Selection of artichoke plants and analysis of correlation between quantitative traits for fresh consumption

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SUMMARY

Los objetivos del presente estudio fueron evaluar y seleccionar plantas de alcachofa aptas para consumo en fresco y establecer correlaciones entre caracteres cuantitativos. Treinta y nueve accesiones pertenecientes a la colección de germoplasma de la Universidad de Passo Fundo fueron clonadas y luego evaluadas para 17 caracteres cuantitativos y 3 cualitativos. Los datos correspondientes a los caracteres cuantitativos fueron sometidos a análisis de varianza seguido por una prueba comparación de valores medios de Tukey (p<0,05); las correlaciones fueron analizadas utilizando el coeficiente de correlación de Pearson. Se observaron diferencias significativas para 9 de los 17 caracteres cuantitativos analizados y 10 de las 39 accesiones mostraron elevados valores para algunos de esos caracteres. Se observaron valores significativos de correlación entre varios caracteres y el rendimiento, lo que facilita la selección indirecta. Considerando los caracteres cualitativos, se seleccionaron nueve accesiones por presentar capítulo esférico, brácteas violetas y ausencia de espinas, las cuales son características deseables para el consumo en fresco.

Palabras clave: alcachofra, consumo en fresco, caracteres cuatitativos.

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RESUMEN

The goals of the present study were to evaluate and select artichoke plants suitable for fresh consumption and to establish correlations between quantitative traits. Clones from 39 accessions were obtained from the germplasm collection of the University of Passo Fundo and evaluated for 17 quantitative and 3 qualitative traits. Data on quantitative traits were subjected to analysis of variance followed by a Tukey test at p<0.05 to compare averages, and correlations were analyzed using the Pearson product moment correlation coefficient. Significant differences were observed for 9 of the 17 quantitative traits analyzed, and 10 of the 39 accessions presented higher values for some of those traits than the remaining tested accessions. Significant correlations were observed between several traits and the capitulum yield, which makes indirect selection easier.

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For the qualitative traits, nine accessions were selected that presented circular head, violet colored bracts and absence of thorns, which are desirable traits for fresh consumption.

Keywords: artichoke, fresh consumption, quantitative traits.

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INTRODUCTION

Artichoke is a crop originating from the Mediterranean basin. Its immature head is eaten both fresh and industrially processed. Its high nutritional and medicinal value (Foti & Mauromicale, 1994) has generated interest in its cultivation in Brazil. However, in contrast with other vegetable crops, there are no intensive improvement programs for artichoke in Brazil. There are also few cultivars adapted to the state of Rio Grande do Sul (RS), and the commercially available cultivars do not present the uniformity of quality parameters demanded by the market for fresh consumption (Reolon-Costa *et al.*, 2012).

The establishment of a genetic improvement program for this crop, with the goal of developing cultivars adapted to RS and with uniform traits, especially in terms of shape (circular), head color (violet) and bract thorns (absence of thorns), could make new varieties available to the region's producers and provide incentive for the distribution of a new and profitable crop. However, producing new varieties requires genetic variability for these traits (Cointry *et al.*, 1999).

After the existence of variability is determined, the next stage is the selection of genotypes and/or individual plants presenting traits desirable for fresh consumption. These genotypes can be used as parental lines for hybridization with the goal of, for example, establishing an initial base population for phenotypic recurrent selection. An important factor in this process is the degree of correlation between the evaluated traits (Carvalho *et al.*, 2003). Correlation coefficients can therefore be used as selection criteria, associating a trait that is easy to evaluate with another that is more difficult or time-consuming to assess.

The goals of the present study were to evaluate and select plants suitable for fresh consumption from a collection of artichokes from the University of Passo Fundo and to establish correlations between the major quantitative traits.

MATERIALS AND METHODS

This study consisted of the evaluation of 39 accessions pre-selected from the artichoke germplasm collection from the University of Passo Fundo based on the presence of desirable traits for fresh consumption such as circular shape, violet color and absence of thorns at the external bracts. These accessions originated from varieties GG - Green globe (11 plants), GGI - Green Globe improved (19 plants), RM - Romanesco (5 plants), VS - Violet the Sicilia (1 plant), RO - Roxa Romana (1 plant) and RE - Roxa Redonda (2 plants).

The assay was conducted at Passo Fundo, Planalto Médio region of Rio Grande do Sul state, at 687 m altitude. The climate of the region is characterized as fundamentally humid and subtropical (Kuinchtner & Burial, 2001).

