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Plant growth and physiological quality of quinoa (*Chenopodium quinoa* Willd) seeds grown in Southern Rio Grande do Sul, Brazil

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Abstract

Quinoa (*Chenopodium quinoa* Willd) an annual grain crop belonging to the Amaranthacea family is the only vegetable food that contains all essential amino acids, micronutrients and vitamins. The study aimed to evaluate the performance, growth and seed physiological quality of two genotypes of quinoa in Southern Rio Grande do Sul region. The cultivar BRS Piabiru and one breeding line were grown at green house. The design was completely randomized with four replications and five harvest times during the vegetative stage of the crop. The variables were shoot length, number of leaves, leaf area index, dry matter of aerial parts, dry matter of root and total dry matter of plant. It was concluded that the line and BRS Piabiru have slow initial growth in the first 30 days and strong growth up to 120 days. The breeding line and commercial cultivar showed the same potential for seed production in the temperate climate of this region.

Keywords: quinoa; leaf area; physiological index.
Abbreviations: CAPES_ Coordination of Improvement of Higher Level Personnel; A_c_ area occupied; CNPq_ National Council of Scientific and Technological Development; DAE_ Days After the Emergency; EMBRAPA_ Brazilian Agricultural Research Corporation; (ESI)_ Emergence speed index; F_ correction factor; L_ length; LA_ leaf area; L_a_ leaf area; LAI_ leaf area index. LL_ longitudinal length; TL_ transverse length;

Introduction

Quinoa (*Chenopodium quinoa* Willd) is an annual grain crop belonging to the Amaranthacea family, native to the Andes and domesticated by the native people of the region.
In Brazil, quinoa (*Chenopodium quinoa* Willd) was introduced in the 1990s aiming to diversify the production system in the Cerrado region (Spehar and Souza, 1993). In this context, the commercial exploitation of this crop constitutes an important instrument to aid the diversification and income increase in several regions of the country.
There are reports of commercial crops in Brazil, specifically in the Central-West region. However, there are studies seeking to evaluate the viability of its cultivation not only in the Brazilian Cerrado, but also in southern states (Vasconcelos et al., 2012; Vasconcelos et al., 2013).
Quinoa (*Chenopodium quinoa* Willd) is the only vegetable food that has all essential amino acids, micronutrients and vitamins. At the same time, it has a high capacity of adaptation to different environments, due to good tolerance to water deficit, saline soils and low fertility. It may be cultivated in altitudes from up to four thousand meters, being able to withstand temperatures between -8°C and 38°C (FAO, 2009). The nutritional composition of quinoa seeds (*Chenopodium quinoa* Willd) varies among ecotypes due to their high genetic variability, as well as environmental differences in the Andean region (Repo-Carrasco-Valencia et al., 2010). The high beneficial nutritional properties of quinoa seeds and the easy adaptation of the plant to different environments make quinoa (*Chenopodium quinoa* Willd) an excellent choice for crop diversification. However, Rocha (2008) pointed out that the commercial exploitation of this crop may be limited by environmental factors due to the great influence they cause in its yield, where the most important is water deficit and occurrence of low temperatures, causing productivity decrease. The knowledge on the behavior of different genotypes of quinoa (*Chenopodium quinoa* Willd) is of great importance, when subjected to the cultivation conditions of Southern Brazil. Thus, knowledge on the growth characteristics of this crop is an important tool for adopting practices aiming to minimize the deleterious effect caused by climatic variations. Aumonde et al. (2011), studied some growth variables and plant responses under certain management conditions in different environmental conditions. Growth analysis

provides basic information on crop production without the need for sophisticated equipment (Falqueto et al., 2009). It is a low-cost analysis that basically uses data on dry matter and leaf area (Lopes et al., 2009). According to Taiz and Zeiger (2009), evaluations should be made along the crop cycle, observing plant leaf area and the phytomass produced.

