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Agronomic and Productivity Performance for Quinoa Genotypes in an Agroecological and Conventional Production System

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Abstract

The objective of this research was to evaluate the agronomic performance and productivity of sixteen genotypes of *Chenopodium quinoa* cultivated in agroecological and conventional production systems. The evaluations were carried out, based on agronomic characteristics and yields of sixteen C. quinoa genotypes, grown in two simultaneous experiments, in an agroecological production and a conventional production system carried out at the town of Entre Rios do Oeste, Paraná, Brazil in the harvest 2015/16. Each experiment was composed of three replicates, following the randomized block design. Number of plants in flowering, number of plants per linear meter, height of insertion of the first panicle, number of days for maturation and productivity were the parameters evaluated. The data were submitted to statistical analysis with the aid of the GENES computational application. Genotype Q13-24 showed a more suitable production for the conventional production system. While the genotype Q13-01, presented the increase of productivity, being more indicated to the system of agroecological production. The characteristics height of plant flowers (HPF) and height of insertion of the first panicle (HIP) had higher values when the plants were cultivated in a conventional system. The number of plants per linear meter (NPLM) was higher in the agroecological crop, when compared to conventional cultivation. The same quinoa genotype can behave differently depending on the area management, being a productivity and the genotype cycle depends on the production system and the genotype used.

Keywords

Chenopodium quinoa, Cultivation Methods, Genotypic Adaptability,

Genetic Breeding

1. Introduction

Quinoa (*Chenopodium quinoa* Willd), also called quinoa is a crop known by its huge environmental adaptability and for its high nutritional value. Annual plant, pseudo-cereal, pseudo-oleaginous [1], belonging to the Amaranthaceous family, Chenopodiaceous subfamily [2], with huge grain importance, is largely cultivated in South America in countries such as: Bolivia, Peru, Ecuador, Colombia, Chile and Argentina [1] [3] [4].

Recently it was discovered by the scientific community, due to its high biological value for food; its grain is rich in proteins with an equilibrated amino acid profile that is essential to human nutrition [5] [6] [7] [8] and without gluten. It can be used in animal nutrition, due to its high energy value and protein content, good palatability and digestibility for animals [9].

In the 1990s, as a way to diversify the grain production system, the crop was introduced in Brazil, initially in the Brazilian cerrado then to another biome [10]. Some problems have been faced for large-scale cultivation of quinoa in the different regions and states of the country, for example, the high variability of environmental conditions of the country and the cultivation systems used [11]; for this reason, studies aimed at genotypes adaptation as well as different cultivation methods are necessary to high quality production of grains and with a satisfactory crop yield [12].

The state of Parana presents high potential of agricultural production; with emphasis to the cultivation of corn and soybean [13], the quinoa crop, can be one alternative of grain production in the off season, favoring crop rotation management. The search for genotypes, more adapted to different regions and conditions of the state of Parana [14] is important to the consolidation of this crop. [7] [15] reported that the interaction genotype-environment and the cultivar variability reflect the heterogeneity of the genetic material, making it possible to identify promisor materials and to indicate adapted genotypes [14].

Conventional agriculture where the focus is the monoculture in large areas, intensive use of soluble fertilizers, chemical pest control, diseases and weeds, high yield and maximum agronomic performance of the cultivated plants [16], is very different from the organic/agroecological agriculture, which seeks to be self-sustain, trying to eliminate the need of external inputs in the property, and manage the soil as a living organism, optimum yield instead of maximum, crops consortium, pests, diseases and weeds' biological and environmental control, use of fertilizes of slow liberation less soluble, the non-use of pesticides that will pollute the environment once one of its pillars is to have allied production with environmental conservation [17] [18] [19].

Because they present many disparities physiologically, as management and cultural practices, the use of equal plants in both production systems, can compromise the adequate development of cultivars obtained from the conventional breeding [20] [21], thus justifying studies of cultivars adapted to differentmanagements and production systems.

