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Crambe (*Crambe abyssinica* H.) development and productivity under different sowing densities

Octavio Henrique Viana[1], Reginaldo Ferreira Santos[1*], Renato Cassol de Oliveira[2], Deonir Secco[1], Samuel Nelson Melegari de Souza[1], Luciene Kazue Tokura[1*], Tiago Roque Benetoli da Silva[3], Flávio Gurgacz[1]

[1]College of Agriculture Engineering, Post-Graduation Program of Energy in Agriculture, Western Paraná State University, UNIOESTE, Cascavel, PR, Brazil
[2]Department of Agriculture Sciences, Assis Gurgacz College, FAG, Cascavel, PR, Brazil
[3]Department of Agricultural Sciences, Maringá State University, UEM, Maringá, PR, Brazil

***Corresponding author: lucienetokura@agronoma.eng.br, reginaldo.santos@unioeste.br**

Abstract

The search for renewable sources of energy gains new options of raw materials every day, such as crops from agriculture. Oil crops, such as soybeans, canola, jatropha and crambe stand out in the west of Paraná state, Brazil. The crambe (*Crambe abyssinica* H.) is a promising plant in the production of oil in Brazil and is an alternative to the crop rotation system. Several studies have been conducted on crambe as there is currently little information regarding this crop in the west of Paraná. Also, studies on plant density are also required, as this factor is important to avoid competition for soil nutrients and reduced grain yield. This study aimed to assess crambe growth and production under different sowing densities. The experiment was conducted on an experimental farm in the city of Cascavel – PR. The spatial arrangement proposed in this study varied according with sowing densities of 8, 12, 17.5 and 24 kg ha^{-1} crambe seeds with spacing of 0.45 m between rows and 5 replications in an experimental design with randomized blocks. Data obtained were subjected to analysis of variance (ANOVA) and to regression test in ASSISTAT software. Results showed that plant height, fresh mass, dry mass, plants per linear meter and grain yield were influenced by variations in plant sowing density. Plant height (110.08 cm) and yield (2118.57 kg ha^{-1}) showed the best results with sowing density of 8 kg ha^{-1}. Fresh mass (67.95 t ha^{-1}), dry mass (22.52 t ha^{-1}) and plants per linear meter (55.60 units) reached the best results with a sowing density of 24 kg ha^{-1}.

Keywords: Plant populations; energy crop; production; spatial arrangement.
Abbreviations: CV _ Coefficient of variation; DAS_ Day after sowing; Plants/linear meter _ plants per linear meter; ANOVA _ Analysis of variance; RLe _ eutroferric Red Latosol

Introduction

Crambe (*Crambe abyssinica* Hochst) is an early-cycle winter plant that flowers at 35 days after emergence and should be harvested at 90 days (Carneiro et al., 2009). There are 39 known species in the crambe genus. *Crambe abyssinica* Hochst belongs to the *Leptocrambe* section, which has narrow genetics, what interfere in plant genetic improvement (Warwick and Gugel, 2003). Crambe is an annual herbaceous plant that reaches around 1 m of height and develops branches near the ground (thirty or more), which ramify and form terciary branches. Its leaves are oval and assymetric. It has white flowers that produce several seeds (Oplinger et al., 1991). Crambe fruit is a spherical-shaped silique that is initially green, but becomes yellow over maturation. They are distributed on all branches. Each silique presents green or greenish brown seeds measuring from 0.8 to 2.5 mm in diameter (Desai et al., 1997).

According to Souza et al. (2009) and Pitol et al. (2010), crambe presents elevated concentrations of oil (40%) and protein (29%). According to Endres and Schatz (2003), crambe oil is composed of 60% erucic acid, which allows the oil to be used in the industry due to its high stability to oxidation. Due to these features, crambe is considered to be promising for the oil industry as well as an additional source of protein for animal nourishment (Wang et al., 2000; Knights, 2002).

