SpDW, g)	3.02 ^{a}	3.22 ^{a}	3.41 ^{a}
Dry weight stem + spike (DWSSp, g)	12.28 ^{b}	14.25 ^{a}	12.54 ^{b}
Leaf length (LL, cm)	51.96 ^{b}	57.65 ^{a}	55.94 ^{a}
Root length (RL, cm)	32.79 ^{a}	27.99 ^{b}	31.91 ^{a}
Aerial biomass (AB, g)	120.71 ^{a}	88.20 ^{b}	131.62 ^{a}
Number of corms/plants (NC)	25.67 ^{b}	30.25 ^{a}	23.94 ^{b}
Corm diameter (CD, cm)	1.27 ^{a}	1.34 ^{a}	1.27 ^{a}
Days to appearance of spike (APSp)	158.0 ^{a}	142.5 ^{b}	118.1 ^{c}
Days to pre-flowering (PRE)	177.6 ^{a}	169.0 ^{a}	142.0 ^{b}
Days to flowering (FLO)	185.3 ^{a}	173.5 ^{ab}	156.7 ^{b}

Means in a row with the same letter are statistically equal (Tukey, $p < 0.05$).

3.1.4. Effect of Planting Date on Postharvest Quality of Tuberose Flowers

For the variable number of open flowers (OF), there were statistical differences on days 2, 7, 8, and 9 in vase. On days 7, 8, and 9 in vase, the plants established in June had the largest number of open flowers (April, 8.20; May, 10.30; and June, 12.08). On the ninth day in vase, the average number of open flowers was higher for plants established in June than for those established in April and May, with values of 12.08, 10.66, and 10.86, respectively. For the variable water uptake (WU) of the floral stems, significant differences were observed only on days 1 and 9 after cutting; the floral stems from plants established in June consumed the most water. Average water uptake of the floral stems was 24.0–26.6 mL on the cutting day and decreased to 3.1–3.6 mL on day 9 in vase.

For the variable flower fresh weight (FW), the average values of all the treatments established in June were statistically superior on all the evaluated days. At cutting, FW was 96.4, 102.1, and 119.7 for the plants established in April, May, and June, respectively. As the days in vase passed, FW decreased such that after nine days, FW was 69.3, 77.1, and 88.3 g for April, May, and June plants, respectively. In terms of the number of senescent flowers, significant differences were observed on vase days 2, 7, 8, and 9. It is outstanding that on vase day 2, the stems from the plants established in April had a higher number of senescent flowers, contrasting with the floral stems from plants established in June, which had the highest number of senescent flowers on days 7, 8, and 9 (Table 4).

Table 4. Number of open flowers (OF), water uptake (WU, mL), flower fresh weight (FW, g), senescent flowers (SF) in a nine-day period (1–9) in vase of tuberoses planted on three planting dates: April, May and June 2019.

Month	OF1	OF2	OF3	OF4	OF5	OF6	OF7	OF8	OF9
April	0.05 ^{a}	0.25 ^{a}	0.96 ^{a}	2.32 ^{a}	9.28 ^{a}	5.40 ^{a}	7.29 ^{b}	9.18 ^{b}	10.66 ^{b}
May	0.00 ^{a}	0.10 ^{ab}	0.89 ^{a}	2.26 ^{a}	9.63 ^{a}	5.61 ^{a}	7.57 ^{ab}	9.59 ^{ab}	10.86 ^{b}
June	0.01 ^{a}	0.08 ^{b}	0.67 ^{a}	2.18 ^{a}	10.24 ^{a}	6.07 ^{a}	8.20 ^{a}	10.30 ^{a}	12.08 ^{a}
	WU1	**WU2**	**WU3**	**WU4**	**WU5**	**WU6**	**WU7**	**WU8**	**WU9**
April	24.0 ^{b}	17.9 ^{a}	13.2 ^{a}	10.0 ^{a}	7.0 ^{a}	5.8 ^{a}	4.8 ^{a}	4.0 ^{a}	3.0 ^{b}
May	24.1 ^{b}	17.6 ^{a}	13.3 ^{a}	9.9 ^{a}	7.8 ^{a}	5.8 ^{a}	4.5 ^{a}	3.8 ^{a}	3.2 ^{ab}
June	26.6 ^{a}	18.4 ^{a}	12.6 ^{a}	9.4 ^{a}	6.8 ^{a}	5.6 ^{a}	4.8 ^{a}	3.9 ^{a}	3.6 ^{a}
	FW1	**FW2**	**FW3**	**FW4**	**FW5**	**FW6**	**FW7**	**FW8**	**FW9**
April	96.4 ^{b}	96.3 ^{b}	95.4 ^{b}	93.6 ^{b}	90.7 ^{b}	86.0 ^{b}	79.7 ^{b}	74.2 ^{b}	69.3 ^{c}
May	102.1 ^{b}	101.5 ^{b}	98.6 ^{b}	98.4 ^{b}	96.3 ^{b}	92.4 ^{b}	86.9 ^{b}	81.7 ^{b}	77.1 ^{b}
June	119.7 ^{a}	119.8 ^{a}	120.6 ^{a}	120.7 ^{a}	114.8 ^{a}	109.26 ^{a}	103.1 ^{a}	96.0 ^{a}	88.3 ^{a}
	SF1	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**	**SF9**
April	0.5 ^{a}	0.25 ^{a}	0.10 ^{a}	2.32 ^{a}	3.75 ^{a}	5.40 ^{a}	7.29 ^{b}	9.18 ^{b}	10.66 ^{b}
May	0.0 ^{a}	0.10 ^{ab}	0.89 ^{a}	2.26 ^{a}	3.74 ^{a}	5.61 ^{a}	7.57 ^{ab}	9.59 ^{ab}	10.86 ^{b}
June	0.0 ^{a}	0.08 ^{b}	0.67 ^{a}	2.18 ^{a}	4.00 ^{a}	6.07 ^{a}	8.20 ^{a}	10.30 ^{a}	12.08 ^{a}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.2. Fertilization Doses

