AGRONOMIC PERFORMANCE OF QUINOA (*Chenopodium quinoa Willd.*) UNDER TWO MOISTURE REGIMES IN A BRAZILIAN SAVANNAH SOIL

DESEMPENHO AGRONÔMICO DE QUINOA (Chenopodium quinoa Willd.) SOB DUAS CONDIÇÕES DE UMIDADE EM UM SOLO DE CERRADO

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ABSTRACT: Sustainable grain production in the Brazilian Savannah (Cerrado), relies on biological diversity and tillage improvement. The present practice of no-tillage, which depends on soil cover, includes few species, i.e., maize, millet, sorghum (*Gramineae*), soybean and common bean (*Leguminosae*). Quinoa, the Andean grain crop (*Chenopodium quinoa* Willd., Chenopodiaceae), has been introduced in the savannah to utilise residual moisture in double cropping, for mulch and grain production. Selected genotypes were grown in autumn, after soybean harvest, in Planaltina, DF, Brazil, located at 15^{O} 36' S and 47^{O} 12' W, elevation of 1,000 m.a.s.l. A randomised complete block experiment, with three replications, was used on an oxisol (Ferralsol, FAO), under residual moisture and supplemental irrigation regimes. Grain yield for, Q18 and Q24, was 2,200 and 1,153 kg ha^{-1} for respective irrigated and stressed condition. This character was positively associated with plant height and plant cycle. Early maturity genotypes had higher yields under stress than late, with few exceptions, like Q24, yielding 56% of its performance in sufficient water supply. Selection for drought tolerance and vigorous growth, combined to early maturity in main crop, to anticipate sowing, will contribute for commercial cultivation of quinoa in the tropics.

UNITERMS: Moisture regimes; Genotype; Drought tolerance; Maturity; Yield

INTRODUCTION

Modern technology has turned the Brazilian Savannah (Cerrado) into a major grain producer (SPEHAR, 1998). In this region, prevail the oxisols (Ferralsol, FAO), naturally acidic and devoid of nutrients. Cation-exchange capacity of these soils is reduced and amendments with lime and fertilisers are necessary before growing annual crops. The physical properties make them prone to erosion in conventional cultivation (SPEHAR, 1998). No-tillage practice has been introduced, to avoid compounding effects of bad soil management and unsuitable crop husbandry (SPEHAR; LANDERS, 1997).

Crops with limited botanical diversity have been grown, i.e., maize, millet, sorghum (*Gramineae*), soybean and common bean (*Leguminosae*), in rotation or double cropping. This vulnerable system has shown increasing pests, diseases and weeds; soil compaction, erosion and production cost. Excessive or unbalanced use of fertilisers and pesticides, consequence of reducing organic matter, has caused negative environmental impact (SPEHAR, 1998). Crop diversification is essential to improve farming systems, protect the soil in the dry season and provide additional income (SPEHAR; LARA CABEZAS, 2001).

Average annual precipitation of 1,500 mm is concentrated between the months of October and April (SPEHAR, 1998). Thus, selection criteria for crop adaptation shall be based on drought tolerance, rapid growth, nutrient cycling and diversification of uses (SPEHAR; SANTOS; SOUZA, 1997).

Quinoa (*Chenopodium quinoa* Willd., Chenopodiaceae), is one of these alternative crops (SANTOS, 1996; SPEHAR; SANTOS, 2002). It is a major source of protein with high quality and a range of vitamins and minerals. It has been domesticated and used for human and animal consumption in the Andes of South America, since thousands of years. It is becoming

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important in other parts of the world, as a component of production systems (RIVERO, 1994; SPEHAR, 2002).

Quinoa can be cultivated under high evapotranspiration conditions and low soil moisture; tolerance to drought has been attributed to deep root system and the presence of calcium oxalate vesicles in the leaves (CARBONE RISI, 1986; SANTOS, 1996). The presence of this hygroscopic salt, prevents moisture loss by the leaves, in addition to thick walled epidermic cells; above them there is a layer of thin cells that also contribute to save moisture (GANDARILLAS, 1976).

The root system shows a considerable rate of secondary formation and the length of tap root reaches 90% of stem length (LESCANO, 1981). In the savannah soils, the roots seemed to penetrate the compact layer found at a 30 cm depth, as a result of intensive cultivation (SANTOS 1996).

