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Yield and viability of quinoa seeds as affected by planting arrangement

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Abstract

Quinoa has great capacity to diversify agricultural production, due to its characteristics as functional food, rich in protein and fibers, besides having drought tolerance and high phenotypic plasticity. The objective of this study was to evaluate the effects of population arrangements and crop year on seed production and physiological potential of BRS Piabiru quinoa cultivar. The experiments were conducted in the experimental area of the Plant Science Department of the Federal University of Ceará, at the Pici Campus, in Fortaleza, CE, Brazil, for two agricultural years (2014/2015 and 2015/2016) under irrigated regime. The treatments resulted from a 3x3 factorial scheme (3 spacings between rows: 20, 40 and 60 cm, and 3 planting densities within the row: 10, 15 and 20 cm), and these treatments were distributed in four randomized blocks. The physiological tests of the seeds were carried out in the seed laboratory of the same institution. The 1000-seed weight, M%, GSI, MGT, G%, accelerated aging, panicle length and yield were evaluated. The seeds produced in the different planting arrangements showed high physiological quality, and the agricultural year was determinant. Increasing planting density reduced panicle size and increased yield of quinoa during the two cycles.

Keywords: *Chenopodium quinoa,* planting density, pseudocereal, physiological quality

Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an annual herbaceous species with erect stem native to the Andean region (Colombia, Chile, Bolivia, Ecuador and Peru) and belonging to the family Amaranthaceae, subfamily Chenopodiaceae. It is a millenary crop in the region of origin and has been adapting to different edaphoclimatic conditions, being cultivated from sea level up to 3,800 m altitude, with cycle ranging from 80 to 150 days under the conditions of the Brazilian Cerrado, besides being tolerant to drought (Garrido et al., 2013; Spehar; Santos, 2002).

The species presents itself as an option to diversify Brazilian agriculture. Introduced in Brazil in the 1990s, it has been cultivated in the Cerrado in succession and in the off-season with annual crops such as soybean and corn under no-tillage, due to its high potential for phytomass production (Spehar; Trencenti, 2011).

Due to its properties, this grain crop has been demanded worldwide, aiming to reduce food insecurity, which has led to the expansion of its cultivation, including as an alternative to commercial crops (Spehar, 2007a).

There is variation in the nutritional components of quinoa, which may be due to the site or forms of planting or even to the cultivated variety (Balbi; Oliveira; Chiquito, 2014).

Attractive prices increase the interest of producers and researchers, as well as the search for technologies through research (Oliveira et al., 2013; Spehar & Rocha, 2009; 2010).

It is indispensable to use a population arrangement that, in addition to favoring cultural practices, results in maximum yield, low competition between plants and produces propagative material with high standards of quality and vigor, in order to avoid failures in the crop stand or the emergence of plants with low vigor (Marcos

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Filho, 2005).

Quinoa seeds deteriorate rapidly when they are in contact with high humidity, and they may lose viability still in the field in the period preceding harvest, when they are produced or stored in an environment with unfavorable air humidity (Parsons, 2012; Spehar et al., 2007b). Thus, the northeastern region of Brazil presents itself with a strong potential for seed production, due to its high temperatures and low relative humidity for most of the year, enabling the production of lots with high vigor.

In seed development, environmental conditions determine the level of embryonic and seed coat dormancy, and germination is conditioned to the presence of gibberellin and incubation temperature. Dormancy, on the other hand, is regulated by the production of abscisic acid, through variations in the thickness that covers the seed in response to the growth environment (CECCATO et al., 2011).

The objective of this study was to evaluate the effects of the combination of plant row spacing and planting density on the physiological potential of BRS Piabiru quinoa seeds subjected to irrigated cultivation during two agricultural years.

Material and Methods

The experiments were conducted in the Experimental Area of the Plant Science Department of the Federal University of Ceará, at the Pici Campus (3°44' South latitude, 38°33' West of Greenwich and 19.5 m altitude), in Fortaleza-CE, Brazil, from October 2014 to February 2015 (First Cycle) and from September 2015 to January 2016 (Second Cycle).