In the center-west region of Brazil, crambe must be planted between April and July, depending on the rainfall in the pre-sowing, using a spacing from 0.17 to 0.45 meters between rows, sowing density between 8 and 22.5 kg ha^{-1} and a depth of 0.03 meters (Knights, 2002; Pitol et al., 2010). Glaser (1996) highlights the occurrence of diseases when there is heavy rainfall, such as Alternaria spots (*Alternaria sp*.), Fusarium (*Fusarium sp*.), Blackleg (*Leptosphaeria maculans*) and white mold (*Sclerotinia sclerotiorum*). Oplinger et al. (1991) mention the turnip mosaic virus as an impacting disease on crambe cultivation. Crambe is tolerant to drought stress and cold weather, and can be sown belatedly due to its short cycle of 90 days, which allows it to be sown in regions with climatic risks (Roscoe and Delmontes, 2008). Crambe grain yield is approximately 1500 kg ha^{-1} and its oil yield is roughly 750 L ha^{-1} (Trezeciak et al., 2008).

Crambe development and productivity may be affected by a few factors; one of them is spatial arrangement, or sowing density, which represents the distribution of plants per area.

Table 1. Polynomial regressions and analysis of variance on crambe cultivation for the following variables: plant heights, fresh mass, dry mass, plants per linear meter, grain yield and mass of 1000 grains under different sowing densities.

Variables	Regression equation	R^2	$\hat{Y}$	$\ddot{X}$	CV(%)
Plant height (cm)	$\hat{Y}$ =143.82 – 5.333x + 0.1455x^2	0.99**	94.95	18.32	2.86
Fresh mass (t ha^{-1})	$\hat{Y}$ = 95.725 - 8.644x + 0.309x^2	0.80*	35.07	14.04	26.97
Dry mass (t ha^{-1})	$\hat{Y}$ =25.319 + - 1.97x + 0.076x^2	0.93**	12.55	12.96	17.16
Plants/linear meter (unit)	$\hat{Y}$= 26.327 + 0.457x + 0.032x^2	0.99**	31.21	7.14	13.28
Mass of 1000 grains (g)	$\hat{Y}$ = ns	-	-	-	11,68
Grain yield (kg ha^{-1})	$\hat{Y}$ = 2774 – 98.363x + 2.235x^2	0.98**	1691.34	22.01	8.80

**: Significant at 1% probability (p < 0.01). *: Significant at 5% probability (0.01 = < p < 0.05). ns: non-significant. (p > = 0.05). $\hat{Y}$: estimated value of y. $\ddot{X}$: estimated value of x.

As the arrangement consists of intra-row and inter-row spacing (Argenta et al., 2011), its alteration affects the availability of space occupied by plants in the soil and in the aerial part causing competition (Kruger et al., 2010). Stress caused by competition leads to losses in plant growth, development and production (Zanine and Santos, 2004). In order for plants to show their maximum potential there should be no stress between them, so that they can perform maximum solar energy interception (Kruger et al., 2010).

According to Tragnago et al. (2011), proper plant density reduces stress, allowing plants to intercept solar energy by creating an adequate environment for the usage of natural resources, what leads to a more efficient soil coverage. Solar energy interception is considered to be a key element for the conversion of solar energy into chemical energy, which is essential for vegetal production since it affects grain yield. High grain yield can be achieved by maximizing the duration of radiation interception and distributing it in adequate proportions for the formation of leaves, culms, roots and reproductive structures (Loomis and Amthor, 1999). Besides affecting the interception of solar energy by plants, spatial arrangement also influences the availability of nutrients (Sangoi, 2000). According to Nakagawa et al. (2000), as productivity increases, so does plant density, however, there is a point in which the competition for nutrients starts to cause reduction in grain yield. As most information regarding the crambe crop refers to the state of Mato Grosso do Sul by the MS Foundation (where a variety that is adapted to local soil and climate issues was developed), other states such as Goiás and Paraná are conducting studies for the production of insulating vegetable oil at teaching and research institutions. The little information on crambe in other Brazilian states hampers its commercial propagation across the country, as crambe requires an adequate sowing density. As there is no structured market for this crop in Brazil, it is commercialized only in a few places. It is clear that in the west of Paraná there is little research and dissemination of crambe implementation technology, storage and trade. In that sense, this study aimed to assess crambe development under different sowing densities in the west of Paraná.