In the case of quinoa plants, the variability of the agronomic and productive responses is related to the site and cultivation area [7]; therefore, establishing the existent association between cultivars and production systems is important to adaptation and obtaining of productive cultivars to different cultivation environments [22] [23].

Therefore, the objective of this research was to evaluate the agronomic performance and productivity of sixteen genotypes of *Chenopodium quinoa* cultivated in agroecological and conventional production systems.

2. Material and Methods

The experiment was conducted in the crop years of 2015/2016, in the town of Entre Rios do Oeste, Parana, Brazil under the geographical coordinates of 04˚14' west longitude and 34˚14' south latitude, with an altitude of 260 m. The average annual temperature varies from 17˚C to 19˚C and the average annual rainfall for the region is from 1600 to 2000 mm [24], the local soil is classified as Eutroferric Red Latosol, of very clayey texture and good drainage [25].

During the period of conduction of the experiment the meteorological information represented in **Figure 1** was detected.

Were conducted two experiments simultaneously, one in an agroecological area and the other with a conventional production system. Plants were sowed in October with a density of 400.000 plants per hectare. For the experiment in the agroecological area, the managements applied were: soil preparation with a plowing, two harrowing, and base fertilization of 250 kg·ha^{-1} of worm humus, one weeding, at the moment that the plants had three completely expanded

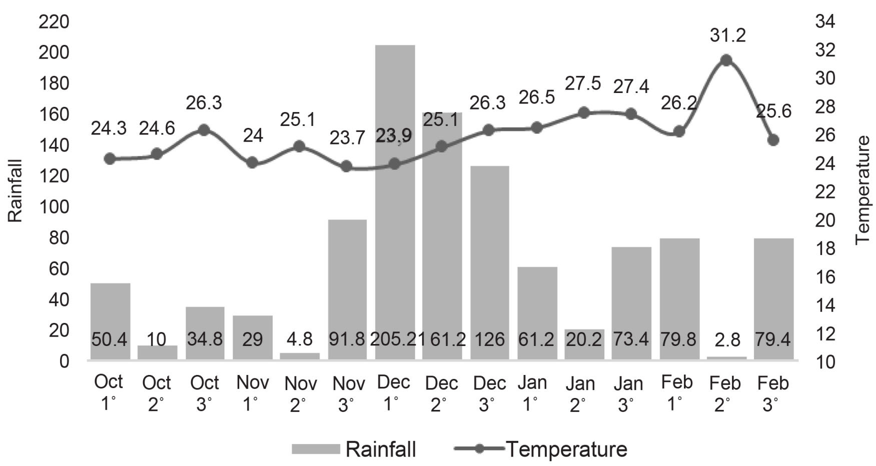

Figure 1. Rainfall data accumulated every ten days in millimeters (mm) and average temperature in degrees Celsius (˚C) between October 1st, 2015 and February 28, 2016. Source: Automatic meteorological station of Entre Rios do Oeste.

leaves and other when the plants were beginning to bloom. In addition, was applied neem oil at 60 ml·ha^{-1} to prevent pests at the time of flowering.

In the experiment implanted in the conventional cultivation area, was used the direct seeding on straw, in the base fertilization was applied 250 kg·ha^{-1} of the commercial formula NPK 02-20-20, during the seeding. A weeding was carried out at the moment that the plants had three expanded leaves and one application of the commercial product Engeo Pleno (150 ml·ha^{-1}) at flowering to control bed bug and caterpillar present in the area.

The experimental design was randomized blocs (RB) with three replicates and sixteen genotypes of C. quinoa. The genotypes used came from previous selections in conventional areas carried out within the Quinoa Breeding Program of UNIOESTE, from populations of Quinoa Real, Cherry Vanilla, Brilliand Rainbow and Quinoa Orange. The genotypes used were: Q12-23, Q13-01, Q13-02, Q13-03, Q13-04, Q13-06, Q13-07, Q13-10, Q13-17, Q13-18, Q13-20, Q13-21, Q13-24, Q13-31, Q seleção-1 and Q2014.