3.2.1. Effect of Fertilization Doses on Physiological Characteristics

The factor fertilization dose had a statistically significant effect on the evaluated physiological variables. The dose N_{300}-P_{200}-K_{200} produced the highest values for photosynthetically active radiation and greenhouse temperature, with values of 121.8 µmol $m^{-2}s^{-1}$ and 28.66 °C, respectively. However, in contrast, the values for stomatic conductance were the lowest, 0.083 mol $m^{-2}s^{-1}$, while the formula N_{100}-P_{50}-K_{50} resulted in the highest values of stomatic conductance and photosynthetic rate, 0.099 mol m^{-2} s^{-1} and 3.475 µmol m^{-2} s^{-1}, respectively, but in the lowest values for photosynthetically active radiation and greenhouse temperature, 100.6 µmol $m^{-2}s^{-1}$ and 27.53 °C, respectively (Table 5).

Table 5. Photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}), leaf chamber temperature (LChT, °C), transpiration rate (TR, mmol m^{-2} s^{-1}), stomatic conductance (SC, mol m^{-2} s^{-1}), and photosynthetic rate (PR, µmol m^{-2} s^{-1}) of tuberose with different fertilizer doses.

Dose	PAR	T	TR	SC	PR
N_{80}-P_{60}-K_{40}	109.6 ^{bc}	28.18 ^{b}	1.578 ^{a}	0.091 ^{ab}	2.918 ^{bc}
N_{300}-P_{200}-K_{200}	121.8 ^{a}	28.66 ^{a}	1.521 ^{a}	0.083 ^{b}	3.228 ^{ab}
N_{100}-P_{50}-K_{50}	100.6 ^{c}	27.53 ^{c}	1.604 ^{a}	0.099 ^{a}	3.475 ^{a}
N_{0}-P_{0}-K_{0}	115.2 ^{ab}	28.21 ^{b}	1.590 ^{a}	0.090 ^{ab}	2.718 ^{c}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.2.2. Effect of Fertilizer Dose on Leaf Colorimetric Characteristics

Luminosity "L" oscillated between 49.36 and 54.16. The dose N_{300}-P_{200}-K_{200} resulted in the darkest values, while the control was the most transparent or light. The "a" values were negative (indicating green coloring), from −11.08 for the dose N_{300}-P_{200}-K_{200} to −12.73 for the control. Positive values of "b" were found (indicating yellow coloring), from

14.07 for the N_{300}-P_{200}-K_{200} dose to 17.61 for the control, indicating that the control leaves (without fertilizer) were yellower (Table 6).

Table 6. L*, a*, b*, hue, and chroma in tuberose leaves fertilized with different doses.

Dose	L*	a*	b*	HueR	HueG	CH
N_{80}-P_{60}-K_{40}	51.55 ^{b}	−11.86 ^{c}	15.5 1 ^{b}	−0.917 ^{b}	52.56 ^{b}	19.53 ^{b}
N_{300}-P_{200}-K_{200}	49.36 ^{c}	−11.08 ^{a}	14.07 ^{d}	−0.901 ^{a}	51.65 ^{c}	17.91 ^{d}
N_{100}-P_{50}-K_{50}	50.16 ^{c}	−11.43 ^{b}	14.75 ^{c}	−0.909 ^{a}	52.06 ^{c}	18.67 ^{c}
N_{0}-P_{0}-K_{0}	54.16 ^{a}	−12.73 ^{d}	17.61 ^{a}	−0.943 ^{c}	54.05 ^{a}	21.74 ^{a}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.2.3. Effect of Fertilization Dose on Spike Characteristics and Biomass

The fertilization dose N_{300}-P_{200}-K_{200} resulted in average values that were statistically superior in the variables number of spikes (1.32), number of flowers/spikes (38.93), stem diameter (0.9 cm), and days to appearance of the spike (154.0), to pre-flowering (182.3) and to flowering (187.8). Only in the case of the variables stem length (67.62 to 85.983 cm) and spike length (12.88 to 26.84 cm) were all the fertilization doses statistically equal, except for the control, which was statistically inferior (Table 7).

Table 7. Tuberose spike, stem and leaf characteristics, and days to appearance of spike, to pre-flowering and to flowering with different doses of fertilization.