Results and Discussion

Crambe polinomial regression according to sowing density

All variables showed coefficient of variation (CV) (Table 1 and Figure 1) in accordance with classification by Pimentel Gomes and Garcia (2002). Low dispersion CV was verified in plant height, grain yield and mass of 1000 grains; medium dispersion CV in plant dry mass and plants per meter; and high dispersion CV in plant fresh mass. High dispersion CV observed in fresh mass indicates low data precision and possible experimental error. Climate conditions and heterogeneous soil in tropical regions are factors that contribute to increasing error. Also, variables present different coefficients of variation due to their nature (Ledo et al., 2007). Sowing density did not influence the mass of 1000 grains in the current study. Mean values of each parameter are presented in Table 2 and the evaluations of each variable are described below:

Sowing density influenced plant height. As sowing density increased, plants tended to present lower height, except with the rate of 17.5 kg ha^{-1} (94.36 cm), when plant height was lower than with the sowing density of 24 kg ha^{-1} (99.82 cm).

Dalchiavon et al. (2012) performed an experiment with crambe sowing density of 18, 36, 54, 72 and 90 plants per meter and evaluations on plant height at 30, 60 and 90 DAS, and observed that only at 30 DAS the density of 90 plants per meter differed statistically from the others. At 60 and 90 days there was no significant difference between treatments. Potafos (1997) describes that sowing density is one of the factors that interfere in crop environment. On the canola and crambe family (*Brassicaceae)* inter-row spacing and sowing density are factors that interfere in plant structure, possibly affecting yield (Cordeiro et al., 1999). Sowing density affected fresh mass production. By increasing sowing density, we observed an increase in plant fresh mass, except with the rate of 17.5 kg ha^{-1} (32.26 t ha^{-1}), when fresh mass was lower than with the density of 24 kg ha^{-1} (67.95 cm).

According to Argenta et al. (2011) one of the factors that interfered with grain yield is the foliar area index, which varies with different plant arrangements. For Costa (2009), foliar area index oscillates according to fresh mass production. By decreasing photosynthetic activity, there is a reduction in plant fresh mass (Taiz and Zeiger, 2004). Sowing density influenced in dry mass production, in which the highest dry mass yield of 22.52 t ha^{-1} was obtained with a density of 24 kg ha^{-1} (Table 2). There was a positive linear response regarding this variable, showing an increase in plants per linear meter with increased sowing density. The best yield average was 2,118.58 kg ha^{-1} for a seed rate of 8 kg ha^{-1}, in which density influenced in grain yield. Increasing sowing density causes crambe grain yield to decrease. According to Pitol et al. (2010), crambe has the capacity to compensate low population by significantly increasing its branching, what leads to high productivity. The highest crambe branching was achieved in this study at a seed rate of 8 kg ha^{-1}. Argenta et al. (2011) state that grain yield is influenced by plant arrangement. With an adequate plant arrangement it is possible to increase plant radiation interception, usage efficiency and grain yield. Pitol et al. (2010) did not obtain any statistical differences when analyzing crambe in clayey soil and assessing crop yield with inter-row spacing of 0.21 and 0.45 m and density of 8, 12 and 16 kg ha^{-1}. The highest yield (1886 kg ha^{-1}) was achieved in the treatment with inter-row spacing of 0.45 m and density of 12 kg ha^{-1}. This variable was not influenced by other treatments.

