Article

Does amaranth have the agronomic potential to be a global phenomenon like quinoa

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Abstract

Amaranth and quinoa belong to the family *Amaranthaceae* characterized by having species that grow in adverse conditions, in addition to presenting high contents of proteins, unsaturated fatty acids and vitamins, as well as functional properties, which could be an excellent option to face the great problems that afflict the world. Due to these characteristics, quinoa has become a worldwide phenomenon and is already grown in more than 100 countries. The study was proposed in order to determine if amaranth has the agronomic potential to increase the cultivated area as happened with quinoa. An experiment was established with three varieties of quinoa and three varieties of amaranth in three environments of the Highs Valleys of Mexico, under a randomized complete block design with an arrangement of treatments in split plots. Agronomic variables, as well as yield, were evaluated. The results found showed that amaranth surpassed quinoa in inflorescence length, inflorescence width, stem diameter, hectoliter weight and yield, while quinoa presented higher values for seed diameter and weight of one thousand seeds. The Tlahuicole and L-145 amaranth genotypes observed the best performance, followed by the Suyana variety of quinoa. Amaranth has characteristics to be a worldwide phenomenon, as has happened with quinoa.

Keywords: *Amaranthus* spp., *Chenopodium quinoa*, varieties, yield.

Reception date: September 2021
Acceptance date: November 2021

Introduction

To face the great forces that are moving society such as malnutrition, public health problems and especially climate change, it is necessary to use plant species with characteristics that contribute to the solution of these issues. Likewise, genetic improvement programs should look for intelligent varieties that respond to the environmental conditions that occur in the growing season. Generally, this type of varieties can be created using species that by nature can grow in adverse agroclimatic conditions, such is the case of the *Cariophyllales*, known to contain several extremophile species.

Within this group, there is the family *Amaranthaceae*, which includes, among others, the genera *Amaranthus* and *Chenopodium*, characterized by having species that grow in adverse conditions, in addition to presenting high contents of proteins, unsaturated fatty acids and vitamins, as well as functional properties, therefore, they could be an excellent option to face these great health, food and environment problems the world is going through. Amaranth is an annual herbaceous plant that belongs to the genus *Amaranthus*, predominantly tropical, includes about 70 species native to the tropics and temperate regions around the world; of which 40 are from America and the rest belong to Australia, Africa, Asia and Europe.

Within the genus are the species *A. cruentus*, *A. hypochondriacus* and *A. caudatus*, which are the most important to produce amaranth grain (Espitia, 1992). Quinoa is a plant of the genus *Chenopodium*, has wide worldwide distribution, with about 250 species (Zurita-Silva *et al*., 2014).

The cultivation of amaranth in Mexico is poorly developed, as 3 000 to 7 000 ha are sowed annually, fluctuating according to supply and demand. There are many limitations that this crop faces, such as the low technological level with which it is carried out. Most of the sowings are carried out with low-yielding Creole varieties and disadvantageous agronomic characteristics, such as late ripening and tall plants, variation in plant and seed color, among others. There is no well-founded production technology for fertilization doses, sowing dates, densities, pest and disease control. Recently, amaranth was included in the basic basket, therefore, in order to increase the area of sowing and harvesting, it is necessary to improve the technology used so far.

Amaranth and quinoa, in addition to their agronomic potential to grow in adverse conditions, are super grains recognized among the most promising crops to help achieve food security and combat malnutrition (Präger *et al*., 2018). In recent years, interest in these grains, rich in protein and as a source of nutraceutical compounds, has increased (Venskutonis and Kraujalis, 2013; Rastogi and Shuklam, 2013). This interest is due to the great current problems associated with chronic degenerative diseases, ischemic heart diseases, cerebrovascular diseases and chronic liver diseases, which are closely linked to factors such as malnutrition, overweight and obesity.

On the other hand, quinoa is a crop of recent introduction in Mexico; however, in recent years, it has gained great boost due to the growth of its consumption globally. This interest is due to its agronomic, nutritional and nutraceutical characteristics (Präger *et al*., 2018). This species has been cultivated in the Andes for 5 000 to 7 000 years, adapting to altitudes close to 4 000 masl. Quinoa and amaranth have high water-use efficiency and can even produce acceptable yields with rainfall of 200 mm per year. Also, some varieties of quinoa tolerate salinity conditions like those of seawater (40 dS m^{-1}), exceeding in many cases the tolerance of known cultivated species (Espitia 1994; Zurita-Silva *et al*., 2014).

