

EVALUATION OF QUINOA GERMPLASM IN ENVIRONMENTS OF THE CENTRAL HIGH-VALLEY LANDS OF MEXICO

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ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) is a crop that grows under conditions of environmental stress, has high nutritional value, and agronomic potential. It is grown and marketed on a small scale in Mexico. However, there are no varieties or technology for its production. The objective of this research was to determine the performance of quinoa germplasm in the Central high-valley lands of Mexico. Sixteen genotypes of different origins and characteristics were evaluated in three environments in the localities of Nanacamilpa, Tlaxcala; and Santa Lucía de Prías, Texcoco, State of Mexico. Statistical differences ($p \leq 0.05$) were found for genotypes. Late genotypes Suyana, Suma, Pata de Venado, Blanca Ayacucho, and Huauzontle showed higher grain yield (4004.9, 3888.3, 3091.1, 2999.7, and 2967.2 kg ha⁻¹, respectively). Among the intermediate genotypes, Tokio rosa and Pasankalla reventona were the better with 2858.4 and 2118.4 kg ha⁻¹, respectively. Whereas among the early genotypes, Tarpuna had the highest grain yield (3005.8 kg ha⁻¹). Regarding seed diameter, only Huauzontle and Quinoa negra had a seed size equal to or smaller than 1.8 mm; the rest of the genotypes can be marketed as grains because of their seed size. Of the environments evaluated, the least favourable was Nanacamilpa 2019, while Santa Lucía de Prías 2019 was the most favourable environment. Overall, the performance of the evaluated genotypes was as expected, as they mostly come from the Inter-Andean Valleys region, which are very similar in altitude and temperature to the Central high-valley lands of Mexico.

Keywords: *Chenopodium quinoa*, adaptation, yields, grain size, varieties.

INTRODUCTION

Climate change affects agricultural production conditions (Hasegawa, 2013). The impact on agriculture and the implications for food security are alarming. Farmers, ranchers, fishermen, and community foresters depend on activities inextricably linked to climate. These groups are also the most vulnerable to climate change (FAO, 2016), as human health hazards are on the rise, particularly in lower-income populations, as a result of extreme temperatures and declining water, air and food quality (WHO, 2017). Droughts and soil salinity are major problems (Zeglin *et al.*, 2013). Coupled with the

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continuous increase in population, farmers need to explore new alternatives to adapt to changes.

Quinoa (*Chenopodium quinoa* Willd.) is one of the oldest crops in the Andean region of South America, domesticated more than 7000 years ago in its centre of origin (Peru and Bolivia). It is an annual, dicotyledonous species of the Amaranthaceae family (Bazile *et al.*, 2016). Quinoa has a high genetic variability. It is grown under severe drought conditions, reflecting its adaptability to agroecological stress conditions, such as marginal soils, low temperatures and fertility, drought, salinity and environments rich in ultraviolet radiation (Tapia, 1997; Bosque *et al.*, 2000).

Approximately 40 commercial genotypes are known in Andean countries, which have wide variability in plant, inflorescence and seed colour. They are characterized by a branched growth habit up to the second third, with about 1 to 2 m height. The growing season and physiological maturity of Quinoa take 4 to 6 months, and it is considered a preponderantly self-pollinated species (Mujica *et al.*, 2001; Zurita-Silva *et al.*, 2014; Curti *et al.*, 2016). This allows varieties to be selected, adapted and cultivated for a wide range of environmental conditions (Jacobsen, 2003).

Quinoa is an expanding crop used as human food and animal feedstock due to its high nutritional value. It is high in vitamins, proteins and minerals, and is reported to provide all essential amino acids for humans (FAO, 2011; Rojas *et al.*, 2015). It is also attributed medicinal properties, such as healing, anti-inflammatory, analgesic and disinfectant (Valenzuela *et al.*, 2015; Nowak *et al.*, 2016). Another characteristic of quinoa is the presence of saponins found in the seed husk and the absence of gluten (Jacobsen *et al.*, 2005).

In regard to yield, Gómez and Aguilar (2016) reported that in plantations in their centre of origin, yields range from 1200 to 3500 kg ha⁻¹, while DGPA (2021) notified yields of 740 to 3632 kg ha⁻¹. Regarding the potential in countries where it is not traditionally planted, yields from 200 to 2050 kg ha⁻¹ are reported (Bazile *et al.*, 2016), while Chura *et al.* (2019) recorded 2836.55 to 5099.18 kg ha⁻¹. The crop has been introduced in regions of North America, Europe, China, and the Middle East (Jacobsen, 2017; Katwal and Bazile, 2020). The commercialization and use of quinoa depend on seed size. Seed diameters from 1.2 to 2.5 mm and thousand-kernel weight from 2.09 to 3.8 g are reported (Zurita-Silva *et al.*, 2014; Chura *et al.*, 2019).