Quinoa is sensitive to day length and classified as short day plant, although originated at low latitude. It is also sensitive to temperature and the plant cycle results from the conjugation of these two factors. Varietal response has been detected at flowering and maturity under different temperature and day length regimes (BERTERO, 2001), although the onset of flowering in the savannah did not vary between early and late maturity types (SANTOS, 1996).

The crop is adapted to average low temperatures prevailing in the Andes; evapotranspiration is reduced under that environment, although compensated by the low air density. In the savannah condition, it increases sharply at the end of rainy season and during the winter (dry season). Experimental results in the savannah, with locally selected genotypes, indicate its growth potential (SPEHAR; SOUZA, 1993). High grain yields have been obtained in Brazil and other countries (CARBONE RISI, 1986; SPEHAR; SANTOS, 2002; WAHLI, 1990) illustrate the opportunity to enhance quinoa for commercial production.

The aim of this experimentation has been to assess the effect of two moisture regimes on agronomic performance of quinoa genotypes, in savannah autumn (double crop) sowing.

MATERIAL AND METHODS

Twelve quinoa breeding lines, selected in the Brazilian Savannah (SANTOS, 1996; SPEHAR; SOUZA, 1993) were tested under two moisture regimes. They were selected from a bulk originated from hybrids among the varieties Amarilla de Marangani, Blanca de Junín, Chewecca, Faro-4, Improved Baer, Kancolla, Real and Salares-Roja, of Bolivian, Chilean and Peruvian source (CARBONE RISI, 1986).

The experiments were conducted in the Savannah National Research Centre station (Embrapa Cerrados), Planaltina, DF, Brazil, on a Dark Red Latosol, oxisol soil type (Typic Haplustox, fine, kaolinitic, isohyperthermic, USDA; Ferralsol, FAO). The experimental area is located at the latitude of 15° 35’30” S, longitude of 47° 42’ 30”, altitude of 1,000 m.a.s.l. Sowing was in March 30, 1994, at the end of the rainy season.

Soil physical and chemical characteristics of experimental field are: sand 340 g kg^{-1}, silt 190 g kg^{-1} and clay 460 g kg^{-1}, organic matter 2.8 g kg^{-1}; pH (H_20) 5.8, Al 0.01 cmol$_c$ kg^{-1}, Ca+Mg 3.6 cmol$_c$ kg^{-1}, P 8.9 mg kg^{-1} and K 0.23 cmol$_c$ kg^{-1}. Lime and fertilisers were applied to reach these pH, Al, Ca+Mg, P and K values. The area was cultivated during four years with soybeans, prior to this experiment.

A maintenance fertilisation of 60 kg ha^{-1} N, 46 kg ha^{-1} P and 60 kg ha^{-1} K was used. Nitrogen, at the rate of 60 kg ha^{-1}, was divided into two applications: furrow, at sowing and band, at 35 days after emergence. Average temperature was recorded during the months of April, May and June.

The experiments were conducted on a randomised complete blocks design, with three replications, for each of the two moisture regimes. Each plot consisted of 14 rows, equally spaced by 0.20m, 3.0 m long. Ten central rows, discarding 0.25m at the extremes, consisted the harvest area.

The irrigated experiment was monitored with tensiometers, to maintain the water tension in the soil between 30 and 60 cBar, at 30 cm depth. The irrigation was done with self-propelled sprinkling to supply 20 mm water/h. Water supply stopped at filled grain phase, 20 days before physiological maturity of late cultivars. This experiment received a total of 371.4 mm water, including rain, distributed in 127.3, 115.2 and 128.9 for the months of April, May and June. The non-irrigated experiment had 122.5 mm rain, distributed in April (87.3) and May (35.2).

During the conduction of experiments, data were collected on: days to flower differentiation, days to maturity (when plants reach physiological maturity, i.e., filled grains and panicles changing colour), plant height, length and diameter of inflorescence and grain yield.

The data were statistically analysed per individual observation. Relative values for grain yield and plant height (irrigated/nonirrigated*100) were obtained as a reference to drought tolerance. Correlation coefficients were calculated for the characters, in irrigated and non-irrigated experiments, to assess their relationship under presence and absence of moisture stress.