The pre-selected accessions were cloned: axillary buds of each plant were collected at the end of the harvest (January 2010) and considered replicates of each mother plant evaluated. Seedlings collected in the field were established in flower box-type recipients containing 3 kg commercial substrate, and they were kept in a greenhouse until being transferred into the field. Seedlings were established in the field in April 2010, with a completely randomized experimental design, with 4 to 6 replicates (buds) per mother plant.

Evaluations were performed when the primary capitulum reached the commercial stage, or Stage 4 (Baggio *et al.*, 2012), in terms of the following quantitative traits: length, width and thickness of the bract base (mm), length, diameter (cm) and fresh mass of the primary head (g), diameter, thickness (mm) and fresh mass of the bottom (g) of the primary head, harvest duration, period from planting until harvest, number of secondary heads (head massing more than 100 g), height, diameter (cm) and fresh mass of secondary head (g), total head per plant at the end of the harvest, and yield (total number of head x head fresh mass).

The following qualitative traits were evaluated: (1) shape of primary head: circular, elliptical, oval, triangular or large transverse elliptical; (2) external bract color: green, violet-striped green, green-striped violet, mostly violet, or completely violet; and (3) presence or absence of thorns at the external bracts.

Quantitative data were subjected to analysis of variance (ANOVA) followed by a Tukey test, with $p<0.05$ considered significant. Correlations between quantitative traits were tested by calculating the Pearson product-moment correlation coefficient. Quantitative traits were visually assessed, and the percentage of plants in each category was recorded.

RESULTS AND DISCUSSION

Significant differences among the 39 studied accessions were observed for 9 of the 17 traits evaluated (p<0.05): length and width of the bract base of the primary head, harvest duration, number, height, diameter and fresh mass of secondary head, total head per plant and yield (Table 1).

The observed variations in the evaluated traits between accessions may be due to genetic differences because the mother plants of the germplasm collection were mostly established from seed (and thus each plant has a different genotype), to environmental differences, and sometimes to interactions between genotype and environment. However, variability between replicates (clones) of a given mother plant are due to environmental effects because the replicates possess the same genetic makeup.

The highest coefficients of variation were observed for traits that can be influenced by environmental factors, including bottom fresh mass, bract base thickness, number of secondary heads, yield and total head per plant (Table 1). This was expected because these traits are governed by many genes with additive effects, and they present continuous phenotype distribution and low heritability (Cointry *et al.*, 1999).

Table 1: Analysis of variance for 17 quantitative characters evaluated in 39 plants of artichoke, Passo Fundo -2014

Variables	GL	SQ	QM	CV%	Test F
LBB	38	1.1215	0.031	1.42	0.0009*
WBB	38	2598.97	68.39	16.41	0.0000*
TBB	38	169.31	4.45	37.73	0.1592ns
LPH	38	46.62	1.22	11.29	0.048ns
WPH	38	49.13	1.030	13.12	0.333ns
FPH	38	42246.50	1243.42	25.78	0.647ns
DB	38	2821.56	74.25	15.50	0.142ns
TB	38	246.10	6.47	24.94	0.198ns
FMB	38	5430.60	142.91	40.65	0.250ns
HD	38	363.69	9.57	12.27	0.0000*
PPH	38	9982.95	262.70	6.20	0.041ns
NSH	38	37.053	0.975	32.66	0.0073*
HSH	38	31.494	0.85	9.60	0.021*
DSH	38	41.143	1.082	10.26	0.005*
FSH	38	42532.10	1119.26	18.45	0.0002*
TPH	38	409.08	10.78	26.68	0.000*
Y	38	17395.26	4577.00	32.72	0.001*

Analysis of variance (p<0.05*) length of the bract base (LBB), width of the bract base (WBB), thickness of the bract base (TBB), length of the primary head (LPH), width of the primary head (WPH), fresh mass of the primary head (FPH), diameter of the bottom (DB), thickness of the bottom (TB), fresh mass of the bottom (FMB), harvest duration (HD), period from planting until harvest (PPH), number of secondary heads (NSH), height of secondary heads (HSH), diameter of the secondary heads (DSH), fresh mass of the secondary heads (FSH), total heads per plant at the end of the harvest (TPH) and yield (Y).