In Mexico, quinoa is an alternative for the production of high-quality foods that contribute to solve nutritional problems. It is an alternative for late plantings and crop rotation. However, it is grown on a small scale and there are no varieties or technology for its production (Espitia *et al.*, 2019). The objective of this study was to determine the agronomic performance of 16 quinoa genotypes to evaluate their adaptability in the Central high-valley lands of Mexico.

MATERIALS AND METHODS

Fifteen recently introduced genotypes from Peru, Ecuador, and Bolivia, and one Huauzontle (also known as Mexican quinoa) were evaluated. These materials were

selected based on a characterization carried out at INIFAP - CEVAMEX, where materials adapted to the conditions of the Central high-valley lands of Mexico were chosen (Table 1).

Location and climate conditions

Genotypes were evaluated at two locations: Santa Lucía de Prías, Texcoco, State of Mexico (19° 26' 42'' N, 98° 53' 15'' W), in 2019; and Nanacamilpa, Tlaxcala, in 2018 and 2019 (19° 29' 22'' N, 98° 33' 46'' W). Those locations have environmental conditions (Table 2) similar to the inter-Andean valleys where is the origin of most of the genotypes in the trial. Sowing dates were in Nanacamilpa, July 25 (2018) and June 18 (2019); in Santa Lucía de Prías, June 28 (2019).

Table 1. *Chenopodium* genotypes used in the study.

No.	Name	Fruit colour	Quinoa type	Ecological region of origin
1	Huauzontle	Yellow	Bitter	High valleys
2	Suma	Green	Sweet	Highlands
3	Tokio rosa	Green	Bitter	Highlands
4	Blanca Ayacucho	Green	White	Inter-Andean valleys
5	Choclo	Green	Sweet	High-Andean
6	Tarpuna	Green	Bitter	valleys Inter-Andean
7	Pata de Venado	Green	Sweet	valleys
8	Suyana	Yellow	Bitter	Inter-Andean valleys
9	Misa amarilla	Yellow	Bitter	Inter-Andean valleys
10	Marangani	Yellow	Bitter	Inter-Andean valleys
11	Roja ku	Red	Bitter	Highlands
12	Rojita	Red	White	Highlands
13	Pasankalla lila	Gray	Sweet	Highlands
V14	Quinua negra	Gray	Sweet	Highlands
15	Pasankalla reventona	Gray	Sweet	Highlands
16	Pasankalla plomo	Gray	Sweet	Highlands

Table 2. Soil type and precipitation in the three evaluation environments. P-V 2018-2019.

Location	Altitude (m)	Soil type	Precipitation in the cycle (mm)
Nanacamilpa, Tlaxcala. 2018	2829	Sandy-loam	299.6
Nanacamilpa, Tlaxcala. 2019	2829	Sandy-loam	364.05
Santa Lucía de Prías, State of Mexico. 2019	2250	Sandy-loam	263.6

Experimental design and crop management

In each experiment the genotypes were distributed in a randomized complete blocks design with six replicates; the experimental plot consisted of three furrows 5 m long and 0.8 m apart. The crop was grown under rainfed conditions, without fertilization. In all experiments, two manual weeding operations were carried out 25 and 45 days after sowing (das).

Variables studied

The following variables were recorded: days to panicle emergence (d), days to maturity (d), and grain filling period (d). The first two were recorded when 50 % of the plants in each plot were at the inflorescence bud or the physiological maturity of the grain, respectively. Stem diameter (cm) of 10 representative plants per plot was measured at flowering, and plant height (cm) at grain maturity was recorded. The biological yield was taken from representative samples of aboveground biomass (500 g), which were dried at 60 °C until a constant weight was obtained and extrapolated to useful areas of 3 m². Seed diameter (cm) was obtained from 10 groups of 10 seeds per plot, with a digital Vernier ruler (Stainless Hardened). The hectolitre weight (kg hL⁻¹) was determined from the weight of a known volume of seed and extrapolated to 100 L weight. The thousand-kernel weight (g) was determined based on the weight of five groups of 100 grains per plot, and grain yield (kg ha⁻¹) was measured in 3 m of the central furrow and extrapolated per hectare. The harvest index was estimated by the ratio of economic yield to biological yield.

Data analysis

Data were analysed using GLM of SAS® (SAS 9.4 2012). An analysis of variance was performed for environments and genotypes. Tukey tests ($p \leq 0.05$) were performed for comparison of means among environments and genotypes.