Variable/Dose	N_{80}-P_{60}-K_{40}	N_{300}-P_{200}-K_{200}	N_{100}-P_{50}-K_{50}	N_{0}-P_{0}-K_{0}
Number of spikes (NS)	1.28 ^{ab}	1.32 ^{a}	1.26 ^{ab}	1.09 ^{b}
Stem length (SL, cm)	85.98 ^{a}	85.78 ^{a}	85.01 ^{a}	67.62 ^{b}
Spike length (SpL, cm)	24.36 ^{a}	26.84 ^{a}	24.62 ^{a}	12.88 ^{b}
Number of flowers/spikes (NFSp)	36.56 ^{ab}	38.93 ^{a}	34.26 ^{b}	19.30 ^{c}
Stem diameter (SD, cm)	0.842 ^{b}	0.900 ^{a}	0.834 ^{b}	0.647 ^{c}
Stem dry weight (SDW, g)	10.90 ^{ab}	12.15 ^{a}	10.70 ^{b}	5.46 ^{c}
Spike dry weight (SpDW, g)	3.48 ^{a}	4.09 ^{a}	3.61 ^{a}	1.70 ^{b}
Dry weight stem + spike (DWSSp, g)	14.37 ^{b}	16.24 ^{a}	14.32 ^{b}	7.16 ^{c}
Leaf length (LL, cm)	56.21 ^{a}	57.65 ^{a}	55.01 ^{ab}	51.85 ^{b}
Root length (RL, cm)	31.17 ^{a}	30.61 ^{a}	31.11 ^{a}	30.69 ^{a}
Aerial biomass (AB, g)	105.60 ^{b}	195.73 ^{a}	116.84 ^{b}	35.86 ^{c}
Number of corms/plants (NC)	26.69 ^{ab}	28.18 ^{a}	28.36 ^{a}	22.61 ^{b}
Corm diameter (CD, cm)	1.34 ^{b}	1.50 ^{a}	1.38 ^{ab}	0.94 ^{c}
Days to spike appearance (APSp)	138.8 ^{b}	154.0 ^{a}	147.4 ^{ab}	117.9 ^{c}
Days to pre-flowering (PRE)	161.7 ^{b}	182.3 ^{a}	172.2 ^{ab}	135.3 ^{c}
Days to flowering (FLO)	168.5 ^{ab}	187.8 ^{a}	175.5 ^{ab}	155.5 ^{b}

Means in a row with the same letter are statistically equal (Tukey, $p < 0.05$).

It is important to underline that with the N_{00}-P_{00}-K_{00} control, we obtained the lowest number of spikes and flowers, the shortest stem and spike length, the smallest stem diameter; the lowest stem and flower dry weight and the lowest dry weight of stem plus spike had values of 5.46, 1.70, and 7.16 g, respectively, meaning lower flower production and quality. In contrast, the dose of N_{300}-P_{200}-K_{200} resulted in the highest stem and flower dry weight, and dry weight of stem plus spike, with values of 12.15, 4.09, and 16.24 g, respectively. The fertilization doses of N_{80}-P_{60}-K_{40} and N_{300}-P_{200}-K_{200} in leaf length were superior and statistically equal with 56.21 and 57.65 cm, respectively. Average values for aerial biomass were from 35.86 for the control to 195.73 for the dose of N_{300}-P_{200}-K_{200}. The formula N_{300}-P_{200}-K_{200} also resulted in the largest corm diameter, 1.50 cm, while the control had the lowest value, 0.94 cm. For the variable number of corms, the doses of N_{300}-P_{200}-K_{200} and N_{100}-P_{50}-K_{50} resulted in the highest values, 28.21 and 28.36, respectively, while the control obtained the lowest value, 22.61. In root length, there were no significant differences (Table 7).

3.2.4. Effect of Fertilization Dose on Postharvest Spike Variables

There were significant differences in the number of open flowers on days 2–9 by the effect of the fertilizer doses evaluated. All the treatment doses were statistically equal, except for the control, which obtained the lowest values. The number of open flowers on the ninth day varied from 8.67 to 12.54, indicating that approximately $\frac{1}{2}$ to 1/3 (19.30–38.93) of all the flowers opened (Tables 7 and 8). The variable WU from day 1 to 4 had the same trend as OF (where the control had the lowest values, and the rest of the treatment doses were statistically equal). For days 5 and 6 in vase, the control had the lowest number of OF, and the dose N_{300}-P_{200}-K_{200} obtained the highest WU. Finally, for days 7–9, there were no significant differences. Regardless of the treatment, WU was the highest on the cutting day (18.5–28.4 mL), and during postharvest it decreased up to an uptake of 3.04–3.47 mL (Table 8). For the variable flower weight (FW), the dose N_{300}-P_{200}-K_{200} resulted in the heaviest FW throughout the nine days, while the lowest FW was found for the control treatment on day 9 in vase. For the variable number of senescent flowers, there were significant differences from days 4 to 9, and the control had the highest number of senescent flowers. The other doses were statistically equal and lower than the control (Table 8).