Cravero *et al.* (2004) also observed significant variations in fresh mass, height, diameter and number of secondary heads and yield, but with lower coefficients of variation than the ones found in the present study. The authors also observed higher variation for secondary than for primary head fresh mass. In the present study, however, no significant variations were observed in primary head fresh mass or length or in bottom thickness or fresh mass. This may be because the evaluated accessions were pre-selected based solely on the appearance of the primary head.

However, the existence of variability among the accessions evaluated allows better use of these genotypes, as well as the identification of superior plants based on traits useful for selection. These plants could then be used as progenitors in crossings with the goal of establishing new segregating populations onto which different selection models and improvement methods could be applied, such as recurrent phenotypic selection (Cointry *et al*., 1999; Cravero *et al*., 2004).

The edible parts of the artichoke are the bract base and the bottom (flower receptacle). The evaluation of these traits is therefore important because they can be used as parameters of head quality for fresh consumption (Reolon-Costa *et al*., 2012). Accessions GGI16 and GGI76 presented greater bract base length than accessions RM6, RM2, GG15, GG19 and GGI57 and were not significantly different from the remaining accessions evaluated. For the bract base width, accessions GG40 and GG31 were superior to 20 of the remaining accessions evaluated, and they were not significantly different from accessions GGI67, GGI70, GGI72, GGI76, GGI13, GGI9, GGI16, GGI38, GGI65, GGI64, GGI58, GGI29, GG39, GG29, VS5, RM1 and RE21 (Figure 1a). The deviation for this trait varied between 0.52 and 12.22 mm. Variation was also observed between replicates (clones); this variation was environmental in origin and not genotypic because the replicates are genetically identical.

Harvest duration is correlated with the time over which the plants remain productive and corresponds to the period between the harvest of the primary head and the harvest of the last secondary head with acceptable market traits (in this case, head with fresh mass greater than 100 grams). This trait influences total plant productivity and depends on environmental conditions and plant vegetative vigor. GGI64 presented longer duration of the harvest period than accessions RO26, RM4, GG19, GGI29, GGI65 and was not significantly different from the remaining accessions evaluated. This trait varied between 9 and 16 days (Figure 1b).

Accession GGI38 presented high average height for secondary head, significantly different from accessions GGI71 and GGI13. For the secondary head diameter, accessions RO26 and GG9 were larger than GGI72 but were not significantly different from the remaining evaluated accessions (Figures 1c, d).

Among the traits related to productivity, the fresh masses of the primary and secondary head are highlighted. Accession GG39 presented higher averages for these two traits than accessions RM4, GG29, GGI58, GGI19, GGI16 and GGI72 (Figure 2a). A wide range of variation was also observed for this trait, between 0.82 g and 163.2 g, indicating the possibility of its selection. The production of head with higher fresh mass is important for both consumption fresh and production of hearts and bottoms for the canning industry.

Accession GGI19 presented higher numbers of secondary heads than 10 of the remaining accessions evaluated (Figure 2b). GGI19 was also superior to the majority of the tested accessions in the total head per plant (Figure 2c). The number of head per plant is a varietal trait (Foti & Mauromicale, 1994; Miccolis *et al*., 1999) and the main yield component in artichoke (Cravero *et al*., 2004).

Accessions GGI19 and GGI70 presented higher yield per plant than accessions RM4 and GGI71 (Figure 2d). The large observed range of variation for the yield (220.73 to 719.21 g) was because this trait is determined by several genes with minor effects and low heritability and is influenced by environmental factors (Borém & Miranda, 2009).

Accession GGI19 also presented higher numbers of secondary heads and head per plant, along with good yield (1000 g). This is consistent with Bagget *et al*. (1982) and Cravero *et al*. (2004), who reported that the yield is mainly influenced by the number of heads and less by their fresh mass. This also suggests the existence of a correlation between these traits and poses the following two questions: Is there a correlation between these traits? What is the degree of this correlation?

The Pearson product-moment correlation coefficient tests the correlation between variables (Falconer & Mackey, 1996) and estimates the joint influence of genetic and environmental factors on the expression of a given trait (Ferreira *et al*., 2003). The estimation of these associations allows indirect selection and allows the analysis of a smaller number of variables in an improvement program. Bract base length was positively correlated with bract base thickness and bottom fresh mass, and it was negatively correlated with harvest duration. A significant positive correlation was also observed between the bottom thickness and diameter (Table 2).

Bottom fresh mass is also significantly correlated with bottom diameter and thickness, primary head length and diameter, and bract base thickness and length. This indicates that selecting head with higher diameter will indirectly select head with higher bottom fresh mass, diameter and thickness, eliminating the need for specific evaluations of these traits, thereby resulting in higher efficacy and speed of the selection process.

