Article

Population density and organic fertilization in fava bean from central Mexiquense

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Abstract

Two experiments were established in 2017 and 2018 in San Nicolás Guadalupe, San Felipe del Progreso, State of Mexico, to evaluate the effects of spacing between plants at 20, 30, 40 and 50 cm with the application of chicken manure, vermicompost, mushroom compost and 30N-60P-60K in cultivars identified as Xalatlaco, Calimaya and San Felipe. The 48 treatments were evaluated in a series of randomized complete block design experiments with three replications per year in a split plot arrangement. In the combined analysis, it was observed that in both years (A) there were highly significant differences (p= 0.01) in 13 variables. In 2017, the best phenotypic expression in plant height (PH), flowering (DF), pods per plant (NPP), weight of pods per plant (WPP), seeds per pod (NSP), clean seeds (NCS) and weight of clean seeds (WCS) were favored, compared to 2018, but the yield (YLD) in both years was 1.5 t ha^{-1}. In densities (D), there were significant differences (p= 0.01) in 13 variables, and it was detected that at a distance between plants of 20 cm there was more NPP (18.5 cm), PH (1.4 cm) and HFP (47.5 cm); at 40 and 50 cm between plants, there was more NB and NPB. In the NCS, WCS and YLD characteristics, the same behavior appeared at 20, 40 and 50 cm. In organic fertilizers (F), there was a significant phenotypic differentiation (p= 0.01) in PH, NPP, WPP, WCS and YLD; with chicken manure higher PH and HFP were obtained. The mushroom compost favored WPP, NSS and weight of 100 seeds (W100S) and the vermicompost did it in NPP, WPP and WCS. The three cultivars (C) were significantly different (p= 0.01): Xalatlaco was better in efficiency (EFF), WPP, WCS, W100S and YLD (1.74 t ha^{-1}).

Keywords: *Vicia faba* L., biplot graph, series of experiments in subdivided plots, technology.

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Introduction

Fava bean (*Vicia faba* L.) is grown from 1 800 to 3 000 masl, it provides a high value in protein (from 24 to 32%) and carbohydrates to the human population (Volpelli *et al*., 2010; Vioque *et al*., 2012; Pérez *et al*., 2014) in green and dry (Crepón *et al*., 2010). It is currently of great importance in agroindustry (Baginsky *et al*., 2013) and is used as a rotation crop for its ability to fix atmospheric nitrogen (Kalia and Sood, 2004). In Mexico, it is sown in the High Valleys of the Central Plateau under different conditions of fertility and humidity (Rojas *et al*., 2012) and produces 1.27 t ha^{-1} in grain (SIAP, 2019).

The increase in its yield is relevant for this region, since it is a strategic species in the cultivation systems of small and medium farmers (Díaz *et al*., 2008), but this legume is negatively affected by climatic factors, soil fertility and pests and diseases. It also depends on water supplement, type of variety and population density, among others (Dobocha *et al*., 2019; Cucci *et al*., 2019; Mohamed and Rashed, 2020).

Population density affects yield and its components (Ayaz *et al*., 2004; Kubure *et al*., 2015), competition for natural and nutritional resources is affected by the distance between plants and between furrows. Bakry *et al*. (2011) reported that as plant density increased, the number of branches, pods per plant and seeds per plant decreased; pod weight, harvest index and yield also decreased; the greater the distance between plants, the more pods per plant and yield (Al-Suhaibani *et al*., 2013), but seeds per pod did not change.

In another study, there was an increase in plant height at 33.3 plants m^{-2} (Khalil *et al*., 1993; Al-Suhaibani *et al*., 2013; El Hag, 2017) or in the production of fodder and dry matter in pods at 16 plants m^{-2} (Estrada *et al*., 2017). As the density of plants m^{-2} has a direct effect on the cost of the seed and on the yield, it is necessary to establish an optimum to maximize the favorable expression of agronomic characters in each variety and in each environment (Dobocha *et al*., 2019). *Vicia faba* L. responds well in vertisol soils to a greater distance between furrows and between plants, which allows a better phenotypic expression in branches per plant, pods per plant, seeds per pod and seed weight (Gezahegn *et al*., 2016).