Quinoa is native to the Andes and is more adapted to regions between 2 500 to 4 000 masl (Mujica *et al*., 1997), amaranth, on the other hand, is native to Mesoamerica and is more adapted to regions between 0 to 2 600 masl. Although, in recent times, these crops have been taken to environments outside their original range of adaptation. In relation to its yield potential, Bazile *et al*. (2014) reported yields from 200 to 2 050 kg ha^{-1} in a test of 21 quinoa genotypes in different countries where quinoa was not sown in Europe and Asia. Chura *et al*. (2019) mention 2 836.55 to 5 099.18 kg ha^{-1} for a group of six quinoa lines, whereas Zurita-Silva *et al*. (2014) report yield from 400 to 4 500 kg ha^{-1}.

For amaranth in a similar test (Mujica *et al*., 1997), yield from 203 to 7 208 kg ha^{-1} is reported for 12 genotypes in nine countries of America, in this case, it was in countries where amaranth is sown. The yields reported for Mexico are highly variable and depend on the variety and production conditions, for example, they are mentioned from 2 062 to 5 274 kg ha^{-1} (Espitia, 1992), from 3 875 to 4 583 kg ha^{-1} (Mujica *et al*., 1997), from 950.7 to 2 922.2 kg ha^{-1} and from 1 382 to 1 668.7 kg ha^{-1} (Ramírez, 2011) and from 1 382 to 3 439 kg ha^{-1} (Ortiz *et al*., 2018).

In other characteristics of agronomic importance, very variable values are also reported, for example, for the maturity variable, 132.5 to 161.38 days are reported in 60 genotypes of the species *A. cruentus* and *A. hypochondriacus* (Espitia *et al*., 1992), from 63.2 to 97.4 for 54 genotypes of *A. hypochondriacus*. For plant height, values from 141.88 to 228.94 cm (Espitia *et al*., 1992) and 81.3 to 148 cm (Tiwari *et al*., 2018) are reported. Other important characteristics are those that express the size and density of the seed, in this regard, one thousand seed weight from 0.684 to 1.32 g (Tiwari *et al*., 2018) and hectoliter weight from 82.51 to 83.51 kg L^{-1} (Espitia *et al*., 1992) are reported.

In quinoa, the size of the seed is very relevant because the commercialization and use depend on that, so the variables that express size and weight of the seed are relevant, in this regard, seed diameter from 1.2 to 2.5 mm are reported (Zurita-Silva *et al*., 2014), while Chura *et al*. (2019) report diameters from 1.64 to 2.2 mm. The same authors refer for the weight value of one thousand seeds, from 2.09 to 3.8 g, Delgado *et al*. (2009) explained 2.52 to 3.45g, while Curti *et al*. (2014) establish values from 2.2 to 3.5 g. For maturity, Zurita-Silva *et al*. (2014) presented values ranging from 135 to 210 days, while Bhargava *et al*. (2007) report values from 109.3 to 163.33 days to maturity. For the plant height variable, Delgado *et al*. (2009) showed values from 111.23 to 176.65 cm and the same authors report for panicle length, values from 24.03 to 37.25 cm.

Recently, quinoa has become a worldwide phenomenon, it is cultivated in many countries and with prospects of continuing to grow (Bazile *et al*., 2016). Amaranth and quinoa are two crops with many morphological, nutritional, use and even historical development similarities; the question arises as to why quinoa has grown so much in production and consumption and amaranth, far from growing, suddenly the cultivated area has been reduced and consequently its consumption. Therefore, the objective of this work was to make an agronomic comparison of amaranth and quinoa to determine the potential of each species in the High Valleys of central Mexico.

Materials and methods

Genetic material

The amaranth genotypes used were L-145, Tlahuicole and Nutrisol of species *A. hypochondriacus*, while Suyana, Tokyo and Suma were the quinoa genotypes used, the genotypes to represent the two species were chosen based on their cycle and plant appearance and in the case of quinoa, they were also selected for presenting good adaptation to the conditions of central Mexico.