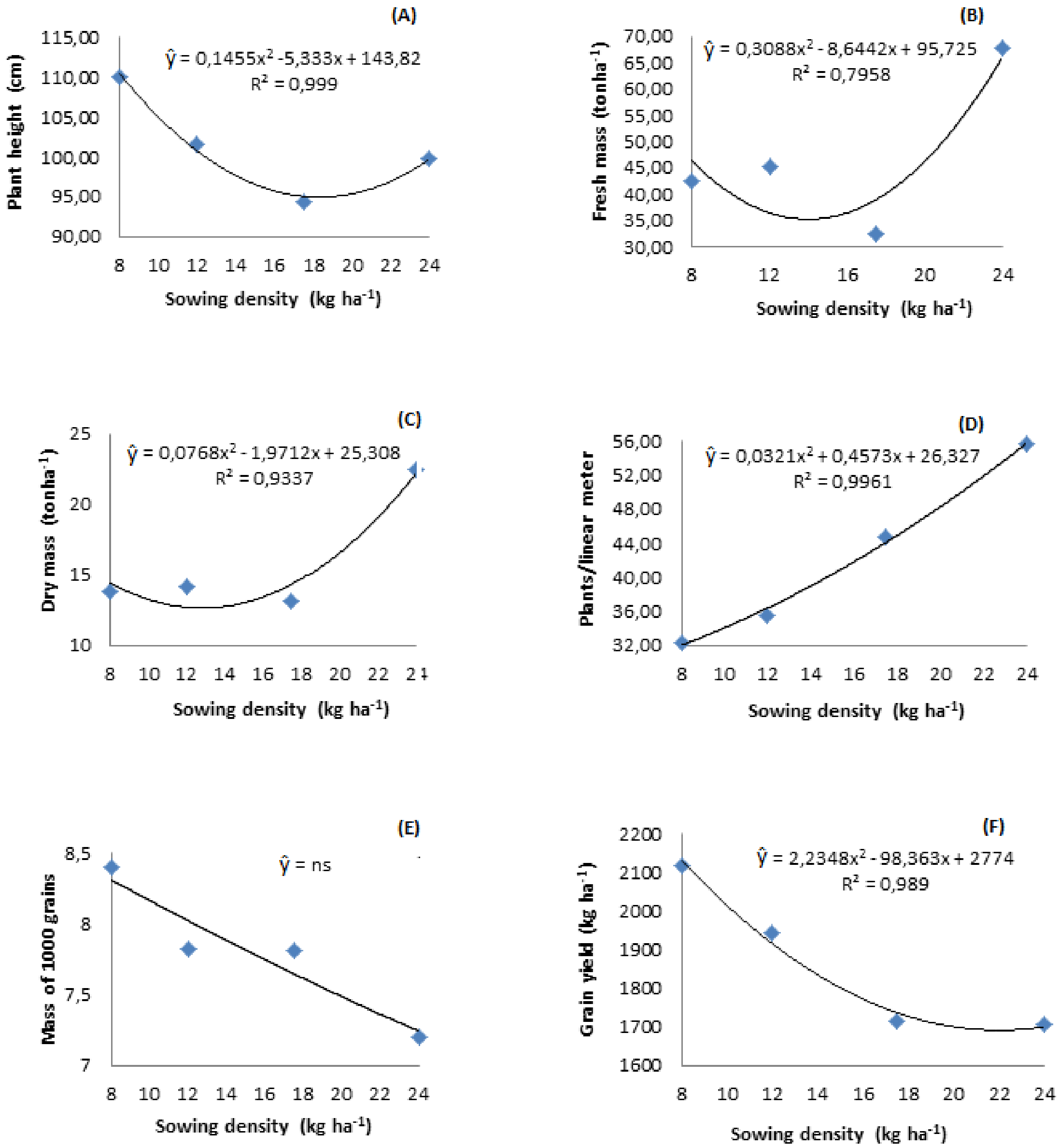

Fig 1. Polynomial regression of plant height (A), fresh mass (B), dry mass (C), plants per linear meter (D), mass of 1000 grains (E) and crambe grain yield (F) under different sowing densities.