Mineral fertilization (Gai *et al*., 2018) to the soil is indispensable for plants, but the type of fertilizer applied may not be the most effective; those of organic origin, rich in organic matter, are important in their structure and in biological processes (Castelo *et al*., 2016). The application of organic fertilizers and manures improve soil fertility and significantly increase the yield in several crops (Afreh *et al*., 2018), such as worm humus composts, vermicompost (Bazán *et al*., 2014), mushroom compost (Fidanza *et al*., 2010), chicken manure (Aguiñaga *et al*., 2020), bocashi, (decomposition and fermentation of organic plant and animal waste (Bertoli *et al*., 2015; Sarmiento *et al*., 2019), Biol (organic foliar manure, product of anaerobic fermentation of animal and plant remains) and green fertilizers and biosolids (industrial organic waste and organic sediments (Felix *et al*., 2008; Bazán *et al*., 2014), all contribute organic matter to sustainable agriculture and improve yields in horticultural crops.

Compost tea + humic acids increased yield and seed quality in fava bean (Mohamed and Rashed, 2020). Sheep manure plus chemical fertilizer increased plant height, number of branches, chlorophyll content and macronutrients in the leaf of fava bean (Husain *et al*., 2016). With 10% vermicompost tea, there were more flowers, higher plant height and more pods per plant (Chaichi *et al*., 2018). The vermicompost plus mushroom compost produced 3.61 t ha^{-1} in grain (Pérez *et al*., 2019). The presence of phosphorus in chicken manure helps the development of the root and good nodulation in fava bean (Kubure *et al*., 2016). Thus, the main objective of the present study was to analyze the effects caused by population density and type of fertilizer on grain yield and other plant and pod characteristics in three cultivars of fava bean evaluated at one site over two years.

Materials and methods

Study area

This work was carried out in spring-summer of 2017 and 2018 in San Nicolás Guadalupe (SNG), municipality of San Felipe del Progreso, State of Mexico, located at 19° 36’ 30” north latitude and 100° 01’ 44” west longitude, at 2 740 masl, its predominant climate is temperate sub-humid with rains in summer. The average annual temperature is 15 °C, it has an annual rainfall of 892 mm and its soil is andosol (Orozco *et al*., 2013).

Genetic material

Three Mexiquense collections from Xalatlaco (C_1), Calimaya (C_2) and San Felipe del Progreso (C_3) were used, which will be identified with the names of these municipalities (Table 1).

Experimental design and plot size

The 48 treatments, formed with the combination of the levels of each factor studied (Table 1), were evaluated in a series of experiments in time in randomized complete blocks with three repetitions per trial, in an arrangement of subdivided plots. The large, medium and small plots housed the density, fertilization and cultivars, respectively, the latter had three furrows of 4 m in length and 0.80 m in width, but the central one was the useful experimental unit (3.2 m^2).

Table 1. Factors and levels of study.

Density (D, cm)	Fertilization (F, 2 t ha^{-1})	Cultivar (C)
D1: 20	F1: Chicken manure	C1: Xalatlaco
D2: 30	F2: Vermicompost	C2: Calimaya
D3: 40	F3: Mushroom compost	C3: San Felipe del Progreso
D4: 50	F4: 30N-60P-60K	

Agronomic management

In 2017, the soil was prepared with fallow, cross and harrowing. Manual sowing in residual moisture was carried out on April 22, at 20, 30, 40 and 50 cm (62 500, 41 667, 31 250 and 25 000 plants ha^{-1}, respectively) and chicken manure, vermicompost and mushroom compost were applied in 2 t ha^{-1}, as well as 30N-60P-60K (urea, 46%, triple calcium superphosphate, 46% and potassium chloride, 60%). It was hoeing on May 30 and June 4 and 10 to hill the plants and efficiently control weeds.

On June 10 and 21 and August 19, Dimethoate (1 L ha^{-1}) was applied to control puffin (*Macrodactylus mexicanus*) and black aphid (*Aphis fabae*) and copper oxychloride + mancozeb (2 kg ha^{-1}) and mancozeb (1 kg ha^{-1}) + foliar 20N-20P-20K (1 kg ha^{-1}) to prevent and reduce damage caused by chocolate spot (*Botrytis fabae*) and rust (*Uromyces*) spp.). The harvest was carried out on December 16.