Evaluation environments

The evaluation environments were two in Santa Lucía de Prías, Texcoco (two sowing dates) and Boyeros, Texcoco (Colonia Netzahualcóyotl), State of Mexico in 2019. The sowing date in Santa Lucía de Prías was May 28 (the first date) and June 30 (the second). With the first date, a normal sowing date is being simulated, when the season is established; with the second, it is being sought that the flowering does not coincide with the high temperatures that occur in July. For Colonia Netzahualcóyotl, it was on June 30, salinity conditions are being evaluated in this environment.

Crop management

The crop was rainfed, without fertilization, there was no pest control and only two weeds with hoe were made at 25 and 45 days after sowing. The fungicide Metalaxil (commercial product: Ridomil Gold) 1 L ha^{-1} was applied to quinoa at 30 days after the plant emerged and Mancozeb (commercial product: Manzate) 1.5 kg ha^{-1}at 50 days after the plant emerged in order to reduce the effect of Mildew (*Peronospora variabilis*).

Variables evaluated

Phenological variables such as days to flowering, days to maturity and grain filling period (days) were evaluated, the days to when 50% of the plants anthesis and maturity and the days elapsed from flowering to maturity, respectively, were counted. Size variables such as stem diameter (cm), plant height at flowering (cm), plant height at maturity (cm) and panicle length (cm), 10 plants per plot were measured.

The seed diameter was determined by measuring 10 groups of 10 seeds from each plot, with a digital vernier (Stainless Hardened). Hectoliter weight (kg hl^{-1}) was determined by weighing a known volume of seed and it was extrapolated to the weight of 100 L. For the weight of one thousand grains (g), five groups of 100 grains from each plot were counted and weighed and it was extrapolated to one thousand grains and the grain yield (kg ha^{-1}) was determined from the yield of the useful plot and it was extrapolated to 1 ha.

Experimental design, experimental unit and statistical analysis

The genotypes were sown under an experimental design of randomized blocks with four repetitions and an arrangement of treatments in split plots, the large plot corresponded to the species and the genotypes to the small plot. The experimental plot consisted of three furrows 0.8 m apart and 5 m long and the useful plot consisted of three m of the central furrow. For the statistical analysis, Proc Glm of Sas was used and for the comparison of means, the Tukey test (0.05).

Results and discussion

Highly significant differences were found in most variables for environments, except for seed diameter and yield per day (Table 1). For species, significant differences were found in all variables, except plant height. For genotypes, within species, significant differences were also obtained, except in inflorescence length, inflorescence width and stem diameter. For the interaction of species by environment, significant differences were obtained for most variables, except for plant height, inflorescence length and seed diameter. This indicates a differential response of species to these sources of variation, coinciding with what was previously reported (Präger *et al*., 2018; Tiwari *et al*., 2018).

Table 1. Mean squares for the variables studied between species in three environments in Mexico. S 2019.

Variable/source of variation (df)	Loc (2)	Rep(loc) (9)	Esp (1)	Var(esp) (4)	Loc∗eng (2)	Error (53)
Emergence of inflorescence (days)	83.6**	1.94	3186.68**	297.01**	200.47**	5.12
Days to flowering	36.3**	2.27	3486.13**	398.67**	156.29**	5.32
Days to maturity	8 553.6**	0.65	826.89**	481.22**	4 311.01**	7.83
Grain filling period	7 712.3**	0.9	7708.68**	335.89**	4 085.18**	12.9
Plant height (cm)	60601.4**	197.42	57.96 ns	1081.44**	30607.65**	194.16
Inflorescence length (cm)	1 698.2**	355.15	2678.63**	147.44 ns	1454**	201.41
Inflorescence width (cm)	564.2**	20.73	598.64**	5.52 ns	420.31**	13.14
Stem diameter (mm)	85.2**	5.12	1146.91**	11.66 ns	104.86**	6.8
Seed diameter (mm)	0.05 ns	1	1081.6**	0.01**	0.07 ns	0.02
One thousand seed weight (g)	0.1**	0.01	60.09**	0.34**	0.11**	0.01
Hectoliter weight (kg)	22.6**	0.36	6595.6**	63.39**	27.63**	3.71
Yield (kg ha^{-1})	10170752**	3594596.9	10957044**	6110264**	11030525**	967667

**= significant differences; ns= non-significant differences.

Table 2 presents the comparison of means between species. In the phenological variables, amaranth presented a greater number of days to the emergence of panicle and days to flowering. However, for grain filling period and maturity, quinoa presented a greater number of days.