Table 8. Number of open flowers (OF), water uptake (WU), flower weight (FW), and senescent flowers (SF) over a period of 9 days (1–9) in vase of tuberose grown with different doses of fertilization.

Dose	OF1	OF2	OF3	OF4	OF5	OF6	OF7	OF8	OF9
N_{80}-P_{60}-K_{40}	0.00 [a]	0.10 [a]	0.84 [a]	2.33 [a]	10.74 [a]	6.28 [a]	8.38 [a]	10.77 [a]	12.54 [a]
N_{300}-P_{200}-K_{200}	0.00 [a]	0.18 [a]	0.89 [a]	2.43 [a]	10.19 [a]	5.86 [a]	8.19 [a]	10.51 [a]	12.06 [a]
N_{100}-P_{50}-K_{50}	0.01 [a]	0.99 [a]	0.87 [a]	2.54 [a]	9.98 [a]	6.48 [a]	8.46 [a]	10.17 [a]	11.53 [a]
N_0-P_0-K_0	0.06 [a]	0.19 [a]	0.75 [a]	1.70 [b]	7.96 [b]	4.14 [b]	5.73 [b]	7.31 [b]	8.67 [b]
	WU1	**WU2**	**WU3**	**WU4**	**WU5**	**WU6**	**WU7**	**WU8**	**WU9**
N_{80}-P_{60}-K_{40}	26.7 [a]	19.0 [a]	13.6 [a]	9.9 [a]	7.2 [ab]	5.9 [ab]	4.6 [a]	4.0 [a]	3.2 [a]
N_{300}-P_{200}-K_{200}	28.4 [a]	20.3 [a]	14.7 [a]	10.9 [a]	8.0 [a]	6.4 [a]	4.7 [a]	4.0 [a]	3.3 [a]
N_{100}-P_{50}-K_{50}	26.0 [a]	18.5 [a]	13.0 [a]	10.1 [a]	7.4 [ab]	5.6 [ab]	4.8 [a]	4.0 [a]	3.5 [a]
N_0-P_0-K_0	18.5 [b]	14.1 [b]	10.7 [b]	8.2 [b]	6.2 [b]	5.1 [b]	4.7 [a]	3.6 [a]	3.0 [a]
	FW1	**FW2**	**FW3**	**FW4**	**FW5**	**FW6**	**FW7**	**FW8**	**FW9**
N_{80}-P_{60}-K_{40}	116.6 [b]	117.4 [b]	118.3 [a]	116.7 [a]	112.6 [b]	107.0 [b]	101.3 [a]	93.3 [b]	85.1 [b]
N_{300}-P_{200}-K_{200}	129.0 [a]	130.0 [a]	128.6 [a]	128.1 [a]	125.3 [a]	120.0 [a]	111.2 [a]	104.6 [a]	99.1 [a]
N_{100}-P_{50}-K_{50}	118.9 [ab]	117.8 [b]	117.8 [a]	118.3 [a]	113.2 [b]	107.4 [b]	101.0 [a]	94.3 [b]	88.2 [b]
N_0-P_0-K_0	59.7 [c]	58.3 [c]	54.8 [b]	53.9 b	51.2 [c]	49.1 [c]	46.0 [b]	43.6 [c]	40.6 [c]
	SF1	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**	**SF9**
N_{80}-P_{60}-K_{40}	0.0 [a]	0.1 [a]	0.8 [a]	2.3 [a]	4.2 [a]	6.3 [a]	8.4 [a]	10.8 [a]	12.5 [a]
N_{300}-P_{200}-K_{200}	0.0 [a]	0.2 [a]	0.9 [a]	2.4 [a]	4.1 [a]	5.9 [a]	8.2 [a]	10.5 [a]	12.1 [a]
N_{100}-P_{50}-K_{50}	0.0 [a]	0.1 [a]	0.8 [a]	2.5 [a]	4.3 [a]	6.5 [a]	8.5 [a]	10.2 [a]	11.5 [a]
N_0-P_0-K_0	0.1 [a]	0.2 [a]	0.8 [a]	1.7 [b]	2.8 [b]	4.1 [b]	5.7 [b]	7.3 [b]	8.67 [b]

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.3. Fertilizer Sources (Chemical, Organic, and Combined)

3.3.1. Effect of Fertilizer Source on Physiological Characteristics

There was no clear effect of fertilizer sources on physiological variables. Statistical differences were found only in temperature and photosynthesis rate. Photosynthetic rate was between 2.718 µmol $m^{-2}s^{-1}$ (control) and 3.378 µmol $m^{-2}s^{-1}$ (combination of chemical and organic fertilizers). Additionally, in the variable temperature, the highest value, 28.40 °C, was found with the combined source (Table 9).

Table 9. Photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}), temperature (T, °C), transpiration rate (TR, mmol m^{-2} s^{-1}), stomatic conductance (SC, mol m^{-2} s^{-1}), tuberose photosynthetic rate (PR, µmol m^{-2} s^{-1}), chemical, organic and combined fertilizer sources, and control, in April, May, and June.