In 2018, sowing took place on April 21. Two hoeings were carried out: May 19 and June 9. Basagran 480 was sprayed in doses of 1.5 L ha^{-1} on May 26 and July 9, and manual weeding was done before physiological maturity. On June 18 and August 21, dimethoate (1 L ha^{-1}) was applied to control puffin and black aphid and copper oxychloride + mancozeb (2 kg ha^{-1}) and Thiabendazole (1 kg ha^{-1}) to combat chocolate spot and rust. The harvest was carried out on December 8.

Variables evaluated

Ten plants were chosen in each useful plot and the following were recorded: plant height (PH: measured in cm, from the base to the apex of the main stem); height to first pod (HFP: in cm), nodes of the main stem (NN), branches (NB), branches with pod (NPB), efficiency (EFF: ratio between NPB and NB); flowering (DF: in days), pods per plant (NPP), weight of pods per plant (WPP: in g), seeds per pod (NSP), clean and spotted seeds per plant (NCS, NSS), weight of clean and spotted seeds per plant (WCS, WSS) and weight of 100 seeds (W100S; in g). Yield per plot (YLD) was extrapolated to t ha^{-1}.

Statistical analysis

An analysis of variance was performed combining the data from both trials, applying the model: $Y_{ijklm} = \mu + \alpha_i + \beta_{m(i)} + \gamma_j + (\alpha\gamma)_{ij} + \varepsilon_{ijm} + \delta_k + (\gamma\delta)_{jk} + (\alpha\delta)_{ik} + (\alpha\gamma\delta)_{ijk} + \varepsilon_{ijkm} + \theta_l + (\gamma\theta)_{jl} + (\delta\theta)_{kl} + (\gamma\delta\theta)_{jkl} + (\alpha\theta)_{il} + (\alpha\gamma\theta)_{ijl} + (\alpha\delta\theta)_{ikl} + \varepsilon_{ijklm}$. Where: μ is the grand mean, α_i is the i-th experiment, $\beta_{m(i)}$ is the m-th repetition nested in the i-th experiment, γ_j is the j-th density, δ_k is the k-th fertilization, θ_l is the l-th cultivar, ε_{ijm}, ε_{ijkm} and ε_{ijklm} are random variability associated with large, medium and small plots, respectively; the other ten components are estimable interactions. The comparison of means (Tukey, $p= 0.05$) and the principal component analysis were also performed with SAS (Statistical Analysis System, 1988) version for Windows; the biplot was made in Microsoft Excel, using the output generated by SAS (Sánchez, 1995).

Results and discussion

Combined analysis of variance

Although there were significant differences ($p= 0.01$) in 13 variables, these did not contribute to a better expression of productivity; 1.5 t ha^{-1} in grain was produced in both years. Population density (D) improved significantly ($p= 0.01$) plant height (PH) and height to first pod (HFP), branches

(NB) and productive branches (NPB), flowering (DF), pods per plant (NPP), weight of pods per plant (WPP), clean and spotted seeds per plant (NCS, NSS), weight of spotted and clean seeds per plant (WSS, WCS), weight of 100 seeds (W100S) and yield (YLD t ha^{-1}), these results are similar to those obtained by Bakry *et al*. (2011).

Organic fertilizers (F) contributed to the significant phenotypic differentiation (*p*= 0.01) of PH, NPP, WPP, WCS and YLD, as well as in HFP and NSS (*p*= 0.05); these results coincide with those of Pérez *et al*. (2019) and Álvarez *et al*. (2010). The effects caused by the cultivars (C) in 16 variables (*p*= 0.01) were similar to those of Pérez *et al*. (2014); Orozco *et al*. (2013). The effects caused by the interactions D x F, D x C and F x C, in 10 of the 16 variables, were also significant (*p*= 0.01) and agree with those of Dobocha *et al*. (2019) in DxFxC (Table 2), only in two variables the differences were not significant, which coincides with Kubure *et al*. (2016).

Table 2. Mean squares and statistical significance of F values in the combined analysis of variance.