Although in quinoa the inflorescence emerges first and flowering begins, this species takes longer to reach maturation, this is due to the longer period of grain filling, but still quinoa is less late than in its places of origin. In Bolivia and Peru, it matures in up to more than 200 days (Rojas *et al*., 2013; Chura *et al*., 2019), this because it grows there near 4 000 masl, while in Mexico it was sown at 2 250 masl.

Table 2. Comparison of means of variables studied between species in three environments of Mexico. S 2019.

Variable/species	*Amaranthus hypochondriacus*	*Chenopodium quinoa*	HSD
Days to inflorescence	77.72 a	64.41 b	1.0675
Days to flowering	90.91 a	77 b	1.0882
Days to maturity	146.63 b	153.41 a	1.3201
Grain filling period (days)	55.72 b	76.41 a	1.6939
Plant height (cm)	234.31 a	236.1 a	6.5721
Inflorescence length (cm)	58.9 a	46.7 b	6.6937
Inflorescence width (cm)	20.21 a	14.44 b	1.7094
Stem diameter (mm)	22.21 a	14.2 b	1.2392
Seed diameter (mm)	1.1 b	1.92 a	0.0253
One thousand seed weight (g)	0.81 b	2.67 a	0.0511
Hectoliter weight (kg)	81.71 a	62.2 b	0.9228
Yield (kg ha^{-1})	3 825.8 a	3 056.9 b	467.44

Means in rows with the same letters are statistically equal.

In the size variables, amaranth has an advantage in length and diameter of the inflorescence and stem diameter, while both species presented the same plant height. In the seed variables, quinoa presented a larger seed diameter, a greater weight of one thousand grains, therefore, amaranth has a greater hectoliter weight; it should be clarified that this value is of quinoa without benefiting; that is, still with the pericarp attached to the seed. In yield, amaranth presented higher grain yield per day and higher grain yield. This can be explained because the evaluation sites are places where amaranth is traditionally sown (Espitia, 1992; Espitia, 1994) and quinoa is introduced into them.

The size of the seed is of the most contrasting characteristics. The seed diameter of the three quinoa varieties evaluated ranged from 1.8 to 1.9 mm, being classified as large grain (Murphy *et al*., 2019). Grain size is also related to utilization, large grains larger than 1.8 mm are used for cooked consumption, which is the most widespread form worldwide (INDECOPI, 2014). Quinoa, due to its larger seed size, presents fewer agronomic management problems, as it germinates after three or four days, while amaranth germinates after eight or ten days, so quinoa presents better emergence of seedlings. The values obtained here for weight of one thousand grains (2.67 g) is comparable to those reported (2.3 to 3.2 g) in South America (Curti *et al*., 2014).

In relation to the yield per day, amaranth had 25.42 kg per day, almost five more than quinoa; while in grain yield, amaranth also presented a higher yield than quinoa, almost 800 kg ha^{-1} more on average of the three varieties of each crop. The yield values for quinoa in the three environments of the present study are higher than those reported in a test for 12 genotypes in northern Argentina (Curti *et al*., 2014), they report 654 to 1 703 kg ha^{-1} in environments exposed to drought.

In general, it can be established that both amaranth and quinoa have the potential to be grown under the conditions evaluated. Quinoa, due to its origin, is likely to show better performance as it is grown in environments closer to 3 000 masl (Zurita-Silva *et al*., 2014). On the contrary, as one descends in altitude, quinoa is likely to present problems, especially if temperatures of 30 °C occur during flowering, as this causes sterility since grain formation reduces (Bertero, 2013).