The plots of each experiment constituted of five lines of 5 meters and spacing between lines of 0.5 m. Were considered as useful plot the three central lines, leaving 0.5 m on the sides of each plot for border. Totalizing 6.0 m^2 of useful area in each plot.

During the crop development, in both systems, were evaluated the number of days for flowering (NDF), height of flowering plants (HFP), number of plants per linear meter (NPLM), height of insertion of first panicle (HIP), number of days for maturation (NDM), and productivity (PRO).

For determination of NDF, it was considered the moment in which approximately 50% of the plants from the useful plot had at least one open flower in the panicle. The NPLM was stipulated counting the quantity of plants per linear meter of the useful area of the plot at the time of harvest, being performed three measurements inside of each plot.

The HFP was evaluated from the measurement of ten plants at random within the useful area of the plot, being measured from the soil surface until the superior extremity of the plant. This procedure was performed at flowering tim and at the maturation. To AIP, at the time of maturation was measured the distance between the soil surface and the beginning of the presence of seed of the first panicle was measured.

In order to determine NDM, the period between the emergence (in average six days after seeding) and the moment that approximately 95% of the plants of the useful plot presented mature seeds was considered. The harvest of the experiment was carried out according to the physiological maturation of each genotype used. After harvested the materials were treshed, cleaned and weighed for PRO determination.

The data were submitted to the normality and homogeneity of variances test and, afterwards, the conjunct variance analysis, and when necessary, the Tukey test was performed, with a 5% probability of error. The analysis was performed with the Genes computational application [26].

3. Results and Discussion

In the conjunct variance analysis (**Table 1**), is possible to verify significant differences among genotypes to NPLM and NDM. There was a significant difference to the production systems to HFP, NPLM, HIP and NDM.

The effects over the analyzed characteristics express high genetic variability of this crop [7] [27], originated from the Andes mountain region, which presents extreme edaphoclimatic conditions and, because of this, elevated levels of tolerance to adversity and environmental variation on its genotypes, which respond differently to some managements, such as nitrogen fertilization, irrigation and sowing time [9] [14].

For the majority of the agronomic performance characteristics of the evaluated quinoa plants (**Table 1**), there was no interaction effect between genotype (G) and production system (PS) indicating that the agronomical performance does not suffer differentiated interference between the genotypes and production systems used.

There was a significant effect of the interaction between (G) and (PS) to the characteristics NDM and PRO (**Table 1**), thus evidencing that different production systems and managements applied to the same culture, influence in the development cycle. According to [3] [10], the same genotype can behave in different ways, according to the management of the cultivation area, increasing or decreasing the production, in a longer or shorter period of time.

Further studies are necessary to detect which genotypes are most suitable for certain crops systems or managements, allied to other environmental conditions

Table 1. Summary of the analysis of joint variance for number of days for flowering (NDF), height of flowering plants (HFP), number of plants per linear meter (NPLM), height of insertion of the first panicle (HIP) and number of days for maturation (NDM) and Productivity (PRO), evaluated in sixteen genotypes of *Chenopodium quinoa* (G) cultivated in an agroecological and conventional production system (A) in Entre Rios do Oeste, Paraná, Brazil, crop year 2015/2016.