Materials and Methods

Experimental area

The experiment was carried out in April 2012 on the experimental farm of Assis Gurgacz College (Faculdade Assis Gurgacz – FAG), located in the city of Cascavel – Paraná, at an altitude of 700 meters, between latitudes 24°56'25.39" S; 24°56'45.39" S and longitudes 53°30'9.89" W; 53°31'17.01" W. Local climate is classified as Subtropical Cfa according to Köppen's classification. Average annual rainfall is superior to 1800 mm. There is possibility of frosts during winter and no defined dry season.

Soil characterization and climatological data

Soil in the experiment area is classified as eutroferric Red Latosol (RLe) with clayey texture (EMBRAPA, 2006). The area had been conducted under no-tillage for over 20 years with maize and soybean in summer crops and wheat and oat in fall/winter crops. Soil samples were collected at 0 - 0.20 m of depth in all experimental area and taken to the laboratory of soil analysis for the assessment of their chemical characteristics. Results are shown in Table 3. Figure 2 shows climatic data observed during crambe development. During crambe development there were 444.90 mm of accumulated rainfall, average temperature of 17.91ºC and also occurrence of frost on July 13.

Experiment deployment and conduction

Weed desiccation was performed on 16/04/2012 with glyphosate herbicide at a rate of 2.5 L ha^{-1}. Crambe cultivar FMS Brilhante developed by Fundação MS with minimum germination of 80% was sown on 23/04/2012 with the aid of a tractor operating at a working speed of 6 $km.h^{-1}$ and a precision seeder-fertilizer machine at a depth of 0.03 m, with

Table 2. Average values of sowing density (kg ha^{-1}) for the following variables: plant heights, fresh mass, dry mass, plants per linear meter, grain yield and mass of 1000 grains under different sowing densities.

Source of variation	Sowing density (kg ha^{-1})			
	8	12	17,5	24
Plant height (cm)	110.08	101.66	94.36	99.82
Fresh mass (t ha^{-1})	42.56	45.15	32.26	67.95
Dry mass (t ha^{-1})	13.82	14.16	13.19	22.52
Plants/linear meter (unit)	32.40	35.60	44.80	55.60
Mass of 1000 grains (g)	8.40	7.82	7.81	7.21
Grain yield (kg ha^{-1})	2118.57	1941.94	1716.42	1706.12

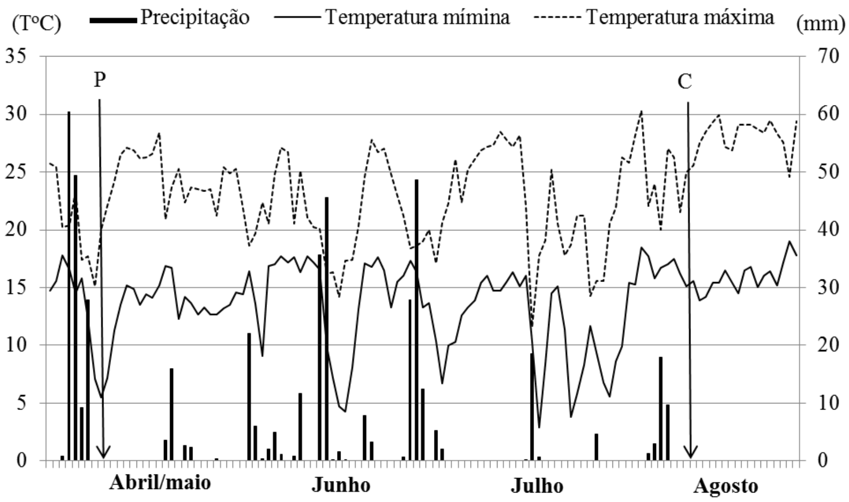

Fig 2. Rainfall, minimum and maximum air temperature during crambe development in Cascavel, PR 2012. P: Planting; C: Harvest.

Table 3. Chemical attributes of soil samples collected at 0 – 0.20 m of depth in the experiment area.