SV	Dof	PH	HFP	NN	NB	NPB	EFF	DF	NPP
Years (Y)	1	0.283**	1377.68**	0.28 ns	37.12**	51.17**	0.503**	10200**	200**
Rep (Y)	4	0.005 ns	9.69 ns	3.87**	0.18 ns	0.58*	0.011 ns	1.19 ns	7.12 ns
Density (D)	3	0.073**	118.67**	3.69 ns	2.08**	1.46**	0.005 ns	16.56**	87.28**
Y∗D	3	0.058**	4.2 ns	0.57 ns	0.28 ns	0.15 ns	0.012 ns	4.76 ns	28.27 ns
Error a	12	0.004	4.83	2.15	0.34	0.19	0.006	5.04	4.63
Fertilizers (F)	3	0.059**	37.9*	1 ns	0.03 ns	0.011 ns	0.002 ns	7.48 ns	55.26**
D∗F	9	0.028**	30.32**	0.89 ns	0.79**	0.88**	0.008 ns	3.40 ns	18.93 ns
Y∗F	3	0.06**	76.31**	2.36*	1.13**	1.16**	0.015*	7.48	53.46**
Y∗D∗F	9	0.029**	36.96**	3.25**	0.66**	0.531**	0.003 ns	3.1 ns	46.38**
Error b	48	0.004	12.56	1.27	0.16	0.18	0.004	3.62	4.3
Cultivar (C)	2	0.271**	1727.42**	84.53**	10.25**	5.43**	0.016*	1176.68**	680.57**
D∗C	6	0.047**	59.993**	2.43**	0.93**	0.79**	0.007 ns	6.35 ns	39.6**
F∗C	6	0.052**	63.55**	2.08*	1.19**	1.2**	0.015**	2.04 ns	17.69 ns
D∗F∗C	18	0.038**	49.85**	1.75**	0.57**	0.45**	0.007 ns	2.26 ns	51.15**
Y∗C	2	0.078**	80.6**	22.78**	2.21**	2.18**	0.042**	35.38**	22.47 ns
Y∗D∗C	6	0.017*	42.8**	0.39 ns	1.29**	0.75**	0.003 ns	7.48 ns	38.31*
E∗F∗C	6	0.022**	9.29 ns	1.4 ns	1.92**	0.76**	0.004 ns	4.08 ns	53.42**
Error c	146	0.007	11.96	0.82	0.2	0.202	0.005	3.75	13.25
Total	287								

*= significant at 0.05; **= significant at 0.01; ns: not significant; SV= source of variation; Dof= degrees of freedom.

Table 2. Mean squares and statistical significance of F values in the combined analysis of variance (continuation).

SV	Dof	WPP	NSP	NCS	NSS	WCS	WSS	W100S	YLD
Years (Y)	1	1591.42^{**}	0.08^{*}	1041.2^{**}	14.4 ns	847.34^{**}	668.408^{**}	1026.8^{*}	0.03 ns
Rep (Y)	4	153.35 ns	0.02 ns	27.019 ns	2.28 ns	19.01 ns	6.92 ns	199.37 ns	0.006 ns
Density (D)	3	1131.39^{**}	0.02 ns	79.59^{**}	37.33^{**}	337.28^{**}	39.78^{*}	1182.82^{**}	0.35^{**}
Y∗D	3	754.54^{*}	0.018 ns	13.92 ns	15.53^{*}	245.12^{**}	8.14 ns	397.87 ns	0.23^{*}
Error a	12	28.63	0.01	13.97	2.83	22.43	8.9	160.73	0.02
Fertilizers (F)	3	993.73^{**}	0.0005 ns	41.66 ns	18.91^{*}	325.49^{**}	19.42 ns	312.62 ns	0.36^{**}
D∗F	9	695.89^{**}	0.02 ns	95.49^{**}	11.81^{*}	366.53^{**}	21.3^{*}	237.57 ns	0.32^{**}
Y∗F	3	1186.89^{**}	0.02 ns	11.27^{**}	35.49^{**}	449.35^{**}	135.18^{**}	617.32^{**}	1.12^{**}
Y∗D∗F	9	942.54^{**}	0.03^{*}	70.25^{**}	20.55^{**}	259.34^{**}	27.35^{**}	372.63^{*}	0.23^{**}
Error b	48	32.74	0.01	10.66	2.56	23.54	5.73	99.23	0.02
Cultivar (C)	2	10629.94^{**}	2.77^{**}	2476.56^{**}	359.41^{**}	3574.05^{**}	78.77^{**}	525176^{**}	4.14^{**}
D∗C	6	251.09 ns	0.005 ns	42.76 ns	6.72 ns	274.29^{**}	23.27^{*}	414.94^{*}	0.25^{**}
F∗C	6	564.72^{*}	0.006 ns	25.58 ns	10 ns	438.73^{**}	13.6 ns	301.57ns	0.38^{**}
D∗F∗C	18	1017.38^{**}	0.031^{**}	59.01^{**}	20.86^{**}	432.01^{**}	47.553^{**}	459.71^{**}	0.55^{**}
Y∗C	2	6.82 ns	0.014 ns	147.06^{**}	126.21^{**}	93.27 ns	74.17^{**}	619.54^{*}	0.001 ns
Y∗D∗C	6	560.78^{*}	0.016 ns	48.63^{*}	32.78^{**}	207.92^{**}	65.11^{**}	830.65^{**}	0.42^{**}
E∗F∗C	6	1473.9^{**}	0.006 ns	102.36^{**}	32.03^{**}	213.31^{**}	98.5^{**}	527.261^{**}	0.52^{**}
Error c	146	222.8	0.012	19.81	5.04	60.32	10.46	153.85	0.08
Total	287								