Source	PAR	T	TR	SC	PR
Chemical	109.3 ^{a}	28.07 ^{c}	1.614 ^{a}	0.0937 ^{a}	3.166 ^{ab}
Organic	113.5 ^{a}	27.91 ^{d}	1.522 ^{a}	0.0904 ^{a}	3.077 ^{ab}
Combined	109.1 ^{a}	28.40 ^{a}	1.566 ^{a}	0.0900 ^{a}	3.378 ^{a}
Control	115.2 ^{a}	28.21 ^{b}	1.590 ^{a}	0.0900 ^{a}	2.718 ^{b}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.3.2. Effect of Fertilizer Sources on Colorimetric Characteristics of Leaves

The control obtained the highest values of "L*", indicating more transparent coloring. In contrast, with the chemical source, the lowest value was obtained, indicating more opaque colors. For "a*", all the fertilizer sources were statistically equal, except for the control, while "b*" values varied from 14.18 (chemical fertilizer) to 17.61 (control), indicating that the control had yellower leaves (Table 10).

Table 10. L*, a*, b*, hue, and chroma in tuberose leaves from plants grown with different fertilizer sources.

Source	"L*"	"a*"	"b*"	HueR	HueG	Chroma
Chemical	49.04 ^{c}	−11.28 ^{a}	14.18 ^{c}	−0.897 ^{a}	51.40 ^{d}	18.12 ^{c}
Organic	51.42 ^{b}	−11.60 ^{a}	15.29 ^{b}	−0.921 ^{c}	52.74 ^{b}	19.20 ^{b}
Combined	50.60 ^{b}	−11.50 ^{a}	14.86 ^{b}	−0.910 ^{b}	52.12 ^{c}	18.79 ^{b}
Control	54.16 ^{a}	−12.73 ^{b}	17.61 ^{a}	−0.943 ^{d}	54.05 ^{a}	21.74 ^{a}

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

3.3.3. Effect of Fertilizer Sources on Spike Characteristics and Biomass

The highest number of spikes (1.41) and flowers/spikes (39.27), as well as the longest spike length (26.89 cm) was obtained with chemical fertilizer. This treatment, together with the combined treatment, also obtained the largest stem diameter, with values of 0.88 and 0.87 cm, respectively. Likewise, the highest stem, spike, and stem plus spike dry weight were obtained with the chemical fertilizer, with values of 12.34, 4.13, and 16.48 g, respectively, followed by the combined source. In contrast, the control treatment resulted in lower values for stem, spike, and total (stem plus spike) dry weight, leaf length, root length, leaf weight, and corm number and diameter (Table 11).

For the variables leaf length (56.99 and 57.15 cm) and aerial biomass (164.92 and 145.61 g), the chemical source and the combined source, respectively, were statistically equal and had the highest values. For the number of corms, the chemical source resulted in the highest value, 31.03, while the combined source obtained the highest value for average corm diameter, 1.53 cm (Table 11).

The chemical, organic, and combined fertilizers were statistically equal, and all were superior to the control for days to spike appearance and to pre-flowering. The combined source resulted in the highest number of days to flowering (Table 11).

Table 11. Tuberose spike, stem, and leaf characteristics and days to appearance of the spike, to pre-flowering, and to flowering with different sources of fertilization.

	Chemical	Organic	Combined	Control
Number of spikes (NS)	1.41 ^{a}	1.24 ^{ab}	1.20 ^{b}	1.09 ^{b}
Stem length (SL, cm)	87.06 ^{a}	86.28 ^{a}	83.43 ^{a}	67.62 ^{b}
Spike length (SpL, cm)	26.89 ^{a}	24.9 ^{ab}	24.03 ^{b}	12.88 ^{c}
Number of flowers/spikes (NFSp)	39.28 ^{a}	34.56 ^{b}	35.91 ^{b}	19.30 ^{c}
Stem diameter (SD, cm)	0.88 ^{a}	0.82 ^{b}	0.87 ^{a}	0.65 ^{c}
Stem dry weight (SDW, g)	12.34 ^{a}	10.45 ^{b}	10.96 ^{ab}	5.46 ^{c}
Spike dry weight (SpDW, g)	4.23 ^{a}	3.21 ^{b}	3.83 ^{ab}	1.70 ^{c}
Dry weight stem + spike (DWSSp, g)	16.48 ^{a}	13.66 ^{b}	14.79 ^{ab}	7.60 ^{c}
Leaf length (LL, cm)	56.99 ^{a}	54.74 ^{ab}	57.15 ^{a}	51.85 ^{b}
Root length (RL, cm)	31.39 ^{a}	31.31 ^{a}	30.19 ^{a}	30.70 ^{a}
Aerial biomass (LW, g)	164.92 ^{a}	107.64 ^{b}	145.61 ^{a}	35.86 ^{c}
Number of corms/plants (NC)	31.03 ^{a}	25.97 ^{b}	26.86 ^{ab}	22.61 ^{b}
Corm diameter (CD, cm)	1.39 ^{ab}	1.30 ^{b}	1.53 ^{a}	0.94 ^{c}
Days to spike appearance (APSp)	149.4 ^{a}	138.9 ^{a}	151.9 ^{a}	117.9 ^{b}
Days to pre-flowering (PRE)	176.0 ^{a}	162.2 ^{a}	178.0 ^{a}	135.3 ^{b}
Days to flowering (FLO)	181.3 ^{ab}	167.9 ^{ab}	182.6 ^{a}	155.5 ^{b}

Means in a row with the same letter are statistically equal (Tukey, $p < 0.05$).