Of the productivity traits, the primary head fresh mass was significantly positively correlated with the bottom fresh mass, secondary head average height, and duration of the harvest period. Another relevant productive trait with high impact, especially

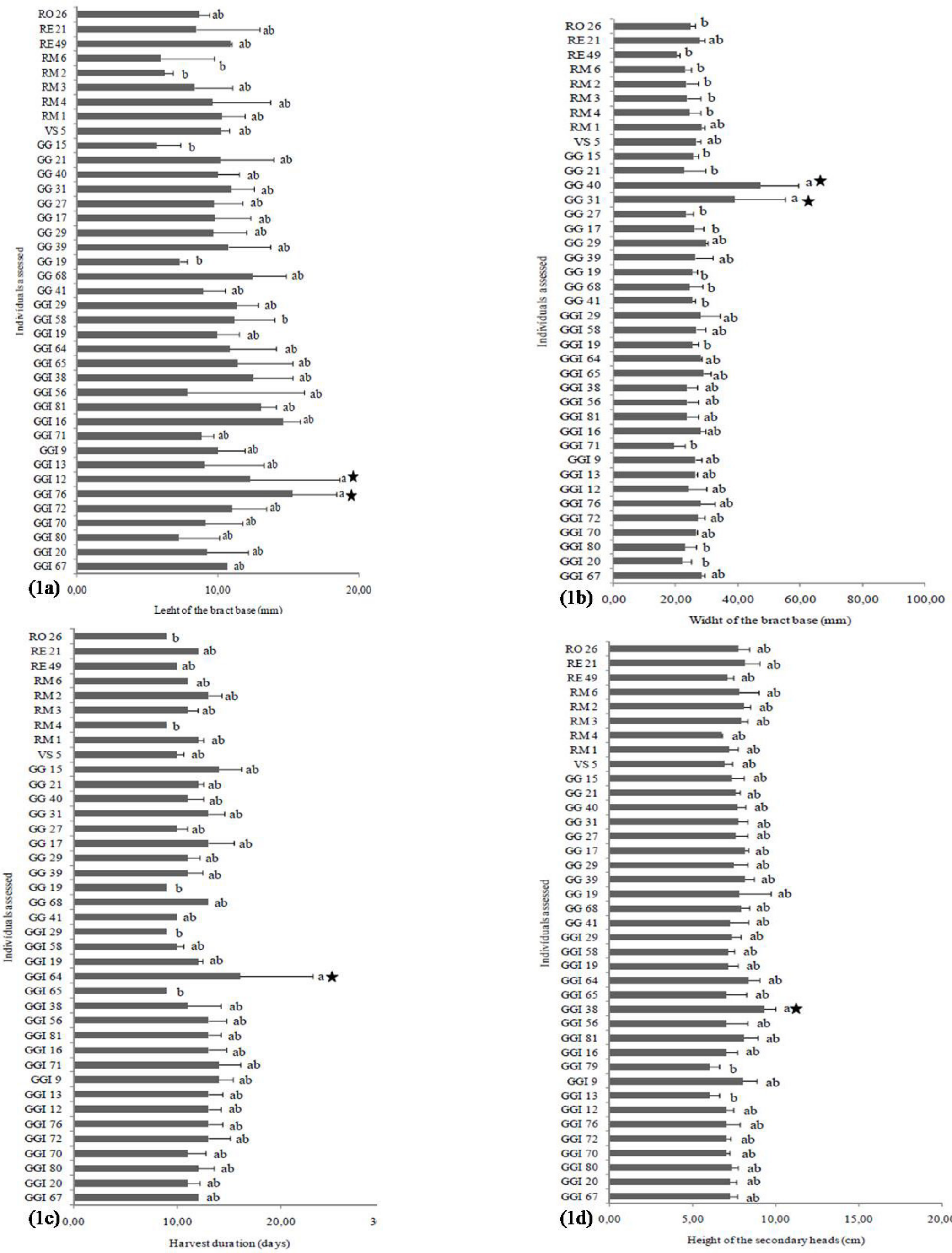

Figure 1. Comparison of averages by Tukey test at 5% of probability de error for characters: length of the bract base (a), duration harvest (b), height of the secondary heads (c), diameter of the secondary heads (d), between 39 plants of artichoke. Letters comparing the averages between treatments, Passo Fundo - 2014.