*= significant at 0.05; **= significant at 0.01; ns= not significant; SV= source of variation; Dof= degrees of freedom.

Comparison between trials

It was detected that both years differed statistically. Pérez *et al*. (2014); Orozco *et al*. (2013); Orozco *et al*. (2016); Rojas *et al*. (2012) concluded that the region formed by the states of Hidalgo, Mexico, Puebla and Tlaxcala is very heterogeneous in soil types, rainfall, altitude above sea level and incidence of frosts and hail. The Tukey test (0.05) indicated that, in 2017, the variables PH, DF, NPP, WPP, NSP, NCS and WCS did not contribute to a better expression in *Vicia faba* L., and on average, 1.5 t ha^{-1} in grain was obtained in the two years (Table 3), the state average, higher than that registered in the present study, is 2.23 t ha^{-1} (SIAP, 2019).

Table 3. Comparison of means between years.

Years	PH	HFP	NN	NB	NPB	EFF	DF	NPP
2017	1.38 a	43.46 b	10.52 a	3.2 b	2.48 b	0.77 b	82.04 a	17.83 a
2018	1.32 b	47.84 a	10.45 a	3.92 a	3.33 a	0.86 a	70.13 b	16.17 b
HLSD	0.017	0.564	0.37	0.15	0.11	0.02	0.57	0.55

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

Table 3. Comparison of means between years (continuation).

Years	WPP	NSP	NCS	NSS	WCS	WSS	W100S	YLD (t ha^{-1})
2017	67.27 a	1.8 a	21.28 a	8.54 b	39.8 a	10.37 b	222.18 b	1.573 a
2018	62.57 b	1.77 b	17.47 b	8.99 a	36.37 b	13.42 a	225.95 a	1.549 a
HLSD	1.37	0.02	0.96	0.43	1.21	0.76	3.25	0.04

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

It has also been observed that the number and weight of pods, seeds per plant and weight of 100 seeds are defined prior to maturity and that these are not significantly affected by environmental conditions (Al-Suhaibani *et al*., 2013), so these could be used in a plant breeding program to generate or commercially exploit new cultivars of high productivity and greater phenotypic stability.

Comparison between densities (D)

In the present study, it was observed that, at a distance between plants of 20 cm, there were more pods per plant (18.5) (Table 4), but Dahmardeh *et al*. (2010), Bakry (2011); Al-Suhaibani *et al*. (2013); Derogar *et al*. (2014) reported that it decreases as the density increases. The improvement that was observed in PH (1.4 cm) and HFP (47.5 cm) agrees with what was published by Khalil *et al*. (1993); Al-Suhaibani *et al*. (2013); El Hag (2017).

At 40 and 50 cm there were more branches and productive branches, results that agree with those of Bakary *et al*. (2011). The NCS, WCS and YLD had the same behavior at 20, 40 and 50 cm (Abdel-Aziz and Shalaby (1999); Dahmardeh *et al*. (2010) concluded that the highest seed yield was produced at 20 cm (33 plants m^{-2}). The weight of 100 seeds was higher at high densities, these results are similar to those of Ibrahim and Esmail (1994) (Table 4).