For a proper plantation of this crop in a certain region, it is important that it presents capacity to produce high quality seeds in addition to its adaptation during development. For production of high quality seeds, the effects of genotype are a determinant factor. However, the effects caused by the cultivation environment and the interaction between genotype and environment are pronounced (Bornhofen et al., 2015). Thus, it is of great importance to study the interaction between the genotype and the cultivation environment, evidencing probable effects on the physiological quality of the seeds produced.

The objective of this study was to evaluate the performance of two genotypes of quinoa (*Chenopodium quinoa* Willd) as to plant growth and physiological seed quality in the southern region of Rio Grande do Sul.

Results

The results obtained for shoot length did not show effects of cultivar, but there was a significant effect for collection time, with a coefficient of determination (R^2) of 0.95 (Fig 2a). We observed that the growth up to 30 days after emergence (DAE) was slow in comparison to the other periods. Between 30 and 90 days after emergence, the growth was more intense, and from 90 days, the growth became slow again. The decrease in shoot growth after 90 days of emergence may be justified by the stage of development of the plant due to the fact that the plant is at the reproductive stage in this period. Therefore, much of the photoassimilates are destined to the development and accumulation of seed reserves.

The number of leaves showed a significant interaction between cultivation and harvesting time (Fig 2b). The cultivar BRS Piabiru was increased up to 120 days after emergence, presenting around 100 leaves at the end of the cycle, with a coefficient of determination (R^2) of 0.902. However, the line showed a cubic behavior (R^2= 0.99) from 90 days after emergence. There was an intense increase in the number of leaves, reaching approximately 320 leaves 120 days after emergence. This can be attributed to genetic effects. Leaf area index was not affected by genotype, presenting a quadratic behavior and a coefficient of determination (R^2) of 0.97 (Fig 2c). During the first 30 days after emergence, the increase in leaf area index was slow, which corresponded to the plant establishment. Between 30 and 60 days, there was a slow increase in this parameter, and from 60 days, there was a marked increase in leaf area index. It is noteworthy that the difference between genotypes for number of leaves was not found for leaf area index. This result may be attributed to specific leaf area, whereas the cultivar BRS Piabiru presented a lower number of leaves, there was a compensation of the index with a greater leaf area. For shoot dry matter, we observed significant effects for the source of variation harvest time, adjusting to a quadratic model with a coefficient of determination (R^2) of 0.99 (Fig 2e). The accumulation of dry matter up to 30 days after emergence was slow. This was because of the low number of leaves and leaf area index presented during this period; thus, resulting in a reduced production of photoassimilates.

After the initial establishment period, the accumulation of dry matter was accentuated. During the other periods, this effect may be associated with increase in number of leaves, flowering, stem structure and branching, and seed development.

Total dry matter (Figure 2d) was not affected by genotype, as occured in different cultivars. Only the effects of development period were relevant. Total dry matter presented a coefficient of determination of 0.96. At 30 days after emergence, during the crop establishment, the accumulation of dry matter was very low. After this period, there was an appreciable increase, and at 60 days after emergence, there was an intense accumulation of dry matter.

Root dry matter presented a behavior similar to the previously described variables (Fig 2f). For the cultivar BRS Piabiru, there was a linear growth, with an R = 0.59. However, for the line, the curve had a quadratic behavior (R = 0.79). The line presented a small growth of the root system up to 30 days after emergence. Between 30 and 60 days after emergence, there was a slight increase in growth. However, after 60 days after emergence, there was intense development of this organ.

We observed that, in the period of crop establishment (up to 30 DAE), there was a slight increase in the variables related to plant growth. Thus, the initial slow development of the culture was evidenced. However, after the initial period, the growth was expressive. A similar result was found by Spehar (2006), reporting that, in the first thirty days the culture presents a slow development, but after this period it presents an intense growth and may reach two meters in height. According to Aumonde et al. (2011), the slow initial growth of mini watermelons may be attributed in part to a low water and nutrient absorption and to the small leaf area during the initial period of establishment. Thus, plant growth is affected primarily by photosynthesis and water and nutrient absorption (Carvalho et al., 2009).