Soil attributes	cmol$_c$ dm^{-3}	Reading
Calcium (Ca^{+2})	5.39	High
Magnesium (Mg^{2+})	2.30	High
Potassium (K^+)	0.30	Medium
Aluminum (Al^{+3})	0.00	Low
H + Aluminum ($H^+ + Al^{3+}$)	5.76	High
Sum of bases (S)	7.99	High
CEC (T)	13.75	High
	g dm^{-3}	
Carbon (C)	27.12	High
Organic matter (OM)	46.65	High
	%	
Base saturation (V)	58.11	Medium
	mg dm^{-3}	
Phosphorus (P)	7.50	High
pH $CaCl_2$	5.20	

Source: Embrapa, 2009.

Table 4. Values concerning to crambe final stand density according to the four sowing densities.

Sowing density (kg ha^{-1})	Final stand density per treatment		
	1 linear meter	1m^2	4m^2
8	32	64	256
12	36	72	288
17.5	45	90	360
24	56	112	448

inter-row spacing of 0.45 m, no fertilization and sowing density. During the entire crop cycle development the occurrence of pests and diseases was monitored periodically; thus at the eleventh day after sowing we applied 0.2 L ha^{-1} of Lambda-cyhalothrin + Thiamethoxam to the crop through a 20 L knapsack sprayer for the control of *Diabrotica speciosa* (Germar). Harvest took place on 17/08/2012. Experimental design consisted of randomized blocks with four different seed densities (8; 12; 17.5 and 24 kg ha^{-1}) and five replications. A 52-hole sorghum disk was used for sowing with densities of 8 and 12 kg ha^{-1}. A 90-hole soybean disk was used for densities of 17.5 and 24 kg ha^{-1}.

Each treatment was distributed in five plots measuring 4 x 5 meters. Total experiment area consisted of 400 m². Table 4 shows values concerning to crambe final stand density under the four different sowing densities studied. Plot edges consisted of two sowing lines.

Assessed variables

The characteristics assessed during crambe development cycle were as follows:

Plant height: Measurements occurred at full flowering. Five plants were randomly collected from each plot. Plants were measured from ground level to their apex with the aid of a graduated ruler (Freitas et al., 2013).

Fresh mass: Five plants at full flowering were collected per plot, cleaned with paper towel and then weighed on a precision balance with readability of three decimal places. Data were converted from grams (g) into mass in kg ha^{-1} (Freitas et al., 2013).

Dry mass: Posterior to determining fresh mass, plants were dried up at 65°C in a greenhouse with air recirculation for 72 hours and then weighed on a precision balance. Data were converted from grams (g) into mass in kg ha^{-1} (Freitas et al., 2013).

Plants per linear meter (Plants/meter linear): Plants per linear meter were counted during harvest with the aid of a 5-meter measuring tape. Measurement was randomly performed in each plot, so that there was no tendency by choosing the best sowing lines.

Grain yield: Samples were collected from each plot by using a wooden frame measuring 1 m^2. All plants within the frame were collected disregarding the edge lines. Grains were put in empty fertilizer bags and separated manually from the plants. Later, grains were cleaned with the aid of sieves. Humidity was determined by drying grains in an oven at 110°C for 24 hours. Then the material was weighed on an analytical balance for the obtainment of grain mass data (Brasil, 1992).

Mass of 1000 grains: After determining grain yield 100 grains per sample were counted and weighed, and the results were multiplied by 10 (Brasil, 1992). Weights were corrected to moisture content of 13%.

Statistical analysis

Data obtained were subjected to analysis of variance (ANOVA) and regression test at 5% significance in ASSISTAT software.

Conclusion

Sowing density affected plant height, fresh mass, dry mass, plants per linear meter and grain yield;

The best results of plant height and grain yield were obtained at a seed density of 8 kg ha^{-1}, whereas fresh mass, dry mass and plants per linear meter showed the best results at a seed density of 24 kg ha^{-1}.

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