3.3.4. Effect of Fertilizer Sources on Postharvest Tuberose Flowers

The average values for the variable number of open flowers on day nine in vase were 13.14, 10.93, 12.07, and 8.67 with chemical, organic and combined fertilizer sources and the control, respectively. Water uptake decreased as days passed in vase: 18.5–30.4 mL on the first day to 3.0–3.6 mL on day nine, indicating spike deterioration. Flowers from plants grown with the chemical fertilizer source had a higher water uptake from day 1 to day 6 in vase and a higher flower weight on days 1 and 2. In the same way, for days 3 to 9, the chemical and combined sources obtained the highest flower weight. Fresh weight of the floral stem with the spike was 134.8, 107.9, 121.9, and 597 g on the cutting day with the chemical, organic and combined fertilizer treatments, and the control, respectively, clearly demonstrating how chemical fertilization contributed to a heavier floral stem weight. For the number of senescent flowers, significant differences were observed only for the different sources on days 4 through 9. For days 4, 5, and 6, chemical, organic and combined fertilization were statistically equal and higher than the control. On days 7 through 9, the chemical fertilizer treatment had a larger number of senescent flowers (Table 12).

Table 12. Number of open flowers (OF), water uptake (WU), flower weight (FW), senescent flowers (SF) in a period of nine days (1–9) in vase of tuberose grown with different sources of fertilization.

Source	OF1	OF2	OF3	OF4	OF5	OF6	OF7	OF8	OF9
Chemical	0.00 ^{a}	0.09 ^{a}	0.72 ^{a}	2.36 ^{a}	11.24 ^{a}	6.42 ^{a}	8.95 ^{a}	11.48 ^{a}	13.14 ^{a}
Organic	1.01 ^{a}	0.15 ^{a}	0.95 ^{a}	2.46 ^{a}	9.49 ^{b}	6.03 ^{a}	7.75 ^{b}	9.57 ^{b}	10.93 ^{b}
Combined	0.00 ^{a}	0.14 ^{a}	0.94 ^{a}	2.49 ^{a}	10.17 ^{ab}	6.17 ^{a}	8.32 ^{ab}	10.40 ^{ab}	12.07 ^{ab}
Control	0.06 ^{a}	0.19 ^{a}	0.75 ^{a}	1.70 ^{b}	7.96 ^{c}	4.14 ^{b}	5.73 ^{c}	7.31 ^{c}	8.67 ^{c}
Source	**WU1**	**WU2**	**WU3**	**WU4**	**WU5**	**WU6**	**WU7**	**WU8**	**WU9**
Chemical	30.4 ^{a}	21.4 ^{a}	14.6 ^{a}	11.2 ^{a}	8.3 ^{a}	6.2 ^{a}	4.7 ^{a}	3.9 ^{ab}	3.2 ^{a}
Organic	23.6 ^{c}	17.3 ^{b}	12.9 ^{b}	9.7 ^{a}	7.1 ^{ab}	5.6 ^{ab}	4.5 ^{a}	3.7 ^{ab}	3.2 ^{a}
Combined	27.0 ^{b}	19.1 ^{b}	13.9 ^{ab}	10.0 ^{a}	7.2 ^{ab}	6.1 ^{a}	4.9 ^{a}	4.4 ^{a}	3.6 ^{a}
Control	18.5 ^{d}	14.1 ^{c}	10.7 ^{c}	8.2 ^{b}	6.2 ^{b}	5.1 ^{b}	4.7 ^{a}	3.6 ^{b}	3.0 ^{a}

Table 12. *Cont.*

Source	FW1	FW2	FW3	FW4	FW5	FW6	FW7	FW8	FW9
Chemical	134.8 [a]	135.1 [a]	133.5 [a]	132.0 [a]	128.7 [a]	122.1 [a]	114.2 [a]	106.6 [a]	99.7 [a]
Organic	107.9 [c]	107.3 [c]	109.0 [b]	109.6 [b]	105.1 [b]	99.9 [b]	94.0 [b]	87.5 [b]	81.3 [b]
Combined	121.9 [b]	122.8 [b]	122.2 [a]	121.6 [a]	117.3 [a]	112.3 [a]	105.4 [a]	98.2 [a]	91.4 [a]
Control	59.7 [d]	58.3 [d]	54.8 [c]	53.9 [c]	51.2 [c]	49.1 c	46.0 [c]	43.6 [c]	40.6 [c]
Source	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**	**SF9**
Chemical	0.0 [a]	0.1 [a]	0.7 [a]	2.4 [a]	4.2 [a]	6.4 [a]	9.0 [a]	11.5 [a]	13.1 [a]
Organic	0.0 [a]	0.1 [a]	0.9 [a]	2.5 [a]	3.9 [a]	6.0 [a]	7.8 [b]	9.6 [b]	10.9 [b]
Combined	0.0 [a]	0.1 [a]	0.9 [a]	2.5 [a]	4.4 [a]	6.2 [a]	8.3 [ab]	10.4 [ab]	12.1 [ab]
Control	0.1 [a]	0.2 [a]	0.8 [a]	1.7 [b]	2.8 [b]	4.1 [b]	5.7 [c]	7.3 [c]	8.7 [c]

Means in a column with the same letter are statistically equal (Tukey, $p < 0.05$).