RESULTS AND DISCUSSION

For both environments and genotypes, significant differences were found at $p \leq 0.01$ for all variables (Table 3). For the genotype*environment interaction, significance was found at $p \leq 0.01$ for most variables, except stem diameter, seed diameter, and harvest index. This suggests a differential response of the genotypes and environments evaluated. Thiam *et al.* (2021) reported significant difference for stem diameter, contrary to what was found in this study. Tan and Temel (2018) found significant differences for environment, genotype and genotype-environment interaction at $p \leq 0.01$ in yield, thousand-kernel weight, days to maturity, and plant height.

In the comparison of means by environment (Table 4), for phenological variables, the Nanacamilpa 2019 environment obtained higher panicle emergence and days to maturity (d), while Santa Lucía de Prías recorded higher grain filling period (d). On the other hand, Nanacamilpa 2018 presented lower values for these three variables. In Peru, quinoa matures in more than 190 d, with a longer grain filling period (Gómez and Aguilar, 2016), due to its growth at 3900 m; while in Mexico the planting conditions

Table 3. Mean squares for the variables studied of 16 quinoa genotypes, in three rainfed environments in the Central high-valley lands of Mexico. P-V 2018-2019.

Source gl.	Environment 2	REP(AMB) 15	Genotypes 15	GEN*AMB 30	Error 225
Emergence of panicle (d)	7821.21**	10.63	980.82**	24.31**	4.66
Days to maturity (d)	18871.34**	9.31	1541.75**	113.49**	3.66
Grain filling (d)	4764.83**	8.77	1207.45**	103.81**	11.10
Stem diameter (cm)	674.05**	4.82	14.84**	2.98ns	2.17
Plant height (cm)	91604.67**	460.42	8238.28**	420.00**	147.42
Seed diameter (mm)	0.985**	0.026	0.318**	0.028ns	0.035
Hectolitre weight (kg hL ⁻¹)	158.68**	13.10	51.33**	8.90**	2.94
Harvest index	1.225**	0.0332	0.041ns	0.030ns	0.035
Thousand-kernel weight (g)	6.16**	0.06	2.46**	0.16**	0.05
Grain yield (kg ha ⁻¹)	64686655**	1180719	8253981**	1231658**	389088

d: days. Different at ** $p \leq 0.01$ and * $p \leq 0.05$; ns, not different.

Table 4. Comparison of means of 10 variables evaluated in three rainfed environments in the Central high-valley lands of Mexico. P-V 2018-2019.

Variable /Environment	Nanacamilpa 2018	Nanacamilpa 2019	Santa Lucía de Prías 2019
Emergence of panicle (d)	44.11c	61.50a	48.90b
Days to maturity (d)	120.08c	147.39a	139.23b
Grain filling (d)	65.41c	73.98b	79.37a
Stem diameter (cm)	12.29b	9.11c	14.38a
Plant height (cm)	148.55b	120.00c	181.73a
Seed diameter (mm)	2.16a	2.03b	1.95c
Hectolitre weight (kg hL ⁻¹)	66.31c	68.70bc	68.34a
Harvest index	0.376a	0.434a	0.216b
Thousand-kernel weight (g)	3.08a	2.78b	2.57c
Grain yield (kg ha ⁻¹)	2743.4b	1734.5c	3360.7a

d: days. Means per column with different letters showed statistical difference ($p \leq 0.05$).

were at 2250 and 2829 m. Präger *et al.* (2018) mentioned that the growth period varies between 122 and 154 d, which agrees with what is found in this study.

The variables size, plant height and stem diameter at maturity were higher in Santa Lucía de Prías, while Nanacamilpa 2019 exhibited the lowest values. Chura *et al.* (2019) reported stem diameter values from 9.70 to 14.49 mm, which is consistent with the results found in this study. Gonzalez *et al.* (2011) reported plant heights from 61.4 to 98.6 cm at maturity, different from what we reported in this study.

For seed variables, Nanacamilpa 2018 showed higher thousand-kernel weight and seed diameter, but lower hectolitre weight. On the other hand, Nanacamilpa 2019 and

Santa Lucía de Prías showed higher hectolitre weight. These results are consistent with those reported by Altuner *et al.* (2019). In the Santa Lucía de Prías environment, the low values of thousand-kernel weight and seed diameter correspond to those obtained by Chura *et al.* (2019). Nanacamilpa 2018 and 2019 had higher harvest index, followed by Santa Lucía de Prías, these values are higher than those reported by Tan and Temel (2017). Finally, the highest yield was obtained in Santa Lucía de Prías environment, which corresponds to that reported by Chura *et al.* (2019). On the contrary, the lowest yield was obtained in Nanacamilpa 2019, which corresponds to González *et al.* (2011) and Tan and Temel (2017).