on the marketable yield, is the total head per plant, which was significantly positively correlated with the yield and negatively with the secondary head fresh mass. Through these results, we can infer that, the higher the number of heads per plant, the lower their individual fresh mass of heads. This is due to the higher number of sinks competing for photoassimilates at the plant. Crippa *et al.* (2011)

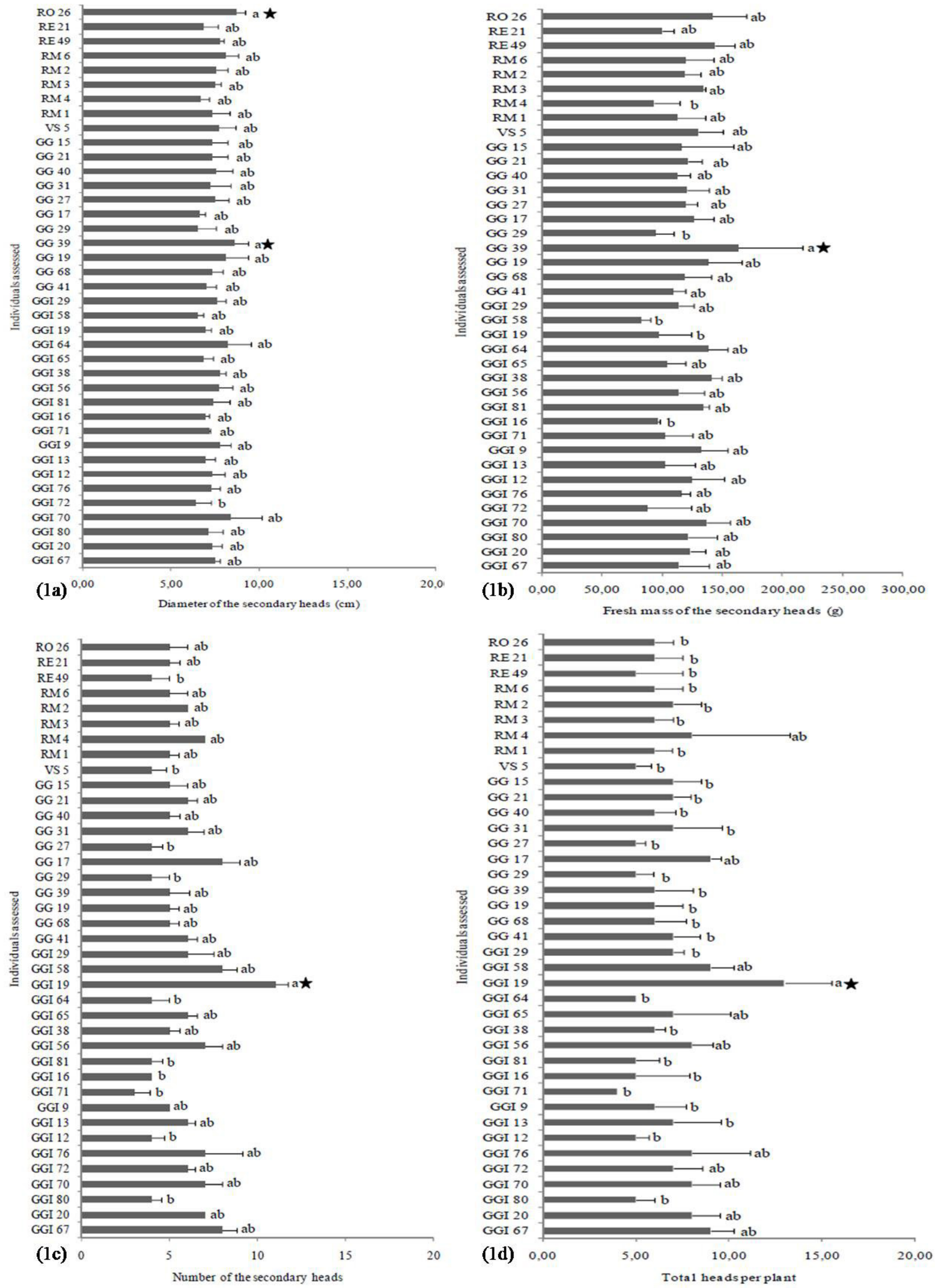

Figure 2. Comparison of averages by Tukey test at 5% of error probability for characters: fresh mass of the primary heads (a), number of the secondary heads (b), total heads per plant (c) and yield (d) between 39 plants of artichoke. Letters comparing the averages between treatments, Passo Fundo - 2014