In this sense, special care should be taken during the first weeks after emergence. Bhargava et al. (2006) reported that quinoa should receive attention due to competition in the first weeks after emergence because it presents a slow initial growth.

By analyzing the data concerning leaf area index, total dry matter and shoot length, there is a relationship between the factors. Thus, with an increasing leaf area index, the other variables are positively influenced. This may be attributed to a consequent increase in the photosynthetic activity caused by an increase in leaf area. In a study on corn crops, Lopes et al. (2009) observed that the increase in leaf area index culminates a high growth rate of this crop.

However, from 60 days after emergence, shoot length and leaf area index showed a distinct behavior, while one tends to stabilization the other continues to present a remarkable increase. This is a consequence of the crop development stage, which corresponds to the period of floral differentiation and; therefore, the beginning of the reproductive stage. At this stage, there is a change in the source-drain relationship. Growth tends to be a secondary activity and the priority tends to be the development of

Table 1. Germination, emergence and emergence speed index of seedlings from quinoa seeds of a lineage and a cultivar.

Genotype	Germination (%)	Emergency (%)	IVE
Lineage	64 b	61a	14.31 a
BRS Piabiru	82 a	63 a	13.46 a
CV (%)	6.25	8.19	10.46

The averages followed by the same letter in the column do not differ by the Tukey test at a probability level of 5%.

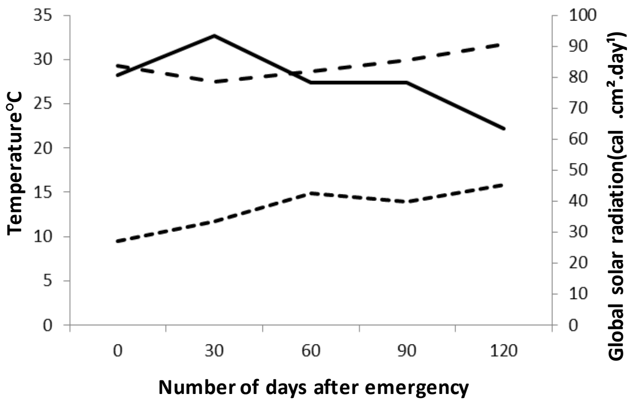

Fig 1. Maximum, minimum (dashed line) and solar radiation (continuous line) temperatures during the quinoa growth period in the Pelotas region, Rio Grande do Sul.