Table 3 shows the means for the three varieties of amaranth studied in the present experiment. The experimental lines Tlahuicole and L-145 were the ones with the highest yield (4 097 kg ha^{-1}), while Nutrisol, which is a commercial variety, yielded a little less than one tonne. It is worth mentioning that the latter showed a maturity 15 days less than the first two, as did the rest of the phenological variables that are inversely correlated with yield (Espitia *et al*., 1992).

Table 3. Comparison of means of variables studied in three varieties of amaranth in three environments of Mexico. S 2019.

Variable/variety	Tlahuicole	L-145	Nutrisol	HSD
Days to inflorescence	80 a	78.4 a	74.7 b	2.105
Days to flowering	93.4 a	91.9 a	87.4 b	2.386
Days to maturity	151.9 a	151.2 a	136.7 b	1.439
Grain filling period	59.3 a	58.5 a	49.3 b	2.485
Plant height (cm)	244.9 a	229.4 b	228.5 b	14.062
Inflorescence length (cm)	60.4 a	56 ab	60.2 b	4.408
Inflorescence width(cm)	20.7 a	19. 4a	20.5 a	2.531
Stem diameter (mm)	23 a	20.8 b	22.8 ab	2.082
Seed diameter (mm)	1.14 a	1.13 a	1.11 a	0.051
One thousand seed weight (g)	0.78 b	0.85 ab	0.81 b	0.042
Hectoliter weight (kg)	81.57 a	81.5 a	81.95 a	6.369
Yield (kg ha^{-1})	4097a	4412 a	2968 b	1155.5

Means in rows with the same letters are statistically equal.

Table 4 shows the comparison of means for the three varieties of quinoa evaluated, Suyana presented higher yield, greater size and weight of seed and greater plant size, yielded more than the variety of amaranth Nutrisol and only 300 kg less than the best varieties of amaranth. The information on mildew (*Peronospora variabilis*) is not shown, but this variety was the one that presented the lowest incidence of this disease, which is one of the adverse factors for the production of quinoa worldwide (Murphy *et al*., 2019). Similarly, the content of saponins is an important aspect in the production of quinoa (Zurita-Silva *et al*., 2014), Suma was the variety with the lowest content followed by Suyana.

Table 4. Comparison of means of variables studied in three varieties of quinoa in three environments of Mexico. S 2019.

Variable/variety	Suyana	Tokyo	Sum	HSD
Days to inflorescence	60.9 b	60.4 b	71.9 a	1.42
Days to flowering	74.3 b	71.1 c	85.5 a	1.43
Days to maturity	151.9 b	151.9 b	156.4 a	1.03
Grain filling period	77.5 b	80.7 a	70.9 c	1.79
Plant height (cm)	247.2 a	232.3 ab	228.7 a	15.5
Inflorescence length (cm)	51.6 a	44.7 a	43.7 a	19.4
Inflorescence width (cm)	15 a	13.7 a	14.5 a	4.84
Stem diameter (mm)	14.9 a	13.8 a	13.7 a	3.37
Seed diameter (mm)	1.9 a	1.9 a	1.8 a	0.04
One thousand seed weight (g)	2.9 a	2.6 b	2.4 c	0.12
Hectoliter weight (kg)	63.2 a	64.82 a	58.5 a	6.86
Yield (kg ha^{-1})	3 800.7 a	2 556.3 b	2 791.7 b	733

Means in rows with the same letters are statistically equal.

Due to the performance of both species, a slight advantage for amaranth is clearly seen, as it has a higher yield and a shorter crop cycle. Quinoa, on the other hand, has a great advantage, which is the size of the grain, which facilitates the agronomic management of the crop. If we look more specifically at the level of individual varieties, the variety of quinoa Suyana has very good performance, comparable to those of amaranth.

A disadvantage of quinoa would be the perigonium of the seed, in which the saponins are found, this forces that in the post-harvest management, the seed has to be scarified or pearled to remove the ‘shell’ and then washed to eliminate all the saponins (Zurita-Silva *et al*., 2014). These post-harvest management processes make quinoa grain more expensive. On the contrary, amaranth is harvested, cleaned and is ready to use because it has no perigonium. Therefore, and in accordance with the stated objective, it can be established that amaranth has the agronomic characteristics to expand its cultivation, similarly as has happened with quinoa. The limitations of amaranth may be of a different nature, such as political will, because being in a more westernized region, local consumption has not become as popular as quinoa in its places of origin.