Table 2: Significant values of correlation of Pearson between characters assessed between plants of artichoke of different cultivars, Passo Fundo - 2013

Variables	Correlation	Probability
LBB x TBB	0.67	0.0006***
LBB x FB	0.57	0.0158**
LBB x DH	- 0.36	1.957*
WBB x TBB	0.38	1.368*
WBB x LPH	0.44	0.4332**
WBB x PPH	- 0.44	0.4321**
TBB x FB	0.42	0.6329**
TBB x PPH	- 0.51	0.0827**
TB x FMP	0.91	0.0011***
TB x PPH	- 0.52	0.0717**
TB x DB	0.40	0.4914*
FMP x DH	0.48	0.1767*
FMP x HSH	0.34	3.1606*
LPH x FB	0.34	2.7621*
LPH x PDH	0.46	0.2639**
DPH x FB	0.36	2.0237*
DPH x PPH	0.32	4.316*
DB x FB	0.33	3.6936*
PPH x FSH	0.36	2.2828*
PPH x DSH	0.33	3.5013*
NSH x FSH	- 0.55	0.0266**
NSH x HSH	- 0.32	3.8664*
NSH x DSH	- 0.39	1.1417*
NSH x THP	0.81	0.0039**
FSH x HSH	0.71	0.0045**
FSH x DSH	0.78	0.000***
FSH x THP	- 0.31	4.9688*
HSH x DSH	0.40	1.1135*
THP x Y	0.99	0.0000***

Significant at 1 and 5% of probability by test t, length of the bracts base (LBB), width of the bracts base (WBB), thickness of the bracts base (TBB), length of the primary head (LPH), diameter of the primary head (DPH), fresh mass of the primary head (FMP), diameter of the bottom (DB), thickness of the bottom (TB), fresh mass of the bottom (FB), harvest duration (HD), period from planting until harvest (PPH), number of the secondary heads (NSH), height of the secondary heads (HSH), diameter of the secondary heads (DSH), fresh mass of the secondary heads (FSH), total of heads per plant (THP) and yield (Y).

also observed that plants with more heads produce higher final yields.

The total number of heads per plant was also positively correlated with the number of secondary heads, whereas the number of secondary heads was significantly negatively correlated with the secondary head fresh mass, height and diameter, again showing an inverse correlation between the head number and fresh mass and size. This answers the initial questions and confirms the existence of a correlation between the yield and the number of secondary head and number of heads per plant (Table 2).

Correlation studies of traits with selection interest in artichoke have been reported by other authors. López Anido *et al*. (1998) evaluated a population of clones in Argentina and determined the number of heads at the end of the harvest, fresh mass of primary and secondary heads, and bottom fresh mass, to be the traits associated with the yield.

Because the genetic improvement of this crop must meet the demands of the consumer market, selection should be applied not only to quantitative traits such as those mentioned above but also to qualitative traits of the head (Mauromicale & Copane, 1989). Traits such as color, shape and absence of thorns at the external bracts, are therefore of great importance. Accessions GGI67, GGI20, GGI80, GGI76, GGI12, GGI13, GGI9, GGI71, GGI65, GGI64, GGI19, GGI58, GGI29, GG61, GG48, RM1, RM4, RM3, and RM2, corresponding to 51% of the evaluated accessions, presented circular primary head (Figure 3a). The remaining accessions evaluated presented heads with elliptical, oval and large transverse elliptical shapes. No triangular head were observed. The head shape is extremely important for genetic improvement programs of artichoke because it is closely related with the head compactness. More compact heads present a circular shape because they possess more internal bracts (Reolon-Costa *et al*., 2012). Conical heads have lower numbers of bracts and do not withstand post-harvest handling, becoming deformed (Foury, 1967). The accessions listed above, presenting circular heads, could therefore be selected as progenitors for future crossings with the goal of improving the capitulum quality for fresh consumption.

The appearance and color are important qualitative traits for the majority of vegetables consumed fresh. Artichoke consumers, in particular, are very sensitive to the head color, and this is a marker trait of this crop's quality (Aubert, 1976). Violet head are preferred in several countries, including France, Italy, Argentina and Brazil. The present study included 38% violet-striped green (GGI76, GGI12, GGI13, GGI9, GGI71, GGI16, GGI81, GGI56, GGI29, GG41, GG68, GG31, GG40, GG21, GG15), 15% green-striped violet, 7% mostly violet, and no (0%) completely violet head. The remaining plants had green head (38%) (Figure 3b).