In the comparison of means by genotype (Table 5), in the phenological variables, the genotypes Suma, Blanca Ayacucho, Suyana, Huauzontle, Pata de Venado, Rojita, and Roja ku had a later growth period of 140 to 149 d. The earliest materials were Tarpuna, Choclo, Maranganí, and Misa amarilla (116, 124, and 125 d, respectively). The remaining genotypes had an intermediate growth period.

The early genotypes showed the shortest grain filling period, from 61 to 64 d, except Huauzontle, which is a late genotype with a grain filling period of 60 d. Huauzontle

Table 5. Comparison of means of 16 quinoa genotypes evaluated in three rainfed environments in the Central high-valley lands of Mexico. P-V 2018-2019.

Variables/ Genotypes	EPA	MAD	LLG	DIT	ALM	DIS	PEH	IC	PMG	REN
Late										
Suma	62b	149a	73bcd	13.7a	206a	2.1ac	66.7cde	0.3d	2.7cd	3888.3a
Blanca Ayacucho	50def	146ab	83a	13.0abc	175b	2.0cd	67.5cde	0.3cd	2.8cd	2999.7acd
Suyana	57c	143abc	72cd	13.5ab	173b	2.1ac	67.4cde	0.3acd	2.9ac	4004.9a
Huauzontle	71a	142abcd	60e	12.0abcde	160bc	1.7e	71.8a	0.4ac	1.9g	2967.2acd
Pata de Venado	49efg	142abcd	81ab	11.0de	150cde	1.9cde	68.9c	0.3acd	2.5c	3091.1ac
Rojita	53cd	141bcd	76abc	11.1cde	149cdef	2.1ac	67.7cde	0.3c	2.6cd	1930.9d
Roja ku	46fgh	140bcd	83a	11.3cde	142cdef	2.0ac	67.8cd	0.4acd	2.7df	2498.2cd
Intermediate										
Tokio rosa	49efgh	139bcd	80ab	12.7abcd	160bc	2.2a	69.0c	0.3acd	2.9acd	2858.4cd
Pasankalla lila	48efgh	135cde	76abc	10.7e	140def	2.2ac	67.4cde	0.3acd	2.9a	1960.2d
Quinoa negra	45hil	135de	80abc	11.1de	131efg	1.8de	69.9a	0.4acd	2.3a	2087.6cd
Pasankalla plomo	46gh	130ef	74bc	11.6cde	131fg	2.1ac	66.5cde	0.4acd	3.3a	2084.9cd
Pasankalla reventona	46gh	129ef	73bc	11.7bcde	131efg	2.1ac	67.0cde	0.3acd	3.3a	2118.4cd
Early										
Tarpuna	53ced	125f	63e	12.1abcde	152cd	2.2a	68.3c	0.4a	3.0a	3005.8acd
Misa amarilla	50defg	125f	62e	12.0abcde	138def	2.2a	64.9e	0.3acd	3.0a	1965.8d
Maranganí	53de	124fg	61e	12.3abcde	149cdef	2.2a	68.5c	0.3acd	3.0acd	2381.9cd
Choclo	41i	116g	64de	11.2cde	117g	2.0acd	65.2de	0.4a	2.8cd	1964.7d

EPA: panicle emergence (days), MAD: days to maturity (days), LLG: grain filling (days), DIT: stem diameter (cm), ALM: plant height (cm), DIS: seed diameter (mm), PHE: hectolitre weight (kg hL⁻¹), IC: harvest index, PMG: thousand-kernel weight (g), and REN: grain yield (kg ha⁻¹). Means per column with different letters showed statistical difference ($p \leq 0.05$).

and Suma had longer panicle emergence times (71 and 62 d); the other late specimens showed 46 to 57 d. Choclo showed less days of emergence (41 d), while the remaining early genotypes were 50 to 53 d. The panicle emergence time for the intermediate genotypes was 45 to 49 d. Other studies conducted in Mexico evaluated 36 quinoa varieties that ranged from 148 to 203 d to maturity (Mujica *et al.*, 2001). In its centre of origin, quinoa has a growing period between 90 and 210 d (Zurita-Silva *et al.*, 2014; Gómez and Aguilar, 2016).

For size variables, stem diameter ranged from 11.2 to 12.3 mm for early genotypes, and from 11.3 to 13.7 mm for late genotypes. The values found in this study agree with those of Chura *et al.* (2019). Pata de Venado, Rojita and Roja ku were the late genotypes with lower height at maturity (142, 149, and 150 cm), followed by Huauzontle, Suyana and Blanca Ayacucho (160, 173, and 175 cm). Suma is the genotype with the greatest height, 206 cm. Choclo is an early genotype with a small height (117 cm), while the others measure 138 to 152 cm. The intermediate genotypes Quinoa negra, Pasankalla plomo, and Pasankalla reventona exhibited a height of 131 cm, while Pasankalla lila and Tokio rosa measured 140 and 160 cm, respectively. In its centre of origin, quinoa ranges from 70 to 200 cm height (Mujica *et al.*, 2001; DGPA, 2021). In Mexico, studies have been performed where quinoa had 110 to 280 cm height (Mujica *et al.*, 2001).