According to Köppen, the climatic classification of the region is Aw', which characterizes a rainy tropical climate. During the experimental period of the first planting cycle, it rained 146 mm in the area. The accumulated rainfall of the second cycle was 51.5 mm, and these precipitations were concentrated between December and January.

The soil of the experimental area is classified as *Argissolo Vermelho Amarelo* (Ultisol) (EMBRAPA, 2013). The chemical analyses of the soil of the experimental area were performed by randomly collecting soil samples at depths of 0-20 and 20-40 cm one month before each planting, and these samples were sent for analysis to the Soil Chemistry Laboratory of the Soil Science Department of the Federal University of Ceará (UFC), showing the characteristics present in Table 1.

Table 1. Chemical characteristics of the soil of the experimental area of the Plant Science Department, Pici Campus, Fortaleza, CE, Brazil, in the 0-20 and 20-40 cm layers of the profile prior to the installation of the experiments, first and second cycle, respectively, 2014 and 2015.

Chemical attributes – First cycle											
pH	Ca^{2+}	Mg^{2+}	K^{+}	Al^{3+}	Na^{+}	$H^{+}+Al^{3+}$	SB	CEC	P^{5+}	V	OM
(1:2.5 H_2O)	$cmol_c\ dm^{-3}$								$mg.dm^{-3}$	%	
5.8	1.00	0.80	0.13	0.10	0.11	1.16	2.00	3.20	10	63	0.76
5.9	1.00	0.80	0.12	0.15	0.17	1.82	2.10	3.90	3	54	0.58
Chemical attributes – Second cycle											
6.5	1.80	0.80	0.21	0.00	0.09	0.99	2.90	3.90	11	74	0.75
6.5	1.20	0.50	0.23	0.00	0.23	1.16	2.20	3.30	4	67	0.46

Source: Soil Chemistry Laboratory, Soil Science Department/CCA/Federal University of Ceará.

The experimental design was in randomized blocks with four replicates. The plots were composed of five rows of three meters in length each and their width varied as a function of the spacing between planting rows; the three central rows corresponded to the useful area of the plot, disregarding 0.5 m from the ends of these rows. The experiment occupied a total area of 273 m^2, and each block consisted of 63 m^2.

Following recommendations for soil preparation and correction, quinoa of the cultivar BRS Piabiru was sown in a 3x3 factorial scheme (three spacings between planting rows: 20, 40 and 60 cm x three spacings between plants within the planting row: 10, 15 and 20 cm, here called planting or sowing density), according to Table 2. These combinations were defined based on studies conducted by Spehar and Rocha (2009) with quinoa crop in the Brazilian Cerrado. The seeds used were acquired from Embrapa Cerrados.

Table 2. Planting arrangements and plant populations of quinoa.

Treatments*	Planting density (cm)		
Spacing(cm)	10	15	20
20	1,000,000	666,666	500,000
40	500,000	333,330	250,000
60	333,330	222,222	166,666

*Two plants $hole^{-1}$.

Sowing was performed manually, by placing 4 to 5 seeds per hole at a depth of 1 to 2 cm, with a thin layer of soil covering the seeds, adjusting the populations by thinning the seedlings at 20 days after emergence, leaving 2 plants per hole. Soil preparation consisted of one plowing and two harrowing operations one week before planting. Weed control was performed manually three times, at 15, 30 and 50 days after emergence.

Fertilizations were based on the recommendation of Spehar (2007a) for the crop. The fertilizers used were urea, single superphosphate and potassium chloride, in a 50-60-80 formulation of $N:P_2O_5:K_2O$, respectively. All phosphorus was applied in the basal fertilization. Potassium and nitrogen were split into 3 portions and applied every 15 days, with 20, 30 and 50% of the total fertilizers applied up to 30 days after sowing. This fertilization was performed in furrows 10 cm apart from the planting holes, with depth of 10 cm.