As can be deduced from the magnitude of the mean squares presented in the analysis of variance (Table 1), the variation due to species x environment interaction is comparable to the variation due to the sources of variation of environment and species. Figures 1 and 2 presented the performance of the species through the evaluated environments. It can be observed that there were changes in magnitude and order in variables, such as days to flowering, grain filling period, panicle length (Figure 1), stem diameter and yield (Figure 2).

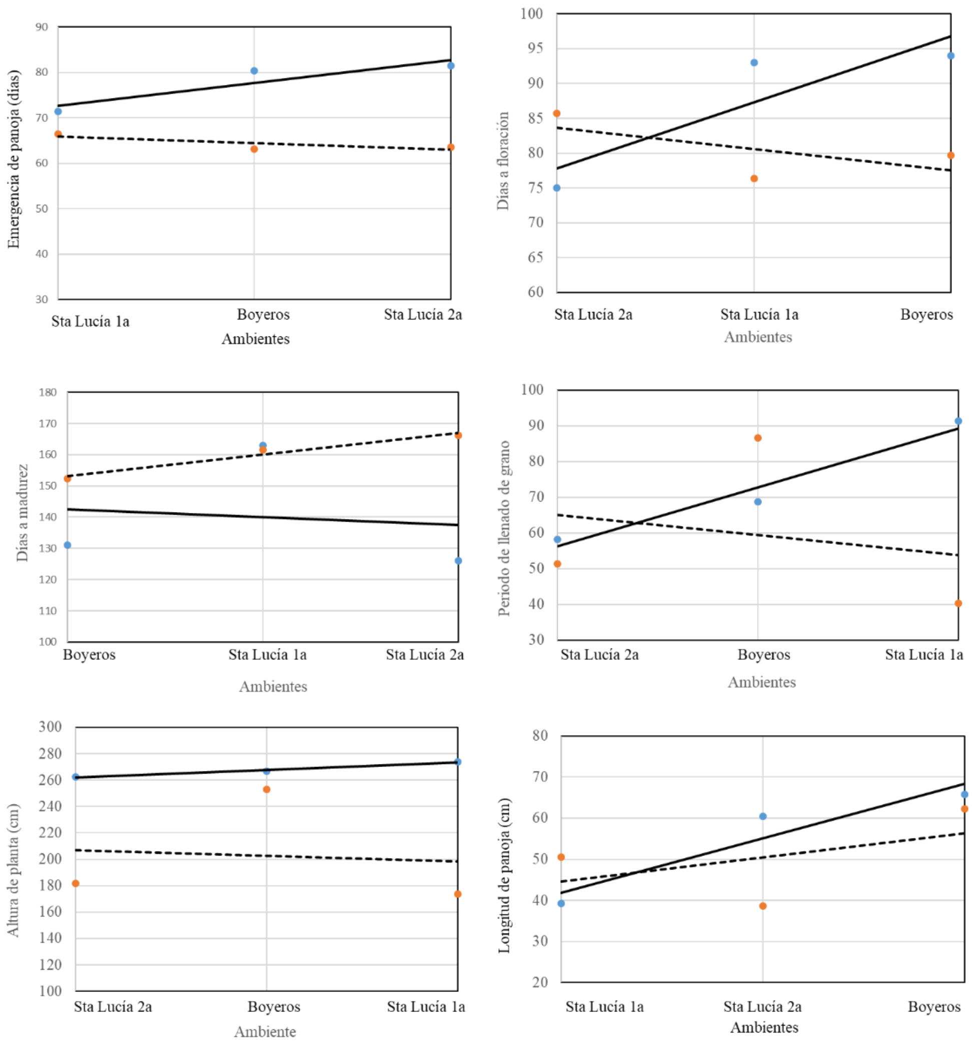

Figure 1. Species-by-environment interaction of six variables of the comparison of three amaranth genotypes (continuous line) and three quinoa genotypes (dashed line) in three environments. S-S 2019.

In the variables associated with phenology, there was variation through environments, in days to flowering and grain filling period there were changes in order and magnitude when changing environment, with amaranth tending to present higher values of these variables when the environment improves, while in emergence of panicle, amaranth remained above quinoa in the three test environments, the opposite happened in days to maturity, these results agree with what was previously reported (Espitia 1992; De Santis *et al*., 2018).