Table 4. Comparison for densities.

Density (cm)	PH	HFP	NN	NB	NPB	EFF	DF	NPP
20	1.4 a	47.5 a	10.65 a	3.34 b	2.74 b	0.82 a	75.84 a	18.54 a
30	1.32 b	45.54 b	10.54 a	3.52 ab	2.84 ab	0.8 a	75.55 a	16.07 b
40	1.35 b	44.66 b	10.6 a	3.67 a	3.01 a	0.81 a	76.62 a	16.37 b
50	1.35 b	44.91 b	10.15 a	3.71 a	3.04 a	0.82 a	76.33 a	17.01 b
HLSD	0.03	1.08	0.72	0.28	0.21	0.04	1.11	1.06

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

Table 4. Comparison for densities (continuation).

Density	WPP	NSP	NCS	NSS	WCS	WSS	W100S	YLD (t ha^{-1})
20	67.04 a	1.78 a	19.72 a	9.55 a	37.73 a	12.5 a	227.39 a	1.57 a
30	59.77 c	1.76 a	17.81 b	8.76 a	35.16 b	11 ab	226.41 a	1.46 b
40	64.03 b	1.79 a	19.92 a	7.81 b	39.85 a	10.93 b	224.11 ab	1.57 a
50	68.83 a	1.81 a	20.05 a	8.94 a	39.59 a	12.47 a	218.35 b	1.62 a
HLSD	2.64	0.05	1.85	0.83	2.34	1.47	6.27	0.08

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

The density of plants m^{-2} has a direct effect on the cost of the seed and on the final yield, so it is necessary to define the optimal population density for each variety and specific environment (Dobocha *et al*., 2019). According to the results observed in this study, the ideal would be to sow at 40 or 50 cm between plants (31 250 and 25 000 plants ha^{-1}); in the last decade, the price of a kilogram of seed reached up to $75.00. Farmers in the Valley of Mexico sow at 40 cm between plants and 80 cm between furrows (Rojas *et al*., 2012). In this work, average yields of 1.5 t ha^{-1} in grain were obtained, almost equal to the national average (1.27 t ha^{-1}).

Comparison between fertilizers

Chicken manure favored PH and HFP but had little effect on other yield components. Peñaloza *et al.* (2019) reported that, with 4 t ha^{-1}, they obtained 24.3 t ha^{-1} in potato and more stems and tubers per plant were produced. Kubure *et al*. (2016) found that the presence of phosphorus in chicken manure favors root development and improves nodulation. Mushroom compost increased the weight of pods per plant (WPP), number of spotted seeds (NSS) and weight of 100 seeds (W100S). These results differ from those of García *et al*. (2014a), who reported that the application of this from 3 to 5 Mg ha^{-1} produced more pods and higher yield in beans (*Phaseolus vulgaris* L.).

In wheat (*Triticum aestivum* L.), mushroom compost increased chlorophyll (15%), photosynthesis (15%) and yield (10%) (García *et al*., 2014b). In this study, vermicompost showed improvements in NPP, WPP and WCS (Table 5); Chaich *et al*. (2018) reported that, with the use of 10% vermicompost tea, the number of flowers, height and number of pods per plant increased in fava bean. Rodriguez *et al*. (2010), applying 3 t ha^{-1} of vermicompost, obtained taller plants, with bulbs of greater diameter and better dry weight in spring onion (*Allium cepa* L.).

Table 5. Comparison of means between fertilizers.

Fertilizers	PH	HFP	NN	NB	NPB	EFF	DF	NPP
Chicken manure	1.39 a	46.61 a	10.66 a	3.55 a	2.927 a	0.82 a	76.138 a	16.223 b
Vermicompost	1.35 b	45.61 ab	10.47 a	3.59 a	2.898 a	0.817 a	75.847 a	18.252 a
M. Compost	1.337 b	44.85 b	10.4 a	3.54 a	2.9 a	0.82 a	75.84 a	16.87 b
Chemical	1.338 b	45.53 ab	10.42 a	3.58 a	2.91 a	0.8 a	76.52 a	16.65 b
HLSD	0.028	1.57	0.5	0.17	0.19	0.03	0.84	0.92

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

Table 5. Comparison of means between fertilizers (continuation).