Foliar fertilization was performed with the Greenleaf® fertilizer, which contains macro and micronutrients, starting at 20 days after emergence and extending up to 35 days after emergence, with two weekly applications of the 20x20x20 formulation of $N:P_2O_5:K_2O$, respectively. Between 35 and 75 days after emergence, two leaf applications were performed per week with the same product using the 12x48x8 formulation. The fertilizer was applied using a backpack sprayer with capacity for 20 liters and following the manufacturer's recommendations for cereals (200 g/100 L of water), in the hours of mildest temperatures of the day (after 16 hours). The change in fertilizer formulation occurred to aid flowering and reduce vegetative growth, since P contents were increased and N and K were reduced.

The irrigation system used in the study was micro-sprinkler, and the flow rate of each nozzle was 65 L/h. Irrigation was applied daily and the water used had electrical conductivity of 1,180 micro ohms cm^{-1}. Irrigation was suspended at 90 days after planting to facilitate the physiological maturation of the seeds, thus characterized by leaf fall (senescence) and change in panicle color.

Quinoa plants were harvested at 110 days after sowing, manually and simultaneously in all plots, with moisture content in the grains below 20%. Subsequently, the panicles were placed in a dryer at temperature of 40 °C and air circulation for 5 days until reaching moisture content around 10 to 13% and then subjected to manual threshing and cleaning of impurities by the process of ventilation with sieves.

The tests related to seed quality were carried out at the Seed Analysis Laboratory of the Federal University of Ceará, in Fortaleza-CE.

The seeds were subjected to the following tests: 1000-seed weight, by counting and weighing 8 replicates of 100 seeds on a scale with precision of 0.0001g, with the final calculation resulting from the multiplication of the mean of these replicates by 10, with coefficient of variation of less than 4% (BRASIL, 2009); moisture content, according to the oven method at 105° C (± 3 °C) for 24 h, using 2 grams of seeds.

For the germination test, 50 seeds of each plot were sown in Petri dish, containing Germitest® paper at the bottom, with 2.5 times its mass in distilled water and kept in B.O.D.-type incubator, alternating light and dark every 12 hours and with alternating temperatures between 25 and 30 °C for 8-16 hours, respectively (Dias et al., 2003). The count of germinated seeds was performed on the eighth day of incubation, according to the criteria used by Strenske et al. (2015).

Concomitantly with the germination test, the Germination Speed Index (GSI) and the Mean Germination Time (MGT) in days were evaluated.

In the accelerated aging test, saturated NaCl solution (40 g.100 mL^{-1} of distilled water) was used to maintain the relative humidity inside the Gerbox® boxes at 70%. Twelve grams of seeds were distributed evenly on thin screens inside the boxes containing 40 mL of the saline solution at the bottom. The boxes were closed and kept in a B.O.D. chamber at 45 °C for 48 hours. After this period, the seeds were subjected to the germination test and evaluated after eight days.

Yield was quantified based on the mass of clean seeds from the useful area and later converted to hectare, and panicle length was measured with a millimeter measuring tape.

The data obtained were subjected to normality tests and, when they met the assumption, analyses of variance (ANOVA) were performed by the F test, then they were evaluated for the homogeneity of errors through the relationship between the highest and the lowest error (Banzato & Kronka, 2006). After checking the homogeneity of the errors, the data of the two planting cycles were jointly assessed by ANOVA, using the F test ($p<0.05$) to verify the significance of the treatments, as well as their interactions between the factors. Means were compared by Tukey test at 5% probability level, using SAS® 9.3 software (SAS, 2012).

Results and Discussion

The seed quality of BRS Piabiru quinoa was affected by the cycle for all variables analyzed. There was a triple interaction (cycle, spacing and planting density) for 1000-seed weight and significance of the single factors for the accelerated aging test. The other variables showed double interactions between the factors studied, as highlighted in Table 3.