Variation Factor	GL	Square means of parameters					
		NDF	APF	NPL	AIP	NDM	PRO
Genotypes (G)	15	7.47^{ns}	0.02^{ns}	222.06**	0.015^{ns}	12.62**	163.05^{ns}
Production system (A)	1	14.26^{ns}	3.42**	1380.17*	1.14**	17.5104**	21,706.25**
Interaction A × G	15	6.04^{ns}	0.01^{ns}	107.52^{ns}	0.01^{ns}	9.5770**	278.18**
Residue	60	3.63	0.02	84.65	0.01	0.5069	104.15
Average		55.97	1.19	19.19	0.71	77.5520	824.96
VC (%)		3.40	10.39	47.95	14.09	0.92	39.12

*Significant at 0.05; **Significant at 0.01; ^{ns}Non-significant, by the F test.

that quinoa is subjected to. This study evidences the need to select quinoa genotypes in each production condition and not only at each site of implantation.

When compared only the different production systems (Table 2), the characteristics HFP and HIP presented higher values when the plants were cultivated in the conventional production system. The NPLM was lower in the conventional cultivation if compared to the agroecological cultivation (Table 2). These results are justified by the way of soil preparation in the agroecological area in the sowing, which generated favorable conditions to higher emergence and, consequently, higher number of plants per linear meter in this production system. Studies performed with creole corn [28], in similar conditions, found divergent results, the crop system does not interfere in the plants emergence, only the evaluated genotype, in this study both the genotype and cultivation system interfered in the NPLM.

The lower NPLM, in the conventional cultivation may have helped the plants to present higher growth, reaching higher HPF, consequently, higher HIP, because the small number of plants causes a smaller competition for water and

Table 2. Average number of days for flowering (NDF), height of flowering plants (HFP) (m), number of plants per linear meter (NPLM) and height of insertion of the first panicle (HIP) of *Chenopodium quinoa*, cultivated at Entre Rios do Oeste, Parana, Brazil in the crop year of 2015/2016 in area of agroecological and conventional production system.

Production system	NDF	HFP (m)		NPLM		HIP (m)	
Agroecological	55.58	1.00	b	22.97	a	0.60	b
Conventional	56.35	1.37	a	15.39	b	0.82	a
Genotypes	NDF	HFP (m)		NPLM		HIP (m)	
Q12-23	56.5000	1.2400		30.3333	a	0.7100	
Q13-01	57.2000	1.2033		15.6666	ab	0.7683	
Q13-02	57.7000	1.1583		25.3333	ab	0.7433	
Q13-03	55.7000	1.1466		11.1666	b	0.7066	
Q13-04	55.7000	1.1566		20.3333	ab	0.6733	
Q13-06	56.2000	1.2216		13.3333	ab	0.7450	
Q13-07	54.7000	1.1333		19.6666	ab	0.7700	
Q13-10	55.7000	1.1533		25.6666	ab	0.7616	
Q13-17	56.5000	1.1516		11.0000	b	0.5833	
Q13-18	56.5000	1.1933		24.5000	ab	0.7383	
Q13-20	54.3000	1.1783		13.1666	ab	0.6683	
Q13-21	53.8000	1.2733		16.8333	ab	0.6800	
Q13-24	57.0000	1.3033		13.3333	ab	0.6983	
Q13-31	57.5000	1.1300		20.1666	ab	0.7466	
Q seleção-1	55.5000	1.2866		27.3333	ab	0.7383	
Q2014	55.2000	1.1266		19.1666	ab	0.6633	

*Averages followed by uppercase letters in the row and lowercase in the column do not differ statistically by the Tukey test ($p < 0.05$).

nutrients, allowing a better development condition, as observed by [29] [30].

The analysis of the different genotypes evidences that the Genotype Q12-23, presented (**Table 3**), NPLM superior than the others, 30 plants per linear meter in average, differing statistically of the genotypes Q13-03 and Q13-17, which had only 11 plants per linear meter. The difference between genotypes may be related to the low vigor of some used seeds, according to [28] the decrease of vigor, even with elevated germination in the field, directly influences in the emergence and initial development of plants, reducing the final population and final yield of the plants [15] [29].

The NDM was lower than those determined by [31] (**Table 3**) with a cycle varying from 80 to 150 days, these values are dependent on the variety and environmental conditions.