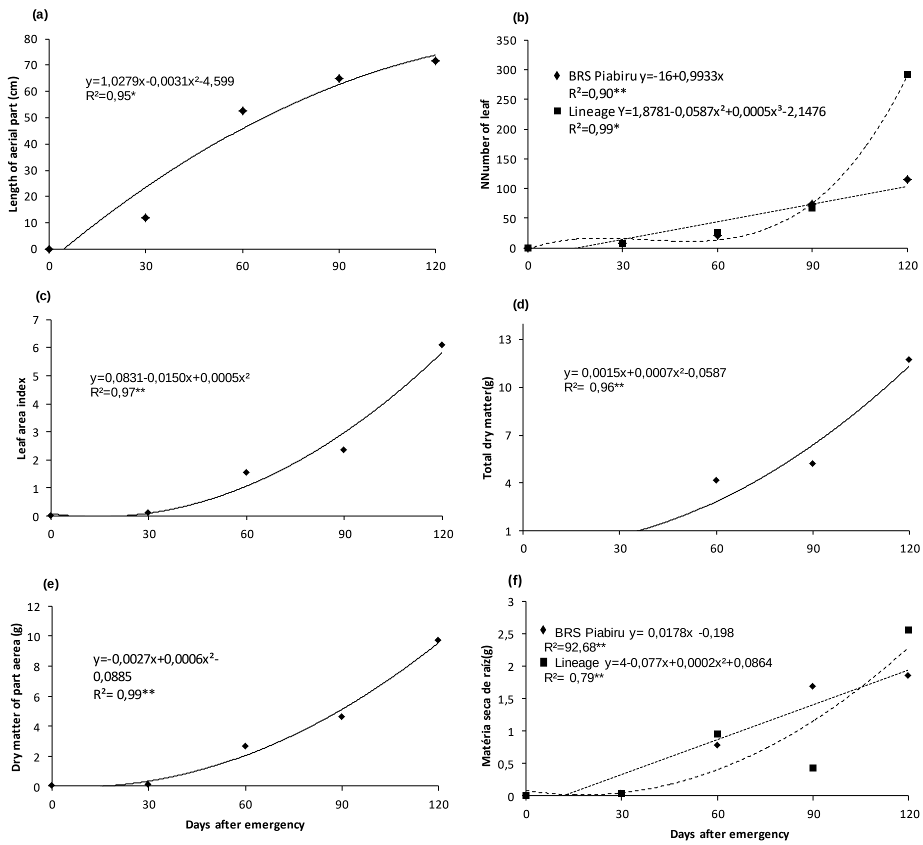

Fig 2. There should be a general legend. (A) Aerial part length, (B) Number of leaves, (C) Leaf area index, (D) Total dry matter, (E) shoot dry matter, (F) plants of a cultivar and a quinoa strain throughout the crop cycle.

reproductive organs and the later accumulation of reserves in seeds. However, during this period, the relationship between leaf area index and shoot dry matter is still maintained, but vegetative growth is lower than during previous periods. This increase in shoot dry matter may be attributed to the accumulation of reserves in reproductive organs. According to Oliveira et al. (2013), the accumulation of dry matter is more intense near the reproductive period. The great heterogeneity in the quinoa culture is worth noting along with lack of uniformity for both height and cycle.

Discussion

We observed that shoot length did not exceed 80.0 cm among individuals, although Spehar and Santos (2002) described the average height of plants of the cultivar BRS Piabiru is 190 cm. The sowing at times that provide the occurrence of low temperatures during the crop vegetative stage causes smaller heights during the development of plants (Vasconcelos et al., 2012). In this study, such a relationship was found, since we observed the occurrence of low temperatures during the vegetative stage (Fig 1), resulting in lower plants.

By observing the data presented in Table 1, it can be noted that there is a significant difference between the genotypes as for germination. Therefore, the line presented a significantly lower germination than the Brazilian cultivar. This may be attributed to a marked occurrence of abnormal seedlings in the germination test.

For emergence speed index and seedling emergence in field (Table 1), we verified that there are no differences between the genotypes for these variables. Thus, it is evident that there are no differences between the vigor of seeds produced by the cultivar and by the line. Thus, the high germination percentage of the cultivar BRS Piabiru in the germination test may be attributed to overestimation of the actual physiological quality in comparison with the results of emergence speed index and emergence in field tests.

The occurrence of a better seed lot performance when subjected to germination tests is due to the way that researchers conduct the test, since favorable conditions are offered for the germination process, a fact generally not found under normal field conditions.

By observing the growth characteristics along with the physiological quality of seeds produced by the different genotypes, we verified that they have similar characteristics. Thus, the line used has a performance similar to the cultivar BRS Piabiru, which presents an adaptation to the environmental conditions of the region.

Materials and Methods

The experiment was conducted in a greenhouse in a Pampa arch vegetation, and the analyses were conducted in the Laboratory of Seed Analysis at the Federal University of Pelotas, located at 31°52' S, 52º21' W and altitude of 13 m. The experiment took place from June to October 2015.

Data on global solar radiation and temperature during crop development are shown in Fig 1. The air temperature was obtained by a thermohygrograph recording data weekly installed in a meteorological shelter at a height of 1.5 m from the ground, located in the center of the greenhouse.