Regarding seed variables, all genotypes produced seed diameters between 2.0 and 2.2 mm, except Huauzontle, Pata de Venado (late), and Quinoa negra (early), which had smaller diameters. Seed size is one of the most important variables, as it is marketed according to size. Grains larger than 1.8 mm in diameter are reserved for graining (INDECOPI, 2014), which is the most important form of quinoa marketing worldwide. The thousand-kernel weight of the late genotypes ranged from 2.5 to 2.9 g, except Huauzontle (1.9 g), while the early material had a lower weight.

With black quinoa as the exception, the intermediate genotypes had the highest thousand-kernel weight (2.9 to 3.3 g). The hectolitre weight ranged from 64.9 to 69 kg hL⁻¹ for all genotypes, except Huauzontle (late) and black quinoa (intermediate), which reported higher values due to smaller seed size. The results are consistent with those reported by Altuner *et al.* (2019) and Chura *et al.* (2019). Under the conditions evaluated, it is possible to produce quinoa with a seed size suitable for consumption as grain.

For the rest of the variables, 10 of the 16 genotypes had a harvest index of 0.3, while Huauzontle, Roja ku (late), Quinoa negra, Pasankalla plomo (intermediate), Tarpuna and Choclo (early) had a superior harvest index. Tan and Temel (2018) reported that earlier, high-yielding materials had higher harvest rates, unlike what was found in this study. Among the late genotypes, Suyana, Suma, Pata de Venado, Blanca Ayacucho, and Huauzontle showed higher grain yields (4004.9, 3888.3, 3091.1, 2999.7, and 2967.2 kg ha⁻¹, respectively), while Rojita and Roja ku yields were 1930.9 and 2498.2 kg ha⁻¹. Suyana and Suma are late ecotypes in their place of origin, for which yields of 3500 and 2000 kg ha⁻¹ are reported (Gómez and Aguilar, 2016), lower than those found in this study. Among the intermediate genotypes, Tokio rosa had higher grain yield

(2858.4 kg ha⁻¹), while the others had lower yields. In the early genotypes, Tarpuna had the highest grain yield with 3005.8 kg ha⁻¹; the rest had lower yields.

Yields reported in this study are higher than those 1000-2000 kg ha⁻¹ recorded in the Andean region of South America (DGPA, 2021) but lower than those reported in Chura *et al.* (2019) (2836.55 to 5099.28 kg ha⁻¹). The genotypes Suyana and Suma from the late group, Tokio rosa from the intermediate group, and Tarpuna from the early group may constitute a varietal standard for the commercial cultivation of white grain quinoa in Mexico. The genotypes Pasankalla reventona and Quinoa negra are a good alternative for the production of coloured quinoa, and the genotype Choclo is an option for areas with a short vegetative cycle or as a source of precocity for genetic improvement programs. Overall, these genotypes are good options for the commercial cultivation of quinoa in Mexico, especially for late plantings when other crops cannot thrive. Also, they are excellent options for cereals rotation in high altitude regions with low temperatures or early frosts.

The least favourable environments were Nanacamilpa 2019 and Nanacamilpa 2018; while Santa Lucía de Prías 2019 was the most favourable. There were changes in magnitude and order in the three maturity groups, suggesting that genotypes change their behaviour as growth environment changes (Figure 1). This agrees with previous reports (Ali *et al.*, 2018; Tan and Temel, 2018) which informed that quinoa genotypes interact with the environment. The fact that the Santa Lucía environment was the most favourable may be due to its lower elevation, and therefore higher temperatures. Another probable reason is the higher incidence of downy mildew that occurred in Nanacamilpa during the study.

Among the late genotypes (Figure 1). Suyana had the best performance in favourable environments, followed by Suma genotype, which had the highest performance in the least favourable environment, followed by Pata de Venado. In all environments, the genotypes Blanca Ayacucho, Pata de Venado, and Huauzontle were moderately productive, while Roja ku and Rojita had the lowest yield. It appears normal that the genotypes with higher yields are within this group, since their long cycle and plant size allow higher production of photo-assimilates, and therefore greater quantity of grain (Curti *et al.*, 2016). The genotypes of this group are of inter-Andean origin, where the environment is very similar (Gómez and Aguilar, 2016) to the conditions of this study; which in turn may have influenced their good performance. This group also included Huauzontle, whose yield is comparable to that of the best quinoa, which gives Huauzontle the potential to be used in grain production, in addition to its use as a vegetable.