4. Discussion

4.1. Analysis Relative to Planting Dates

The best date for establishing tuberose corms in Ciudad Guzmán, Jalisco, Mexico, in a greenhouse was in June. The plants established in June had better spike quality, reflected in a longer floral stem (82.45 cm), stem diameter (0.830 cm), spike length (22.8 cm), and flowers/spikes (33.71). Moreover, appearance of the spike, pre-flowering, and flowering was obtained in less time (118, 142, and 156 days, respectively), that is, 28.6 days before cutting (meaning that quality flowers are obtained earlier). This is related to maximum, minimum, and mean temperatures recorded in the greenhouse. April had the lowest temperatures (8 °C) and May had the highest maximum temperature (43 °C), while June had less extreme temperatures, more in accord with those required by tuberose: 20–30 °C (González-Vega, 2016) [3]. Additionally, plants established in June had floral stems with a higher number and quality of open flowers (12.08). In contrast, those planted in April had yellower leaves, possibly due to a greater sensitivity of tuberose to temperature, especially low temperatures, as has been reported by other authors [9]. June plants also had better postharvest quality and water uptake, on which the flower's shelf life depends, since one of the most important factors in flower quality is water balance, i.e., the amount of water absorbed against the amount lost [21]. Kumari et al. (2018) reports that flower senescence is induced by factors such as water deficit, depletion of carbohydrates, and microorganisms. Water deficit is caused by the stem's developing resistance to water flow because transpiration is greater than absorption [22]. Therefore, a higher water uptake by June plants promoted better flower quality.

4.2. Fertilization Dose

Fertilizer dose affects the production and quality of tuberose. The low quality of flowers obtained with the control coincides with results of other authors who have reported better flower yields and quality in treatments with NPK application than in the control treatment [13,15,16]. The N_{300}-P_{200}-K_{200} dose was the treatment that resulted in a higher production and better flower quality expressed in a larger number of spikes/plants (1.32) and flowers/spikes (38.93), and a larger stem diameter (0.9 cm). The number of flowers/spikes found in our study was similar to that obtained by Chawla et al. (2018), who reported 39.93 with a fertilizer dose of N_{300}-P_{200}-K_{100} [23]. However, our results show that the number of flowers/spikes (38.93) are lower than those reported by Banakar and Mukhopadhyay (1990) (44.23 flowers/spike) [14]. Other authors also tested the N_{300}-P_{200}-K_{200} dose and found that the maximum flower yield was 14.2 t/ha [13]. Banakar and Mukhopadhyay (1990) also reported 1.25 spikes/plant, similar to the values obtained in our study: 1.09, 1.28, 1.26, and 1.32 spikes/plants with the control and the treatments N_{80}-P_{60}-K_{40}, N_{100}-P_{50}-K_{50}, and N_{300}-P_{200}-K_{200}, respectively [14]. In addition, the formula N_{300}-P_{200}-K_{200}, as well as the fertilizer doses of N_{80}-P_{60}-K_{40} and N_{100}-P_{50}-K_{50}, resulted in longer stems and spikes. Stem and spike length in our study was similar to those reported by Banakar and Mukhopadhyay (1990), 81.80 cm and 23.24 cm, respectively. Chawla et al.

(2018) report values of stem and spike length similar to those of our study, 30.99 cm and 97 cm, respectively, with a dose of N_{300}-P_{200}-K_{100} [23].

Additionally, with the N_{300}-P_{200}-K_{200} dose, we found the highest number of days to spike appearance (154.0), to pre-flowering (182.3), and to flowering (187.8). Other authors have reported fewer days to spike appearance (134.29 d) with the tuberose cv double, with a dose of N_{200}-P_{200}-K_{400} kg/ha [14]. In this respect, Pal et al. (2020) report that with a larger quantity of nitrogen (200 kg/ha, compared with 100 and 150 kg/ha), flowering is premature. This contrasts with our study, which found early flowering with the control [24], in which no nutrients were applied, causing nutrient deficiency, a type of plant stress that causes the plant to emit flowers prematurely, followed by programmed cell death and degradation of photosynthetic pigments, leading to yield loss (Table 7) [25].

Statistical differences were found among the fertilizer dose treatments in terms of leaf color. The control produced the yellowest and most transparent leaves. This differs from other authors who report that fertilization treatments had very little effect on the leaf color of recently cut *Beta vulgaris* L. var. cicla L., measuring L *, a *, b *, chroma, and hue angle in two areas of photosynthetic tissue of each leaf [26]. This may be because they used different species and the duration of the production cycle is different; the *B. vulgaris* crop was cut before flowering.