In variables of size length of panicle (Figure 1) and diameter of stem (Figure 2), changes in magnitude and order occurred, with amaranth presenting higher values, in plant height (Figure 1) and panicle width (Figure 2) changes in magnitude were obtained, with amaranth being the one that presented the highest values through the evaluated environments, these results are consistent with what was previously reported (Tiwari *et al*., 2018; Thiam *et al*., 2021).

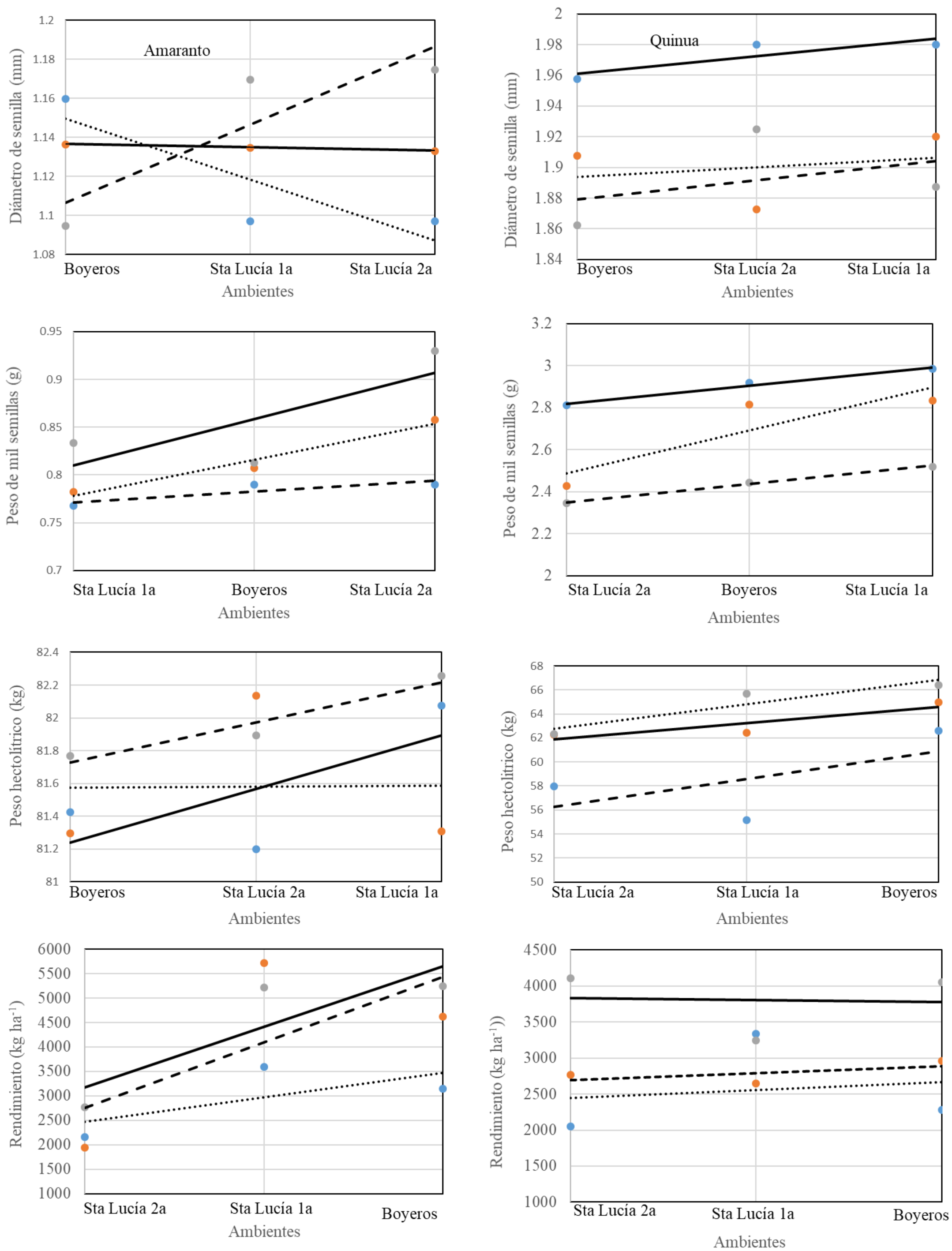

Figure 2. Genotype-by-environment interaction of the yield of the comparison of three amaranth genotypes (continuous line Tlahuicole, dashed line L-145 and dotted line Nutrisol) and three quinoa genotypes (continuous line Suyana, dashed line Tokyo and dotted line Suma) in three environments. S-S 2019.