RESULTS AND DISCUSSION

The recorded average low temperature in April was 18.0ºC; in May and June, period of plant development, it was 16,2ºC and 13.7ºC, respectively. All genotypes had the beginning of flower differentiation between 19 to 23 days after emergence. This narrow range for blooming was observed among genotypes in summer and winter sowing in the savannah. It can be explained by higher temperatures than in the Andean region or long days in temperate zone (CARBONE RISI, 1986; JACOBSEN; HILL; STOLEN, 1996; SANTOS, 1996).

Plant cycle varied between 85 to 115 days and 80 to 90 days for irrigated and non-irrigated experiments and early and late maturity genotypes, respectively. The anticipation of maturity in non-irrigated experiment was caused by exposure of plants to drought. Late maturity genotypes reduced their cycle by up to 25%, whereas the early maturity did not show much variation.

The most productive genotypes, under suitable water supply, are the late maturity ones (Table 1). This confirms previous work in different sowing dates where these genotypes had also higher plants (SANTOS, 1996). This association is expressed by the correlation analysis (Table 2). The moisture stress, however, contributed to level off differences among these genotypes and correlation among plant height and yield was not statistically significant.

Table 1. Grain yield (GY, kg ha^{-1}), plant height (PH, cm), for irrigated and non-irrigated experiments, with respective relative values (RV). Planaltina, DF, 1994.

	Irrigated		Non-Irrigated		RV (%)	
Access	GY	PH	GY	PH	GY	PH
Q18	2200 a	128 a	819 ab	67 a	37	52
Q24	2074 ab	98 cd	1153 a	67 a	56	68
Q1	1974 ab	108 bc	369 b	57 abc	19	53
Q10	1564 abc	122 ab	852 ab	68 a	54	56
Q20	1465 abcd	87 def	758 ab	65 ab	52	75
Q13	1421 abcd	77 f	1028 ab	57 abc	72	74
Q26	1397 abcd	78 ef	609 ab	47 abc	44	60
Q11	1321 bcd	80 ef	511 ab	47 abc	39	59
Q8	1306 bcd	110 bc	331 b	67 a	25	61
Q25	1289 bcd	95 cde	560 ab	44 bc	43	46
Q12	997 cd	80 ef	516 ab	40 c	52	50
Q23	741 d	70 f	827 ab	43 bc	111	61
Mean	1479	95	655	57	44	60
CV (%)	18,7	6,2	10,3	19,0		

[1]means followed by the same letter do not differ at 5% probability by the Tukey test

On the average, reduction in yield was related to low plant height, as shown by the high correlation coefficient (0.73). There were, however, exceptions like Q24, late maturity access, with relative yield of 56 %, whereas Q1 of the same group had a value of 19%. The higher relative yields in short cycle Q23 can be explained by their escape of stress at the grain filling phase.

Table 2. Correlation coefficient for plant height (PH), inflorescence length (IL), inflorescence diameter (ID) and grain Yield (GY), of irrigated and non-irrigated experiments.

PH	IL	ID	GY	
		IRRIGATED		
M	0.65*	0.09	0.51*	0.51*
PH		0.47*	0.74*	0.61*
IL			0.56*	0.66*
ID				0.65*
		NON-IRRIGATED		
M				
PH		0.50*	0.60*	0.31
IL			0.45*	0.56*
ID				0.32

* *Significant at 5% probability.

Plant cycle had an expected significant correlation with plant height (SANTOS, 1996). Inflorescence length was not correlated with plant cycle. This is interpreted that yield in late maturity genotypes is not a function of high inflorescence/stem ratio. This is confirmed by the low correlation coefficients between inflorescence and stem length. Plant cycle and inflorescence diameter were, however, positively correlated. This can be interpreted as late plants are tall and have high fruit density in secondary axes; during their development the axes curve down by the weight of fruits (aquene, type). The present data support the assumption that, under savannah cultivation, inflorescence diameter is more affected by the fruit weight than its type (SANTOS, 1996).

Inflorescence type (varying from glomerulate to amaranthiform) can be used independently to select for grain yield. It is an intrinsic character of genotypes, whereas length and diameter are directly affected by environmental factors such as soil fertility and drought stress.