This shows the existence of variability for this trait and thus the possibility of selection of plants with violet head, which can then be used as progenitors in crossings with the goal of incorporating genes

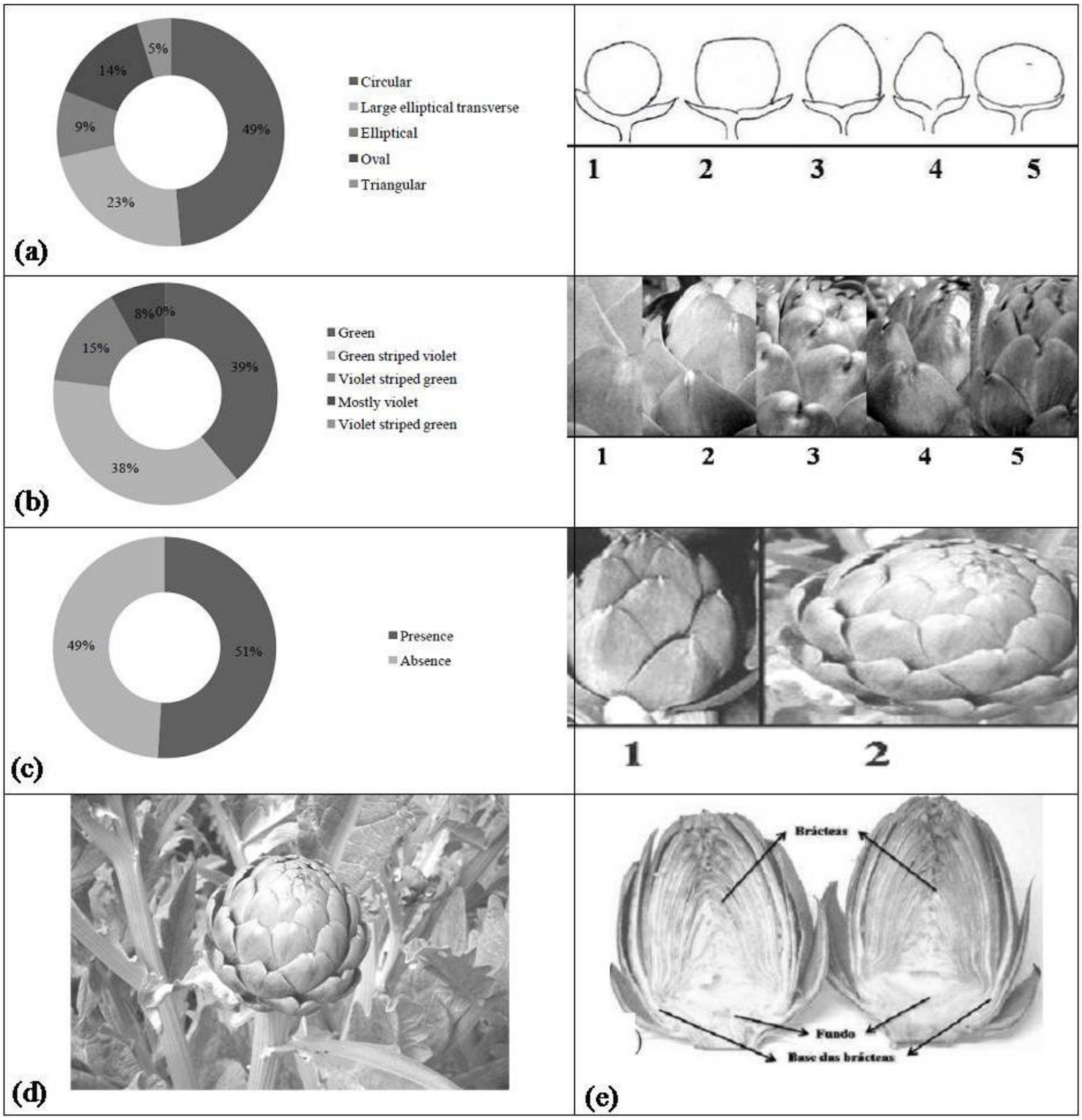

Figure 3. Relative frequencies for each class of characters: shape (a), color of the primary heads (b), presence/absence of thorns (c), heads of the artichoke (d) and identification the bracts and bottom. Passo Fundo - 2014.

responsible for the violet color. This variability also shows the need to develop materials with higher uniformity of head color and possessing the color required by the consumer market. Capitulum color is determined by two allele pairs (P, p and U, u) with complete dominance on each locus and a recessive epistatic relationship (Cravero *et al.*, 2005).