According to the physiological maturity the quinoa cam be classified as late (over 180 days), semi late (150 to 180 days), semi early (130 to 150 days) and precocious (less than 130 days) [32]. Thus, the genotypes evaluated in this study are classified as precocious, since the number of days for maturation were maximum of 80 days. Such results disagree with those found by [33], which found cycles varying from 128 to 187 days. According to [3], the precocious cycle of

Table 3. Average values to number of days to maturation (NDM) of sixteen genotypes of *Chenopodium quinoa*, cultivated at Entre Rios do Oeste, Parana, Brazil in the crop year of 2015/2016 in area of agroecological and conventional production system.

Genotypes	Conventional Production System	NDM	Agroecological Production System	
Q12-23	80.00	Aa	76.00	Bd
Q13-01	74.00	Bd	77.00	Abcd
Q13-02	74.00	Bd	80.00	Aa
Q13-03	77.00	Bc	80.00	Aa
Q13-04	77.33	Abc	76.33	Ad
Q13-06	80.00	Aa	80.00	Aa
Q13-07	80.00	Aa	80.00	Aa
Q13-10	76.66	Ac	76.66	Acd
Q13-17	76.66	Ac	77.00	Abcd
Q13-18	79.33	Aab	77.00	Bbcd
Q13-20	77.33	Abc	77.00	Abcd
Q13-21	77.66	Abc	77.00	Abcd
Q13-24	74.00	Bd	78.66	Aabc
Q13-31	78.66	Babc	80.00	Aa
Qseleção-1	74.00	Bd	76.00	Ad
Q2014	77.33	Bbc	79.00	Aab
DMS	2.08		1.16	

*Averages followed by uppercase letters in the row and lowercase in the column do not differ statistically by the Tukey test ($p < 0.05$).

quinoa is necessary so there is an alternative in the off season and in the rotation of crops such as corn and soybean.

When compared to the agroecological and conventional production systems (**Table 3**), the NDM of the genotypes Q12-23, Q13-01, Q13-02, Q13-03, Q13-24, Q13-31, Qseleção-1 and Q2014 were statistically different among themselves for both systems evaluated. The genotypes Q13-06 and Q13-07 behaved in the same way in relation to the NDM for both systems, completing their cycle in 80 days.

When the systems are individually analyzed, the genotypes with the highest NDM are Q12-23, Q13-06, Q13-07, with average of 80 days and the genotypes Q13-01, Q13-02 e Q13-24 presented the lowest NDM, 74 days to complete their growing cycle. To the agroecological system, the genotypes Q12-23 and Q13-18 presented lowest NDM with an average of 76.5 days to complete their growing cycle. For the other genotypes, the lowest NDM were found in the conventional system. These results are in accordance with the one proposed by [34], which evidences a reduction in the cultivation cycle with the increasing use of doses of nitrogen fertilization in a soluble form, when compared to the use of nitrogen in the vermicompost form. The agroecological production system has as premise the non-use of highly soluble fertilizers on its management system [17]. The kind of fertilize and the management may have interfered in the increase of NDM of the quinoa genotypes in the agroecological production system. These results evidence the existence of the interaction between the crop cycle with the production system adopted, since the same genotypes have different behavior in areas under conventional and agroecological management.

The productivity results for the sixteen genotypes submitted to two different production systems are presented at **Table 4**. There was a significant interaction for productivity, indicating a different behavior from the other genotypes in both production systems.

The productivity of the genotypes Q13-01 and Q13-02 did not differ statistically in the agroecological and conventional systems. For the other genotypes tested, the cultivation area influenced the productivity. The values found to the conventional system were superior to the ones found in the agroecological system, indicating higher adaptability of these genotypes to the conventional production system. This effect can be explained by the selection condition which these genotypes were submitted to, since they are results of four years of breeding in a conventional production system. This was the first crop where these genotypes were submitted to the agroecological production system in Brazil. The lowest NPLM in the conventional system (**Table 2**), was compensated by the quinoa plants, because as it happen with soybean, it has high plasticity of its production components, producing more branches, increasing yield when the population per linear meter is lower [28] [33] [35].