The high correlation between inflorescence length and diameter shows it is directly related to plant development and this to grain yield. The positive association between plant height and inflorescence length illustrate the possibility of selecting high yielding genotypes adapted to combine harvest.

In non-irrigated experiment there was a positive relationship between plant height and inflorescence length and diameter; no correlation was found between plant height and grain yield and this was probably due to effect of drought stress reducing differences.

Under moisture stress condition, yields were reduced and there was no correlation with inflorescence diameter, similarly to what was found by ESPÍNDOLA e GANDARILLAS (1986).

There was no effect of inflorescence/stem rate on grain yield. This trait, however, can be used in selecting short, high yielding plants.

The non-irrigated experiment received 107 mm precipitation during the first 18 days, when plants emerged and grew normally. The first drought stress, between the 19th and 45th day caused reduction in the differences among genotypes, without causing death of plants. The beginning of flower differentiation, between the 19th and 23rd day after emergence, was not affected because residual moisture in the soil was sufficient. Thus, up to flowering the differences among genotypes were not significant and plants were comparable to the irrigated experiment. The non-irrigated plants received only 35 mm precipitation between flowering and physiological maturity.

The satisfactory performance of early maturity Q13, in both environments, indicate that for growing quinoa in double cropping system, after soybean or maize, selection shall be concentrated in vigorous growth in short cycle genotypes. Selection for lateness has resulted in more productive genotypes, like Q18, in absence of moisture stress, confirming results obtained in the Andes and high latitude regions (ESPINDOLA e

GANDARILLAS, 1986; JACOBSEN; HILL; STOLEN, 1996; OCHOA; ALBORNOZ; PERALTA, 1988; SANTOS, 1996). It was, however sensitive to drought, yielding only 37% under stress.

Selection of high-yielding, early-maturity plant cycle of main crops, like soybeans and maize, shall be carried out. This allows early autumn sowing for better utilisation of residual moisture by late maturity quinoa genotypes. The presence of genotypes more tolerant to moisture stress suggest that selection should be practised on a broad base germplasm to increase the probability of quinoa cultivation using the residual moisture at the end or rainy season. It is, however necessary to properly manage the weeds to assure the success of quinoa in double cropping (SANTOS; SPEHAR.; VIVALDI, 2003).

CONCLUSIONS

Differences in days to maturity and grain yield tend to disappear among moisture-stressed quinoa genotypes, although they are present in plant height.

Selection for early maturity and vigorous growth shall contribute to achieve growth and yield before plants are exposed to severe stress at the end of rainy season.

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RESUMO: A produção sustentável de grãos no Cerrado deve basear-se na diversidade biológica e no aperfeiçoamento de cultivo. A prática atual de plantio direto na palha, dependente de cobertura do solo, inclui poucas espécies, como milho, milheto e sorgo (*Gramineae*), soja e feijão (*Leguminosae*). A quinoa, cultivo andino, (*Chenopodium quinoa* Willd., Chenopodiaceae), tem sido introduzida para utilizar a umidade residual em sucessão, gerando palha para proteger o solo e produção de grãos. Genótipos selecionados foram semeados no outono, após o cultivo da soja, em Planaltina, DF, Brasil, situada a 15^{O} 36' S e 47^{O} 12' W, a uma elevação de 1.000 m.s.n.m. O desenho experimental utilizado foi de blocos ao acaso, com três repetições, em um latossolo (Ferralsol, FAO), sob condições de irrigação suplementar e umidade residual. O rendimento foi de 2.200 e 1.153 kg ha^{-1}, para Q18 e Q24, nas respectivas condições de cultivo. Essa característica foi positivamente associada com altura de plantas e o ciclo. Genótipos precoces mostraram valores mais elevados sob estresse do que os tardios, exceto alguns como Q24, com 56% do seu desempenho quando água não foi limitante. A adaptação do cultivo de quinoa aos trópicos deve concentrar-se em tolerância à seca e crescimento vigoroso, combinada com a redução de ciclo nos cultivares da espécie principal, para antecipar a semeadura.

UNITERMOS: Genótipo; Regime de umidade; Tolerância à seca; Maturação; Rendimento.

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