Moreover, the treatment with N_{300}-P_{200}-K_{200} produced longer leaves (57.65 cm) and higher aerial biomass (195.73 g), average corm diameter (1.50 cm), and corms/plants. The corms obtained in our study partially coincide with Kumari et al. (2019), who report that with high levels of N, P and K, tuberose bulb production was higher (309.87 g/plant) than that of the control (159.7 g/plant) [27]. In our study, we obtained 22.611 corms with the control, and 28.18 and 28.36 with the best treatments of N_{300}-P_{200}-K_{200} and N_{100}-P_{50}-K_{50}, relatively.

Additionally, during flower postharvest life, flowers from plants grown with a dose of N_{300}-P_{200}-K_{200} had a higher water uptake during days 1–6 in vase, indicating better flower quality [21,22]. The treatment with this dose also produced heavier flower weight over the nine days in vase, as well as the highest stem dry weight (12.15 g), spike dry weight (4.09 g) and total (spike plus stem) dry weight in postharvest. It is important to mention that water uptake is higher on the cutting day and later decreases. The reason may be that the tuberose is a climacteric flower that, during postharvest in vase, increases respiration and ethylene production, which contributes to flower deterioration [28]. The control flowers had the lowest weight and the largest number of senescent flowers, demonstrating that the application of NPK promotes better quality flowers in postharvest [13,15,16] (Table 8).

4.3. Fertilizer Sources (Chemical, Organic and Combined)

The fertilizer source affects tuberose quality and yield [29,30]. In our study, the chemical fertilizer source obtained the best flower quality, expressed by the number of flowers/spikes (39.27), the spike length (26.89 cm), and the largest number of spikes/plants (1.41). This fertilizer source also produced the best postharvest quality: the highest number of open flowers on the ninth day in vase (13.14) and the heaviest spike stem (134.80 g). We obtained the best flower quality with chemical fertilizer, coinciding with Attia et al. (2018), who report the highest number of flowers/spikes, plant height, and number of leaves with 100% N chemical fertilization, compared with the results obtained with 50–75% N chemical fertilizer combined with organic sources (biofertilizers of nitrogen-fixing bacteria) [30].

The chemical source also had an effect on leaf color, resulting in the most opaque and least yellow value. Plants fertilized with the chemical source also showed the highest stem dry weight (12.34 g), spike weight (4.13 g), and total dry weight of stem plus spike (16.48 g).

In this study, both the chemical source and the combined fertilizer obtained equal results in stem length, flower weight in postharvest, leaf length, plant biomass, and stem diameter. These results are similar to those obtained by Attia et al. (2018) with a combined fertilizer source (75% N plus *Azospirillum* and *Azotobacter*); they found a higher leaf, root, and spike dry and fresh weight and a longer spike length and longevity [30]. Likewise, Choudhury and Sarangi (2020) found that the application of 75% chemical NPK fertilizer combined with farmyard manure (2 kg/m^2), vermicompost (200 g/m^2), and biofertilizers (Azospirillum 2 g/plant, phosphate solubilizing bacteria 2 g/plant) was the most effective combination of nutrients to improve the yield and quality of tuberose flower stems, with the possibility of reducing chemical fertilizers by up to 50%, improving productivity, and maintaining soil sustainability [29].

Moreover, the combined fertilizers obtained the highest photosynthetic rate (3.38 µmol m^{-2}s^{-1}), corm diameter, water uptake in postharvest, and the highest number of days to flowering. For the above reasons, the chemical and combined fertilizer source was the best.

5. Conclusions

*The best planting date for tuberose in Ciudad Guzmán, Jalisco, Mexico, under greenhouse conditions, was in June, obtaining the best quality spike, which was obtained 28.6 days before flowering, and the best flower quality in postharvest.

*The fertilizer formula N_{300}-P_{200}-K_{200} produced the most plant biomass, the largest corm diameter and number per plant, and the least yellow leaves. It contributed to better quality flowers, a higher number of spikes/plants and flowers/spikes, and a larger stem diameter, but lengthened the time to flowering. In postharvest, flowers from this treatment consumed more water and had more open flowers and heavier spikes and stems. In addition, this dose, as well as the doses N_{80}-P_{60}-K_{40} and N_{100}-P_{50}-K_{50}, produced higher values in floral stems and spike lengths.

*The chemical fertilizer source obtained a larger number of spikes and corms/plants, and a higher floral stem quality, with a larger total number of flowers, and longer, heavier spikes. In postharvest, it produced the heaviest flowers (stem and spike) and more open flowers. In addition, this source, as well as the combined sources, obtained the highest stem length, stem diameter, leaf length, aerial biomass, and flower weight in postharvest. Additionally, combined sources obtained the highest photosynthetic rate and water uptake, but also the highest number of days to flowering. Thus, in addition to chemical fertilizer, using a combination of chemical fertilizers and organic matter can be a good alternative for producing tuberose. This points to testing new doses of a combined (chemical and organic) fertilizer for a more environmentally friendly production due to a decrease in the negative effects caused by chemical fertilization.

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