Table 4 shows the mean values for the triple interaction of the 1000-seed weight of BRS Piabiru quinoa cultivated during two seasons, varying the population arrangement and consequently the plant population under localized irrigation regime.

Table 3. Summary of the analysis of variance (mean squares) for: 1000-seed weight (1000SW), seed moisture content (M%), germination speed index (GSI), mean germination time in days (MGT), germination percentage (G%) and accelerated aging (AA) of quinoa as a function of planting arrangement (spacing and density) and cultivation cycle (2014/2015 and 2015/2016), respectively under micro-sprinkler irrigation system.

Source of variation	DF	1000SW	M%	GSI	MGT(days)	G%	AA
Block (cycle)	6	0.054	0.489	8.353	0.086	190.037	201.759
Cycle (C)	1	0.309**	17.385**	1152.751**	0.331**	4736.889**	5724.500**
Spacing (S)	2	0.144**	1.116*	6.428^{ns}	0.010^{ns}	130.889^{ns}	311.722*
C x S	2	0.019^{ns}	1.107*	30.490^{ns}	0.033^{ns}	88.222^{ns}	40.167^{ns}
Density (D)	2	0.056*	0.883*	93.838**	0.067^{ns}	231.056*	622.056**
C x D	2	0.031^{ns}	0.281^{ns}	132.993**	0.191*	227.056*	75.500^{ns}
S x D	4	0.024^{ns}	0.337^{ns}	13.761^{ns}	0.026^{ns}	58.306^{ns}	76.889^{ns}
C x S x D	4	0.034*	0.205^{ns}	18.154^{ns}	0.018^{ns}	81.139^{ns}	103.667^{ns}
Residual	48	0.013	0.272	13.376	0.043	53.829	64.968
Mean		2.17	10.79	28.31	1.63	77.61	70.14
CV (%)		5.27	4.83	12.92	12.72	9.45	11.49

**;* and ^{ns}: significant at 1%, 5% and not significant respectively by F-test.

Table 4. Analysis of the significant triple interaction for the 1000-seed weight (1000SW) of quinoa cultivated in two planting cycles in Fortaleza under localized irrigation with variation for population arrangement.

1000SW	First cycle			Second cycle		
	Planting density (cm)			Planting density (cm)		
Spacing(cm)	10	15	20	10	15	20
20	2.06 aBa	2.21 aAa	2.09 aBa	2.07 aBa	2.10 aAa	1.98 aAa
40	2.29 aAa	2.28 aAa	2.37 aAa	2.33 aAa	2.15 abAa	2.01 bAβ
60	2.30 aAa	2.33 aAa	2.21 aABa	2.06 aBβ	2.21 aAa	2.05 aAa

Means followed by the same lowercase letter between planting density levels, uppercase letter between spacing levels and Greek letter between cycles do not differ from each other by Tukey test ($p \leq 0.05$).

In the first year of cultivation, the effect of plant population led to seeds larger than or equal to those obtained with most of the arrangements adopted in the following year, with no effect of planting density and a slightly more pronounced effect of spacing between rows, and the smallest row spacing (20 cm) reduced the biomass accumulation in the seeds when combined with low and high plant density.

Evaluating the effect of quinoa planting density in the central plateau, Spehar and Rocha (2009) found no significant effects on the 1000-seed weight when populations ranged from 100,000 to 600,000 plants ha^{-1}, and Delgado et al. (2009) working with 16 sweet quinoa genotypes in the region of origin (Colombia) found no differences between the materials for 1000-seed weight. Among the factors that affect seed mass, the planting cycle is determinant, due to abiotic factors, such as temperature and precipitation, even in crops grown under irrigated system.

Isobe et al. (2016) report that the 1000-seed weight of quinoa adapted to sea level were higher than those of ecotypes from highlands and valleys. This indicates the potential of this crop for seed production in low-lying areas and its phenotypic plasticity.