Among the intermediate maturity genotypes (Figure 1), under favourable conditions, Tokio rosa had the best yield, followed by Quinoa negra and Pasankalla lila, while Pasankalla plomo and Pasankalla reventona had the lowest yield. In intermediate environments, Tokio rosa showed higher yields than the other genotypes. Pasankalla reventona is the genotype with the highest yield in the least favourable environment, followed by Pasankalla plomo, Tokio rosa, and Quinoa negra, while Pasankalla lila

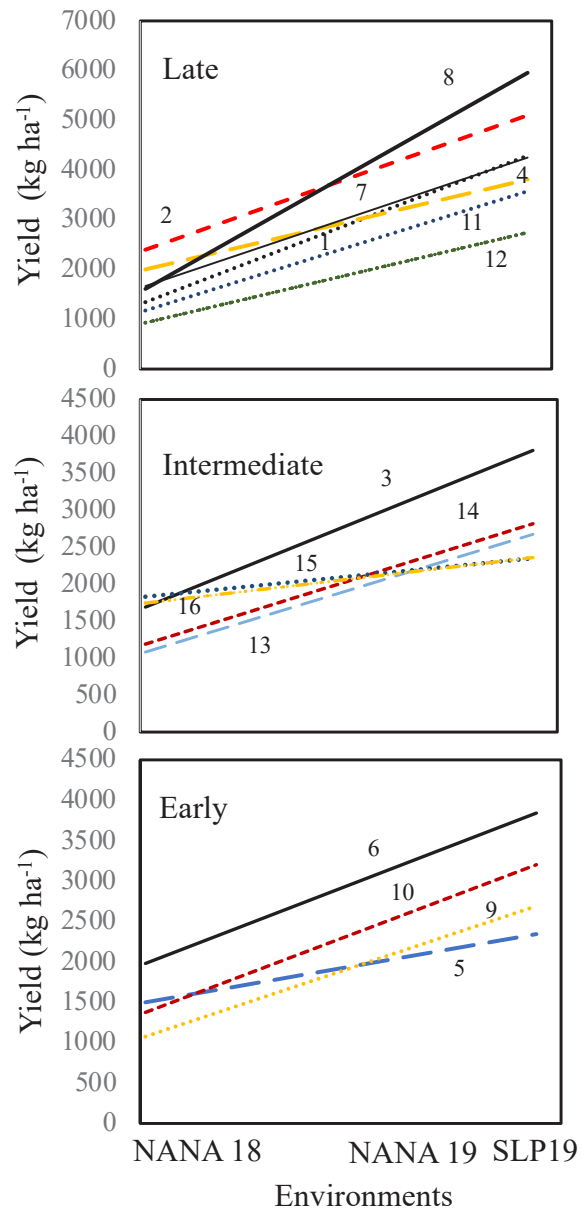


Figure 1. Genotype*environment interaction for yield of 16 genotypes grouped by cycle. Late (1 Huauzontle, 2 Suma, 4 Blanca Ayacucho, 7 Pata de Venado, 8 Suyana, 11 Roja ku and 12 Rojita); Intermediate (3 Tokio rosa, 13 Pasankalla lila, 14 Quinua negra, 15 Pasankalla reventona and 16 Pasankalla plomo); and Early (5 Choclo, 6 Tarpuna, 9 Maranganí and 10 Misa amarilla), evaluated in three environments (NANA18 Nanacamilpa 2018, NANA19 Nanacamilpa 2109 and SLP19 Santa Lucía de Prías 2019).

presented the lowest yield in these conditions. Within the early genotypes, Tarpuna had the best performance in favourable and intermediate environments, followed by Maranganí, Misa amarilla, and Choclo. In less favorable environments, Tarpuna had the best performance, followed by the genotypes Choclo, Maranganí, and Misa amarilla.

Based on the behaviour expressed, it can be established that by selecting the appropriate genotype, good yields can be obtained in different environments, especially in those with low rainfall, as the three evaluated environments. The genotypes Suyana, Suma, Tokio rosa, and Tarpuna, due to their way of interacting with the environment, in addition to their high yields in their respective maturity groups and seed size, are good options for producing quinoa in the evaluated environments. The overall behaviour of the quinoa genotypes occurred as it was expected; since most of them come from the region of the Inter-Andean valleys, very similar in altitude and temperature to the Central high-valley lands of Mexico. The high-Andean genotypes (3200 to 4200 m) showed an erratic behaviour.

CONCLUSIONS

The most favourable environment was Santa Lucía de Prías, State of Mexico, while Nanacamilpa, Tlaxcala, 2019 was the most unfavourable. Within the group of late genotypes, Suyana and Suma had the highest grain yield. In the intermediate group, the best genotypes were Tokio rosa and Pasankalla reventona; whereas in the early group Tarpuna was the best.