The average productivity values were 1.31029 kg·ha^{-1} in the conventional production system and 422.66 kg·ha^{-1} in the agroecological. [14] in an experiment carried out in the state of Parana, Brazil, obtained average productivity of

Table 4. Productivity of sixteen genotypes of *Chenopodium quinoa*, cultivated at Entre Rios do Oeste, Parana, Brazil in the crop year of 2015/2016 in area of agroecological and conventional production system.

Genotypes	Productivity (kg·ha^{-1})			
	Conventional Area		Agroecological Area	
Q12-23	1.52762	Aab	100.90	Bb
Q13-01	834.00	Ab	1.19263	Aa
Q13-02	830.00	Ab	431.30	Aab
Q13-03	1.18950	Aab	71.52	Bb
Q13-04	1.56241	Aab	299.72	Bab
Q13-06	1.01641	Aab	125.66	Bb
Q13-07	1.70637	Aab	599.98	Bab
Q13-10	990.16	Aab	235.05	Bb
Q13-17	1.58212	Aab	267.82	Bab
Q13-18	1.27808	Aab	325.62	Bab
Q13-20	1.39116	Aab	50.08	Bb
Q13-21	1.14816	Aab	85.16	Bb
Q13-24	1.86716	Aa	182.53	Bb
Q13-31	1.15991	Aab	152.00	Bb
Q seleção-1	1.77016	Aab	318.58	Bab
Q2014	1.24633	Aab	171.74	Bb
DMS	529.82		951.17	

*Averages followed by uppercase letters in the row and lowercase in the column do not differ statistically by the Tukey test ($p < 0.05$).

846 kg·ha^{-1}. Such results indicate the need for greater selection to increase this characteristic [3].

The lower values of productivity in the agroecological area may have occurred because this environment was in a transition process to the equilibrium of the productive system. It was the third year of use of the area with agroecological managements, in the beginning of the conversion process from a conventional area to an agroecological, its observed a productivity decrease, which increased with the establishment of the system [36] [37].

In the conventional area the genotype Q13-24 produced 1.867 kg·ha^{-1}, statistically differing only from the genotypes Q13-01 and Q13-02 which produced 834 and 830 kg·ha^{-1} respectively. Thus, the genotype Q13-24 is the best indicated to increase productivity, since its productive potential exceeded 834 kg·ha^{-1}, in the conventional system (**Table 4**).

For the agroecological area, the genotype Q13-01 produced 1.193 kg·ha^{-1}, differing from the nine genotypes (Q12-23, Q13-03, Q13-06, Q13-10, Q13-20, Q13-21, Q13-24, Q13-31 and Q2014), which presented productivity varying from 50 to 235 kg·ha^{-1}. Thus, the genotype Q13-01 would be the best candidate to increase productivity in the agroecological production system (**Table 4**).

These results demonstrate that there are genotypes better adapted to the agroecological condition and genotypes that are better adapted to the conventional condition. The same genotype may behave differently according to the management of the cultivated area, so, it is necessary to consider the planting site and the management adopted prior to choose the genotype.

4. Conclusions

It was concluded that the height characteristics of plants at flowering and height of insertion of the first panicle, had higher values when the plants of *Chenopodium quinoa*, were cultivated in a conventional production system, as opposed to the number of plants per linear meter.

By the verification of the interaction between genotypes and production system, for the productivity characteristics and number of days for maturation, it was verified that the same genotype can behave distinctly when cultivated in an agroecological or conventional way.

Genotype Q13-24 was the best recommended for cultivation in conventional production system, because it obtained the highest productivity in this system, while the genotype Q13-01 was the best indicated for the system of agroecological production, increasing productivity in this system.

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