The moisture content in quinoa seeds showed double interaction for spacing x cycle (Table 5).

Table 5. Analysis of the significant double interaction for the moisture content in the seeds (M%) of quinoa cultivated in two planting cycles in Fortaleza under localized irrigation with variation for population arrangement.

M%	Spacing x Cycle	
	Cycle (season)	
Spacing (cm)	I (2014/2015)	II (2015/2016)
20	10.03 aB	11.39 abA
40	10.36 aB	10.88 bA
60	10.49 aB	11.57 aA

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by Tukey test ($p \leq 0.05$).

The moisture content in the seeds was affected by the planting cycle and by the spacing between rows, so that seeds produced in the second season had higher moisture content than those produced in the first year. On the other hand, the spacing in the first season did not affect the moisture content in the seeds, while in the second cycle the spacing of 40 cm led to lower moisture content, with an average of 10.88%, which also did not differ from those found in seeds from plants cultivated at small spacing (20 cm). The increase in moisture content in the seeds may be related to several factors, such as rainfall in the period preceding harvest, high relative humidity and/or deficiency in the drying process.

Although quinoa seeds have high porosity in the outer layer, which allows them to perform gas exchange with the medium, gaining or losing moisture easily, which may result in the initiation of the germination process in undesirable times or in the loss of viability of these seeds (Spehar et al., 2007b), the seasons and planting arrangements led to seeds with moisture contents below 12%, which facilitates storage for long periods under adequate conditions and may increase vigor.

In the field after the relative humidity of the environment increases due to the occurrence of rains, the panicles show high germination of seeds in the fruit still linked to the mother plant. Taiz & Zeiger (2013) describe this phenomenon as viviparity, showing a strong relationship between the hormones of gibberellin and abscisic acid when they are at high and low concentrations, respectively, in the seed tissues.

The agricultural season (cycle) and planting density interacted simultaneously (double interaction), affecting the germination speed index, mean germination time and germination percentage of seeds of irrigated quinoa (Table 6).

Table 6. Analysis of the significant double interactions for germination speed index (GSI), mean germination time, in days (MGT) and germination percentage (G%) of seeds of quinoa cultivated in two planting cycles in Fortaleza under localized irrigation with variation for planting arrangement.

GSI: Cycle x Density			MGT: Cycle x Density		G%: Cycle x Density	
	Cycle		Cycle		Cycle	
Planting density (cm)	I	II	I	II	I	II
10	29.32 bA	24.43 aB	1.63 aA	1.61 aA	81.67 bA	66.50 aB
15	30.25 abA	24.75 aB	1.63 aA	1.74 aA	84.17 abA	73.50 aB
20	37.23 aA	23.90 aB	1.41 bB	1.74 aA	91.33 aA	68.50 aB

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ from each other by Tukey test ($p \leq 0.05$).

Germination speed index (GSI) was higher in the first agricultural year. This result may be related to the fact that the seeds produced in the first season (cycle I) had lower moisture content (Table 5) and consequently lower damage. In the first cycle, the highest GSI (37.23) was verified when plants were grown at low density (20 cm between plants), which did not differ from the average density (15 cm). In the next cycle, there was no difference between the densities adopted.

The mean germination time evaluated in days, showed a slight double interaction between cycle and planting density, so that almost all densities used in the study, in both the first and the second cycles were higher, except for seeds from plants grown in the first year using a spacing of 20 cm between plants within the planting row (1.41 days). The germination of quinoa seeds occurred before completing two days from the setting-up of the germination test. Parsons (2012) states that quinoa seeds absorb water with ease, germinating within a few hours due to the morphology of their embryo and because it is in the peripheral region of the seed (Burrieza et al., 2014).