The genotypes Tarpuna, Misa amarilla, Maranganí, Tokio rosa, and Pasankalla lila were those with the largest diameter and seed weight. Due to their yield and seed size, the genotypes Suyana, Suma, Tokio rosa, and Tarpuna can form a varietal pattern for white grain production. Meanwhile, Pasankalla reventona and black quinoa are good options for the production of coloured quinoa. The genotype Choclo, due to its precocity, is a good alternative for short growing season areas.

REFERENCES

- Ali MB, El-Sadek A, Salem EM. 2018. Stability Parameters and AMMI Analysis of Quinoa (*Chenopodium quinoa* Willd.). Egyptian Journal of Agronomy 40: 59–74. <https://doi.org/10.21608/agro.2018.2916.1094>
- Altuner F, Oral E, Kulaz H. 2019. The impact of different sowing-times of the quinoa (*Chenopodium quinoa* Willd.) and its varieties on the yield and yield components in Turkey-Mardin ecology condition. Applied Ecology and Environmental Research 17 (4): 10105–10117. https://doi.org/10.15666/aeer/1704_1010510117
- Bazile D, Jacobsen S, Verniau A. 2016. The global expansion of quinoa: trends and limits. Frontiers in Plant Science 7: 1–6. <https://doi.org/10.3389/fpls.2016.00622>
- Bosques H, Lemeur R, Van D. 2000. Análisis ecofisiológico del cultivo de quinua (*Chenopodium quinoa* Willd.) en condiciones de estrés de la sequía y la salinidad. Tropicicultura 18: 198–202.
- Chura E, Mujica A, Haussmann B, Smith K, Flores S, Flores AL. 2019. Agronomic characterization of quinoa (*Chenopodium quinoa* Willd.) progeny from close and distant self-fertilized s5 simple crosses. International Journal of Agriculture and Natural Resources (IJANR) 46: 154–165. <http://dx.doi.org/10.7764/rcia.v46i2.2142>