Fertilizers	WPP	NSP	NCS	NSS	WCS	WSS	W100S	YLD (t ha^{-1})
Chicken manure	65.49 b	1.79 a	19.31 ab	8.4 b	39.37 ab	12.24 a	225.89 a	1.61 a
Vermicompost	68.17 a	1.78 a	20.21 a	8.31 b	39.96 a	11.46 a	223.5 ab	1.59 a
M. Compost	66.4 ab	1.78 a	19.6 ab	8.96 ab	37.8 b	12.44 a	225.51 ab	1.58 a
Chemical	59.5 c	1.78 a	18.38 b	9.4 a	35.2 c	11.44 a	221.36 b	1.45 b
HLSD	2.53	0.04	1.44	0.71	2.15	1.06	4.41	0.06

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

In the production of red tomatoes, worm humus plus humic acid caused a greater number and weight of the fruit (Luna *et al*., 2016). The results obtained with chicken manure and mushroom compost contrast with those of other studies, where it has been reported that, when combining both, there is greater effectiveness. Orozco *et al*. (2016) reported that chicken manure plus mushroom compost in 3 t ha^{-1} resulted in the best phenotypic expression in NN, PH, PP, WPP, WS, W100S, and YLD in seed. Perez *et al*. (2019) found that vermicompost plus mushroom compost produced 3.61 t ha^{-1} in fava bean.

In this study, the effect of chicken manure, vermicompost and mushroom compost showed a similar behavior in the weight of 100 seeds and yield and only differed statistically from inorganic fertilization, which caused the lowest averages (Table 5). Husain *et al*. (2016) reported that sheep manure plus chemical fertilizer increased plant height, number of branches, chlorophyll content and macronutrients in the leaf of fava bean. Diaz *et al*. (2017) recommended replacing conventional synthetic fertilization by using chicken manure and arbuscular mycorrhiza in cabbage production.

The characteristics of plant, fruit and production in zucchini showed that fertilization with processed chicken manure, mycorrhizal inoculation or their combination, yielded results similar to those caused by inorganic fertilization (Díaz *et al*., 2016.).

Comparison between cultivars

The collection from Xalatlaco expressed the highest EFF, WPP, WCS, W100S and 1.74 t ha^{-1} (Table 6). The San Felipe cultivar excelled in PH, HFP, NN and NPP, but these did not contribute to a higher yield (1.3 t ha^{-1}), because its pod and seed size is smaller than that of the other two varieties. The Calimaya cultivar, with more branches and branches with pods, had greater weight of 100 seeds and yield (1.6 t ha^{-1}).

Table 6. Comparison of means between cultivars.

Cultivars	PH	HFP	NN	NB	NPB	EFF	DF	NPP
Xalatlaco	1.3 c	41.49 c	9.71 c	3.5 b	2.9 b	0.83 a	73.85b	16.17b
Calimaya	1.35 b	45.49 b	10.23 b	3.91 a	3.15 a	0.8 b	74.29 b	14.85 c
San Felipe	1.4 a	49.97 a	11.53 a	3.27 c	2.67 c	0.81 c	80.12 a	19.98 a
HLSD	0.02	1.18	0.31	0.15	0.15	0.02	0.66	1.24

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

Table 6. Comparison of means between cultivars (continuation).

Cultivar	WPP	NSP	NCS	NSS	WCS	WSS	W100S	YLD (t ha^{-1})
Xalatlaco	73.67 a	1.69 b	18.05 b	7.59 b	43.93 a	12.17 a	264.85 a	1.74 a
Calimaya	67.84 b	1.68 b	15.09 c	7.7 b	38.56 b	12.63 a	268.65 a	1.6 b
San Felipe	53.24 c	1.98 a	24.99 a	11 a	31.75 c	10.88 b	138.69 b	1.33 c
HLSD	5.1	0.037	1.521	0.76	2.65	1.1	4.23	0.09

Means with the same letter within each column are statistically equal (Tukey, *p*= 0.05).

Commercially recommended cultivars will have more productive pods and greater leaf efficiency, as suggested by Pérez *et al*. (2014 and 2019), Yahia *et al.* (2012), Mohamed *et al*. (2013). The number of seeds m^{-2} depends on the number of pods, but, due to the complexity shown by the interactions between cultivars and environments, it is important to define which of the primary and secondary components of the yield are more stable in time and space, so that they contribute to greater productivity in grain and pod.