Another trait that should be considered in the selection process is the presence of thorns at the external bracts, which is not desirable for the market of *fresh* consumption. Of the accessions evaluated, 49% did not present thorns at the external bracts (GGI20, GGI70, GGI72, GGI12, GGI13, GGI9, GGI71, GGI81, GGI65, GGI64, GGI19, GGI58, GG41, GG68, RM1, RM4, RM3 and RM6) (Figure 3c). Thorn absence is determined by a dominant gene (Sp), and thorn presence is determined by its recessive form (sp) (Pecaut and Foury, 1992). It is therefore very difficult to completely eliminate this trait from a segregating population because it remains masked in the heterozygote.

In the present study, heads were observed to present different sizes, shapes and colors, and variability for the qualitative traits and nine of the quantitative traits evaluated. Knowledge of this variability, and of the correlation coefficients between quantitative traits, will allow better use of the existing materials and the identification of progenitors that can be used in crossings with the goal of establishing a segregating population onto which various selective models can be applied.

Based on their quantitative traits, eight accessions (GGI16, GG40, GG31, GG15, GG39, GGI38, RO9 and GGI19) stand out for traits including bract base length, bract base width, harvest duration, fresh mass, height and diameter of secondary head, number of secondary head, total heads per plant, and yield and could therefore be selected. However, when qualitative traits are considered, accessions GGI12, GGI13, GGI9, GGI71, GG41, GG68, RM4, RM3 and RM6 presented all the desirable traits for fresh consumption: circular shape, violet color, and absence of thorns (Figure 3d and 3e).

The selection of progenitors for genetic improvement is directed by the market demand and the goals of the selection program. Considering the

Table 3: Description of 39 plants assessed as three main characters of head quality for fresh consumption, Passo Fundo - 2014

Genotypes	Shape	Color	Thorns
GGI67	Circular	Green	Presence
GGI20	Circular	Green	Absence
GGI80	Circular	Green	Presence
GGI70	Large transverse elliptical	Green	Absence
GGI72	Large transverse elliptical	Green	Absence
GGI76	Circular	Green striped violet	Presence
GGI12	Circular	Green striped violet	Absence
GGI13	Circular	Green striped violet	Absence
GGI9	Circular	Green striped violet	Absence
GGI71	Circular	Green striped violet	Absence
GGI16	Large transverse elliptical	Green striped violet	Presence
GGI81	Large transverse elliptical	Green striped violet	Absence
GGI76	Elliptical	Green striped violet	Presence
GGI38	Large transverse elliptical	Green striped violet	Presence
GGI65	Circular	Green	Absence
GGI64	Circular	Green	Absence
GGI19	Circular	Green	Absence
GGI58	Circular	Green	Absence
GGI29	Circular	Green	Presence
GG41	Circular	Green striped violet	Absence
GG68	Circular	Green striped violet	Presence
GG19	Large transverse elliptical	Green striped violet	Presence
GG39	Large transverse elliptical	Green	Presence
GG29	Large transverse elliptical	Green	Presence
GG17	Large transverse elliptical	Green	Presence
GG27	Elliptical	Green	Presence
GG31	Elliptical	Green striped violet	Presence
GG40	Elliptical	Green striped violet	Presence
GG21	Oval	Green striped violet	Presence
GG15	Oval	Green striped violet	Presence
VS 5	Oval	Violet striped green	Presence
RM1	Circular	Violet striped green	Absence
RM4	Circular	Violet striped green	Absence
RM3	Circular	Violet striped green	Absence
RM2	Circular	Violet striped green	Presence
RM6	Circular	Violet striped green	Absence
RE49	Oval	Mostly violet	Presence
RE21	Oval	Mostly violet	Presence
RO26	Oval	Mostly violet	Presence

lack of uniformity of the Brazilian varieties for traits related to head quality and that the main goal of the improvement program started at the University of Passo Fundo is to improve head quality.

CONCLUSIONS

(a) Nine accessions were superior for qualitative traits and can be selected for inclusion in crossing blocks with the goal of short-term improvements.

(b) Ten accessions that stood out for the evaluated quantitative traits can be maintained at the collection and included in future cross.

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