Following the same trend of the germination speed index, the germination percentage was very high in the first year when compared to the second. In the first season, the maximum planting density increased the competition to the point that it compromised the germination percentage of the seeds produced, which did not differ from those produced at medium density (15 cm). In the second year, planting density did not affect the quality of the seeds produced. The variation in seed quality between seasons may be related to both environmental factors, such as rainfall and temperatures in the pre and post-harvest, and factors related to the processing of seeds, since they are very sensitive to these factors, favoring or not a more efficient maturation and a high physiological potential of these seeds.

The accelerated aging test applied to quinoa seeds showed significance for the following factors: cycle, spacing and density (Table 7).

Table 7. Accelerated aging (AA) test of quinoa cultivated during two planting cycles, according to the planting arrangement under irrigation.

Cycle		Spacing (cm)		Planting density(cm)	
I	79.06 a	20	72.58 a	10	64.42 b
II	61.22 b	40	66.00 b	15	71.83 a
		60	71.83 a	20	74.17 a

Means followed by the same lowercase letter in the column do not differ from each other by Tukey test ($p \leq 0.05$).

BRS Piabiru quinoa seeds when subjected to unfavorable storage conditions through the accelerated aging test responded differently among the factors tested; those from the first season were more rustic than those from the second season, with higher means of germination (79.06%). Seeds produced at medium spacing (15 cm) showed the lowest germination rates when subjected to the accelerated aging test, while those produced at the extreme spacings (20 or 60 cm) stood out. Plants grown at low and medium density (15 or 20 cm) tend to produce seeds that are more rustic and withstand extreme conditions more easily when compared to seeds of very dense populations within the planting row.

The results obtained from the accelerated aging test attest that seed rusticity and physiological potential have a strong relationship with environmental conditions of climate and soil, in addition to the interference of the plant populations adopted. Hariadi et al. (2011), working with different levels of salinity in quinoa cultivation, suggest that this crop has a very efficient system of osmotic adjustment under conditions of abrupt increases of NaCl, which suggests that quinoa seeds resist the adversities of the environment due to their biochemical and/or physiological characteristics.

There were double interactions of cycle x spacing and spacing x density for panicle length. For seed yield, the interactions occurred for cycle x density and spacing x density when quinoa plants were cultivated during two seasons (2014/2015 and 2015/2016) at low latitude and altitude, as observed in Table 8.

Table 9 describes the mean values of the analysis of the double interactions for the panicle length of BRS Piabiru quinoa cultivated in two seasons, varying the population arrangement and consequently the plant population per hectare in localized irrigation regime.

Table 8. Summary of the analysis of variance (mean squares) for panicle length (PL) and yield (Y) of quinoa seeds as a function of planting arrangement (spacing and density) and cultivation cycle (2014/2015 and 2015/2016) respectively under micro-sprinkler irrigation system in Fortaleza.

Source of variation	DF	PL (cm)	Y (Kg ha^{-1})
Block (cycle)	6	59.403	24667.246
Cycle (C)	1	1132.087**	263613.025**
Spacing (S)	2	1329.224**	170557.314**
C x S	2	442.107**	55899.990^{ns}
Density (D)	2	94.061**	851019.550**
C x D	2	23.949^{ns}	63489.118*
S x D	4	114.126**	142681.434**
C x S x D	4	28.682^{ns}	31145.781^{ns}
Residual	48	17.965	18571.631
Mean		41.58	814.23
CV (%)		10.19	16.74

**;* and ^{ns}: significant at 1%, 5% and not significant respectively by F-test.

Table 9. Analysis of significant double interactions for panicle length (PL) of quinoa cultivated in two planting cycles in Fortaleza under localized irrigation with variation for population arrangement.

PL (cm)	Spacing x Density			Spacing x Cycle	
Spacing (cm)	Planting density (cm)			Cycle	
	10	15	20	I	II
20	29.66 bC	36.71 aB	34.46 abB	32.83 aB	34.39 aB
40	41.13 bB	39.88 bB	47.29 aA	33.92 bB	51.61 aA
60	47.13 abA	52.20 aA	45.74 bA	46.08 bA	50.63 aA

Means followed by the same lowercase letter in the row and uppercase letter in the column do not differ from each other by Tukey test ($p \leq 0.05$).