Plant material

We used seeds of two genotypes of quinoa (*Chenopodium quinoa* Willd) with a different origin; the first is the only cultivar registered in Brazil, called BRS Piabiru, and the second is a lineage of Andean origin not adapted to the climate temperate. Seeds were sown in polyethylene pots filled with soil from the region. As base fertilization, we used a dose of 75 kg*ha^{-1} of phosphorus and 75 kg*ha^{-1} of potassium; as a cover fertilization, we used 45 kg*ha^{-1} of nitrogen.

Conduction of the experiment

After crop emergence, we collected plant samples every 30 days considering as the initial point the full emergence of seedlings, totaly five collections throughout the crop cycle. In each collection, we harvested nine lineage plants and nine cultivar plants. The means were obtained in triplicate, totaling 3 replications for each genotype. The observed variables were shoot length, number of leaves, leaf area index, shoot dry matter, root dry matter and total dry matter. The methodology used to evaluate growth traits is described below.

Shoot length − the plants were measured from the apical meristem up to ground level using a millimeter ruler, and the results expressed in centimeters.

Number of leaves **−** totally developed leaves were counted at each harvest time.

Leaf area index − the longitudinal and transverse lengths of all leaves in the plant were measured using the correction factor obtained by the formula of Benincassa (1988), resulting in the leaf area. Then, this value was divided by the area occupied by the plant canopy, and thus we obtained the leaf area index. We obtained different correction factors for each cultivar: for BRS Piabiru, 0.6079, and for Lineage, 0.5787.

LA=F(LLxTL), where F is the correction factor, C is the longitudinal length, L is the transverse length and LA is the leaf area.

$LAI=L_a/A_c$, where L_a is leaf area in square meters, A_c is the area occupied by the plant canopy in square meters, and LAI is leaf area index.

Shoot dry matter − after separated from the root, the plant shoot was placed in an oven at 70°C for 72 hours. Then, the weighing was performed on a precision scale, and the result was expressed in grams.

Root dry matter − after separated from the shoot, the plant root was placed in an oven at 70°C for 72 hours. Next, the weighing was performed on a precision scale, and the result was expressed in grams.

Total dry matter **−** after weighing the shoot and root dry matter, the individual sum was made for each plant, thus obtaining total dry matter.

For the evaluation of physiological quality, the seeds from the different cultivars were harvested at the end of the cycle. In order to estimate the quality of seeds produced, the following tests were performed:

Germination test − seeds were sown in Gerbox boxes on blotting paper moistened with distilled water using 2.5 times the paper weight in water volume. The test was conducted at a constant temperature of 25°C; the counting was performed seven days after sowing, and the result was expressed as percentage of normal seedlings. During germination test counts, abnormal seedlings, that is, seedlings that did not have the essential structures for development, were also evaluated and the result was expressed as percentage of abnormal seedlings.

Seedling emergence − four replications with fifty seeds each were sown in the soil of the region; the counting was performed seven days after sowing, and the result was expressed as percentage of emerged seedlings.

Emergence speed index (ESI) − the number of emerged plants was evaluated daily, and the formula proposed by Maguire (1962) was used to obtain this value.

Experimental design and statistical analysis

The experiment was established in a completely randomized design with a 2x5 factorial design, considering as sources of variation the two genotypes and the five harvest periods of plants, respectively. Data were submitted to regression analysis. For physiological quality, 15 replications were used. The obtained values were submitted to analysis of variance, and, if significant, they were compared using the Tukey test.

Conclusions

The quinoa lineage and the cultivar BRS Piabiru presented a slow initial growth during the first 30 days and a marked growth up to 120 days under the environmental conditions of the southern region of Rio Grande do Sul. The quinoa lineage and the cultivar BRS Piabiru presented a similar potential for seed production in the southern region of Rio Grande do Sul.

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