- Curti RN, De la Vega AJ, Andrade AJ, Bramardi SJ, Bertero HD. 2016. Adaptive responses of quinoa to diverse agro-ecological environments along an altitudinal gradient in north west Argentina. *Field Crops Research* 189: 10–18. <https://doi.org/10.1016/j.fcr.2016.01.014>
- DGPA (Dirección General de Políticas Agrarias). 2021. Observatorio de las Siembras y Perspectivas de la Producción Quinoa. Ministerio de Desarrollo Agrario y Riego. Viceministerio de Políticas y Supervisión del Desarrollo Agrario. Lima, Perú. pp. 17–37.
- Espitia RE, Valverde RMG, Sesma HLF, Rivas VP, Ayala GAV. 2019. Caracterización de germoplasma de *Chenopodium* spp. en México. *In: Libro de resúmenes del Ministerio de Agricultura. INDAP, Pontificia Universidad Católica de Chile y ODEPA (eds.); VII Congreso Mundial de Quinoa y otros granos andinos. Génesis Impresiones: Santiago, Chile.* pp: 19.
- FAO (Organización de las Naciones Unidas para la Alimentación y la Agricultura). 2011. La Quinoa: cultivo milenario para contribuir a la seguridad alimentaria mundial. Oficina Regional de la FAO para América Latina y el Caribe. Santiago, Chile. <https://www.fao.org/3/aq287s/aq287s.pdf> (Retrieved: August 2021).
- Gómez PL, Aguilar EC. 2016. Guía de Cultivo de la Quinoa. Organización de las Naciones Unidas para la Alimentación y la Agricultura. Universidad Nacional Agraria La Molina. Lima, Perú. pp: 31–33. <https://www.fao.org/3/i5374s/i5374s.pdf> (Retrieved: August 2021).
- Gonzalez JA, Konishi Y, Bruno M, Valoy M, Prado FE. 2011. Interrelationships among seed yield, total protein and amino acid composition of ten quinoa (*Chenopodium quinoa*) cultivars from two different agroecological regions. *Journal of the Science of Food and Agriculture* 92: 1222–1229. <https://doi.org/10.1002/jsfa.4686>
- Hasegawa PM. 2013. Sodium homeostasis and salt tolerance of plants. *Environmental and Experimental Botany* 92: 19–31. <https://doi.org/10.1016/j.envexpbot.2013.03.001>
- INDECOPI. 2014. Compendio de normas técnicas peruanas: Quinoa y Cañihua. NTP 205.062.2014. Comisión de Normalización y de Fiscalización de Barreras Comerciales no Arancelarias. Lima, Perú. pp: 1–25.
- Jacobsen SE, Monteros C, Christiansen JL, Bravo LA, Corcuera JL, Mujica A. 2005. Plant responses of quinoa (*Chenopodium quinoa* Willd.) to frost at various phenological stages. *European Journal of Organic Chemistry* 22 (2): 131–139. <https://doi.org/10.1016/j.eja.2004.01.003>
- Jacobsen S. 2003. The worldwide potential for quinoa (*Chenopodium quinoa* Willd.). *Food Research International* 19: 167–177. <https://doi.org/10.1081/FRI-120018883>
- Jacobsen SE. 2017. The scope for adaptation of quinoa in northern latitudes of Europe. *Journal of Agronomy and Crop Science* 203 (6): 603–613. <https://doi.org/10.1111/jac.12228>
- Katwal TB, Bazile D. 2020. First adaptation of quinoa in the Bhutanese mountain agriculture systems. *PloS ONE* 15 (1): 18. <https://doi.org/10.1371/journal.pone.0219804>
- Mujica A, Izquierdo J, Pierre JM. 2001. Origen y descripción de la quinoa. *In: Ancestral cultivo andino, alimento del presente y futuro. Mujica A, Jacobsen S, Izquierdo J, Pierre JM. (eds.); FAO/RLC: Santiago, Chile.* pp: 1–8.
- Nowak V, Du J, Charrondièrre UR. 2016. Assessment of the nutritional composition of quinoa (*Chenopodium quinoa* Willd.). *Food Chemistry* 193: 47–54. <https://doi.org/10.1016/j.foodchem.2015.02.111>
- WHO (World Health Organization). 2017. Climate-resilient water safety plans: managing health risk associated with climate variability and change. Geneva, Switzerland. <http://apps.who.int/iris/bitstream/10665/258722/1/9789241512794-eng.pdf?ua=1> (Retrieved: June 2022).
- Präger A, Munz S, Nkebiwe PM, Mast B, Graeff-Hönninger S. 2018. Yield and quality characteristics of different quinoa (*Chenopodium quinoa* Willd.) cultivars grown under field conditions in southwestern Germany. *Agronomy*. 8 (10): 197. <https://doi.org/10.3390/agronomy8100197>
- Rojas W, Pinto M, Alanoca C, Gómez LP, León-Lobos P, Alercia A, Diulgheroff S, Padulosi S, Bazile D. 2015. Estado de la conservación *ex situ* de los recursos genéticos de Quinoa. *In: State of the Art on Quinoa around the World in 2013. Bazile D, Bertero HD, Nieto C. (eds.); Chap. N° 1.5. FAO/CIRAD: Rome.* pp: 56–82. <https://www.fao.org/3/i4042e/i4042e.pdf> (Retrieved: July 2021).
- SAS Institute Inc. 2012. Statistical Analysis System User's Guide. SAS Institute, Inc. Cary, NC, USA. 956 p.

- Tan M, Temel S. 2017. Studies on the adaptation of quinoa (*Chenopodium quinoa* Willd.) to eastern Anatolia Region of Turkey. *Agrofor-International Journal* 2 (2): 33–39. <https://doi.org/10.7251/AGRENG1702033T>
- Tan M, Temel S. 2018. Performance of some quinoa (*Chenopodium quinoa* Willd.) genotypes grown in different climate conditions. *Turkish Journal of Field Crops* 23 (2): 180–186. <https://doi.org/10.17557/tjfc.485617>
- Tapia M. 1997. Cultivos andinos subexplotados y su aporte a la alimentación (2a Edición). Organización de las Naciones Unidas para la Agricultura y la Alimentación. Santiago, Chile.
- Thiam E, Allaoui A, Benlhabib O. 2021. Quinoa productivity and stability evaluation through varietal and environmental interaction. *Plants* 10 (4): 714. <https://doi.org/10.3390/plants10040714>
- Valenzuela ARN, Mita GT, Zapana FEY, Quilla DC, Miranda RA, Mita UJC. 2015. Efecto de la germinación y cocción en las propiedades nutricionales de tres variedades de quinua (*Chenopodium quinua* Willd). *Revista de Investigaciones Altoandinas* 17 (2): 169–172.
- Zeglin LH, Bottomley P, Jumpponen A, Rice CW, Arango M, Lindsley A, McGowan A, Mfombep P, Myrold DD. 2013. Altered precipitation regime affects the function and composition of soil microbial communities on multiple time scales. *Ecology* 94 (10): 2334–2345. <https://doi.org/10.1890/12-2018.1>
- Zurita-Silva A, Fuentes F, Zamora P, Jacobsen SE, Schwember AR. 2014. Breeding quinoa (*Chenopodium quinoa* Willd.): potential and perspectives. *Molecular Breeding* 34: 13–30. <https://doi.org/10.1007/s11032-014-0023-5>