Larger spacing between crop rows resulted in larger panicles, showing a strong relationship with planting density in such a way that the increase in density at low and medium spacing led to a competition that reduced the size of the panicles, while only when the rows were wider is that plants at higher densities invested in increment in the size of these inflorescences. All spacings resulted in panicles longer than or equal to those obtained in the second season, when compared to the first one, as can be seen in Table 9.

Ferreira et al. (2014) point out that panicle size reflects the environment where the plant develops: population, soil fertility, water stress and sowing time. In this context, it is observed that there were no differences between cycles for higher densities. The other densities led to different behaviors.

Quinoa plants compete with each other (intraspecific competition) for light, water, nutrients, CO_2, among other production factors, and this competition can reduce the size of panicles when populations are large. However, they rapidly close the spaces between rows, resulting in less lodging, as the panicles are smaller (Spehar et al., 2007b).

The analysis of the double interactions for the yield of BRS Piabiru quinoa cultivated in two seasons varying the population arrangement is described in Table 10.

Quinoa yield was significantly higher when it was cultivated using 20 cm between rows and 10 cm between plants within the row (large populations: 1,000,000 plants ha^{-1}), and these yields exceed 1 ton ha^{-1} (1,162.12 kg ha^{-1}). These results suggest that there was low competition between plants when cultivated at high planting densities, so there was a synergism within these populations. The second season had higher yield than the first one when quinoa plants were cultivated with 10 cm apart from each other within the row. At the other densities, there was no difference between cycles.

Table 10. Analysis of significant double interactions for seed yield (Y) of quinoa cultivated in two planting cycles in Fortaleza under localized irrigation with variation for population arrangement.

Y (kg ha^{-1})	Spacing x Density		
Spacing (cm)	Planting density (cm)		
	10	15	20
20	1,162.12 aA	751.55 bB	752.83 bA
40	997.03 aB	952.37 aA	543.84 bB
60	804.21 aC	818.74 aAB	545.38 bB
	Cycle x Density		
Cycle I	868.71 aB	801.12 aA	591.33 bA
Cycle II	1,106.86 aA	880.66 bA	636.70 cA

Means followed by the same lowercase letter in the row and uppercase letter in the column do not differ from each other by Tukey test ($p \leq 0.05$).

The fact that the population increase results in increased production can be explained by the high amount of light present in the northeast region, where quinoa due to its leaf architecture can, even in large populations, intercept much of this light and convert it into biomass accumulation in the seeds. In other regions, where light is a limiting factor, there may be competition for this production factor. Nadaletti et al. (2014) cultivated linseed sown broadcast and in rows with several plant populations in Paraná, where the amount of light is limiting, and concluded that the increase in planting density was harmful for plants sown both in the row and broadcast.

The reduction in panicle size was compensated by the increase in the number of smaller panicles in larger populations. According to Ruiz and Bertero (2008), plant density is an important key in decision-making in the management for short-cycle cultivars. Unlike the behavior for panicle length between the two seasons, quinoa yield was affected only by the cycle at the highest planting densities, and these yields of the second season were higher than those of the first season.

The cultivar BRS Piabiru satisfactorily adapted to the region of cultivation and the applied cultural practices, with yields similar to those found by Vasconcelos et al. (2012) at different sowing times in off-season in the region of Campo Mourão, Paraná. The maximum yield achieved (1,162.12 kg ha^{-1}) requires optimization in the production system to achieve a better level, since yield can reach 3,000 kg ha^{-1} in the tropical region (Spehar & Santos, 2002).

Conclusions

Seeds of the quinoa cultivar BRS Piabiru have high physiological quality, with good germination index, dependent on the population arrangement;

The agricultural year (cycle) affects moisture content, germination, germination speed index and accelerated aging of quinoa seeds;

Increase in planting density results in increment in seed yield.

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