For the variables related to the seed, changes in magnitude in seed diameter, weight of one thousand grains and hectoliter weight were obtained (Figure 2), with quinoa having the largest seed size, although for seed diameter, the environment x species interaction was not significant, which indicates that this variable is controlled mainly by genetic effects, this is demonstrated since in the analysis of variance only the source of variation species was significant, while environments and environments x species were non-significant. This indicates that the significance in species is due to the expression of the seed diameter so different between the two species since quinoa has a seed diameter almost twice that of amaranth.

This difference is also noticeable in the weight of 1 000 seeds since quinoa has a value three times higher than that of amaranth. The opposite happens in hectoliter weight, where amaranth presented a value of 81.71 kg and quinoa of 62.2 kg, which was expected due to the smaller seed size that gives greater density and fewer spaces between seeds. These results are consistent with what was reported by Thiam *et al*. (2021) for quinoa and for amaranth by Espitia (1992); Tiwari *et al*. (2018).

For yield, changes in order and changes in magnitude occurred; quinoa showed better yield in the most unfavorable environment that was Santa Lucía de Prías second date, while amaranth presented better yield in Boyeros and in Santa Lucía de Prías first date, this indicates that the performance of amaranth improves as the environment improves (Tiwari *et al*., 2018), quinoa, on the contrary, presented a slight decrease, this is perhaps due to the incidence of mildew (*Peronospora variabilis*) on earlier sowing dates, this disease is one of the limitations worldwide for quinoa production (Khalifa and Thabet, 2018).

That amaranth has resulted in a yield advantage is normal, as the evaluations were conducted in its naturally adaptation environment, while quinoa is being introduced. Due to its resistance to low temperatures, quinoa in Mexico can be used in crop rotation in cereal areas where barley, wheat and oats are produced since it is a broadleaf plant, which would allow reducing pests and diseases of cereals by being incorporated into the crop pattern of these regions. The soil would also be improved since the quinoa stubble would be incorporated in its entirety, the straw of the cereals is harvested in bales, increasing the content of organic matter and the cation exchange capacity.

In the three environments evaluated, it can be seen that, in general, amaranth showed better performance than quinoa; however, the variety of quinoa Suyana presented a performance very similar to the best varieties of amaranth (Tlahuicole and L-145), so it can be established that selecting the appropriate genotypes, good yields of both crops can be obtained.

One of the important characteristics for the commercialization and consumption of quinoa is the size of the seed, the Peruvian technical standard reports that the grains classified as large are those greater than 1.7 mm, medium between 1.7 and 1.4 and small grains less than 1.4 mm in diameter (INDECOPI, 2014), the results obtained with the genotypes evaluated were satisfactory since they presented large grain. A disadvantage of quinoa is the fact of having a perigonium, which is where the saponins are found, compounds that give a bitter taste, these must be eliminated by physical methods such as scarification, wet methods such as washing or the combination of both (Zurita-Silva *et al*., 2014), amaranth did not present perigonium and the seed is ready to be used when harvested, this is an advantage of amaranth. Agronomically, it can be established that both crops have good potential; that is, they complement each other since amaranth is more adapted to climates from temperate to hot and quinoa from temperate to cold.

Conclusions

In general, amaranth performed better in the environments evaluated than quinoa. Amaranth surpassed quinoa in inflorescence length, inflorescence width, stem diameter, hectoliter weight and yield, whereas quinoa showed higher values for seed diameter and weight of one thousand seeds. The Tlahuicole and L-145 amaranth genotypes were the ones that present the best performance, followed by the variety of quinoa Suyana. Amaranth observed the characteristics to be a worldwide phenomenon, as has happened with quinoa.

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