Principal component analysis

The percentages of variation explainable by principal components 1 (45.3%) and 2 (19.1%) (Figure 1) suggest that the correlations observed in the biplot are reliable. Neal and Mcvetty (1983) concluded that 68.5 to 76.4% of the variability observed in seed yield is related to the number of pods per plant (Singh *et al*., 1987; Chaieb *et al*., 2011), seeds per pod (Alan and Geren, 2007), weight of 100 seeds (Baginsky *et al*., 2013) and seed size. In the above context, a selection index that considers these traits in a plant breeding program could lead to more outstanding varieties.

In the present study, grain yield was mainly explained by an increase in the weights of clean seed and pods per plant, as well as by more branches, branches with pods and greater weight of 100 seeds.

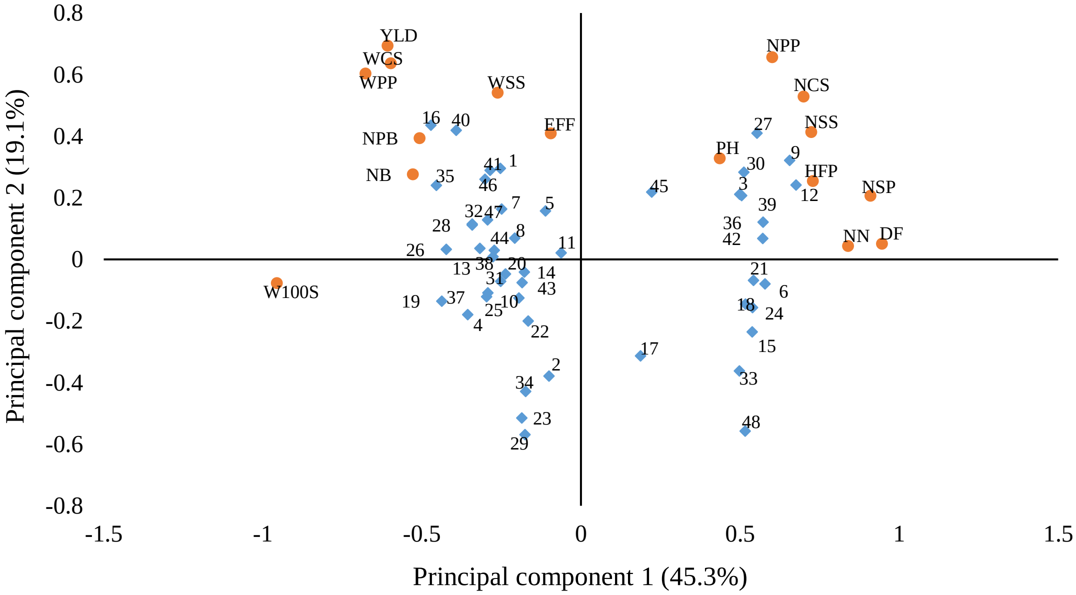

Figure 1. Biplot graph to represent the interrelationships between treatments (number) and variables (letter). Values were averaged over years and repetitions within years.

Conclusions

Between years, between varieties and between densities, there were highly significant differences (p= 0.01) in 13 of the 16 variables evaluated, at a distance between plants of 20 cm there was more NPP (18.5 cm), PH (1.4 cm) and HFP (47.5 cm), at 40 and 50 cm between plants there was more NB and NPB, but NCS, WCS and YLD had the same behavior at 20, 40 and 50 cm. In organic

fertilizers, there was a significant phenotypic differentiation ($p < 0.01$) in PH, NPP, WPP, WCS and YLD; with chicken manure, higher PH and HFP were obtained. Mushroom compost favored WPP, NSS and weight of 100 seeds (W100S), while vermicompost did so in NPP, WPP and WCS. The three cultivars (C) were significantly different ($p = 0.01$): Xalatlaco was better in efficiency (EFF), WPP, WCS, W100S and YLD (1.74 t ha^{-1}). In the biplot, it was observed that the combination 40 cm + chicken manure + San Felipe was positively associated with NPP and NCS; 30 cm + vermicompost + Xalatlaco and 50 cm + vermicompost + Xalatlaco produced more NPB. An increase in WPP and NCS caused higher dry grain production.

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