

## RESPONSE OF PRODUCTIVE AND MORPHOVEGETATIVE TRAITS OF GLOBE ARTICHOKE (*Cynara cardunculus* var. *scolymus*) TO MASS SELECTION AND ESTIMATION OF THEIR HERITABILITY

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### ABSTRACT

There have been few reports on genetic parameters or artificial selection for growth traits in globe artichoke (*Cynara cardunculus* var. *scolymus*), the study of the effect of one cycle of mass selection and realized heritability estimates would be valuable for planning breeding strategies in this species. A  $C_0$  segregating population was formed from the cross of two contrasting seed-grown cultivars, Imperial Star and Estrella del Sur FCA. Selected plants for productive traits were intercrossed to produce a  $C_1$  population. The  $C_1$  population along with the  $C_0$  population, both parents and the  $F_1$  were evaluated obtaining the response to selection and estimating realized heritability. Mass selection for increased yield and precocity was particularly successful, where for the first trait realized heritability reached 0.71 and 0.60 for the second one. For most traits, the observed values for realized heritability in the experiment (0.75, 0.61 and 0.52 for weight of the main head, marketable yield and length of the main head, respectively) indicate that a substantial part of the observed phenotypic variance is of additive nature. Therefore, in general, selection for these traits in seed-grown globe artichoke populations will be effective.

**Key words:** additive actions, breeding program, *Cynara cardunculus* var. *scolymus*, realized heritability.

### INTRODUCTION

Traits of economic importance from a production point of view are usually determined by a large number of genes (Hallauer, 2007) and oftentimes are under considerable environmental influence. Thus, these traits are best studied by means of quantitative genetic techniques, which reduce the most important features of complex systems to relatively few variables, e.g. principal components and cluster analysis that can be estimated from phenotypic measurements (Lande and Arnold, 1983; Falconer and Mackay, 1996). Breeding methodologies utilized for maximizing genetic gain are based on breeding objectives with specific aim of providing farmers with high yielding varieties (de Souza Gonçalves *et al.*, 2009). Extensive research has been conducted to determine the relative importance of different genetic effects in

the inheritance of quantitative traits for most cultivated plant species (Bert *et al.*, 2003; Bhatia *et al.*, 2006, Osekita and Akinyele, 2008). Although progress had been made in cultivar development in most crop species, further genetic progress in improved cultivars requires more information on the inheritance of the primary and association traits.

Lush (1945) defined heritability ( $h^2$ ) either as the ratio of the additive genetic variance to the phenotypic variance or as the ratio of the total genetic variance to the phenotypic variance. The first was designated as  $h^2$  in the narrow-sense, and indicates the portion of the trait variation associated with the gene action of additive nature; whereas the second was designated as  $h^2$  in the broad-sense. The heritability in narrow-sense is generally more meaningful than heritability in broad-sense because the last one determines the amount of progress than can be made from selecting and recombining the best individuals in a population. In contrast, heritability in broad-sense is more meaningful when all types of genetics variance can be exploited, as in selection among clones (Gonçalves *et al.*, 2006).

Dudley and Moll (1969), Moll and Stuber (1974), and Dudley (1997) have emphasized that information on

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the inheritance of quantitative traits have application to planning breeding strategies for cultivar development. Furthermore, Dudley and Moll (1969) stated that plant breeding includes three stages: identify or create pools of germplasm, select superior individuals from the chosen germplasm, and develop a superior cultivar from the selections. A fourth stage would be to intermate the superior individuals to improve the original germplasm pool (i.e., some type of cyclical or recurrent selection). Estimates of the relative importance of the types of genetic variation and heritabilities are of value in making decisions in all these stages. The estimates of heritability are meaningful for the reference population from which the genetic and phenotypic variances were estimated. Hanson (1963), Nyquist (1991), and Holland *et al.* (2003) have discussed the factors that are important in determining estimates of  $h^2$  in plant populations. Mating designs imposed on populations can provide estimates of variances, and these used to calculate  $h^2$  for different combinations of progenies and testing conditions. Estimates of  $h^2$  can also be obtained from evaluation trials where progenies are developed from populations that are under some type of recurrent selection. Population biologists often use an index called realized heritability ( $h_r^2$ ) to quantify the degree to which a trait in a population can be improved by selection. This value measures the change in breeding value per unit change in phenotypic value. Realized heritability estimation relies on determining how much of the selection differential applied in a previous generation is achieved as a response in the progeny of the selected parents. Even when it is a retrospective approach, the estimate can be used to make predictions about future responses to selection in similar populations, for at least a short period.

Globe artichoke (*Cynara cardunculus* var. *scolymus* Fiori) is commercially propagated mainly by vegetative means. Consequently, many diseases are transmitted causing considerable losses of heads and even plants, thus lowering crop productivity (Ryder *et al.*, 1983). These problems could be avoided if seed-propagated cultivars were available to growers. One of the exciting and potentially rewarding tasks would be the replacement of the asexual multiplication system by genetically improved seed-grown populations, better suited for the culture environment and the consumer's preferences. At the present time, seed-grown varieties of good quality and uniformity are scarce in the globe artichoke market. Consequently, their attainment is an important objective of artichoke breeding programs.

There have been few studies on genetic parameters or artificial selection for growth traits in globe artichoke. A considerable genetic variation, which might be exploited

in selection programs aimed at improved populations, could be inferred from the great phenotypic variation observable among clones in this species. Heritability estimates have been obtained for yield and their components by analyzing differences among clones, but there are not estimates from breeding seed-grown populations. The genotypic advance made from a single generation cycle would be important as a measure of the potential success achieved through more cycles of breeding.

The objectives of the present contribution were to determine the response of productive and morpho-vegetative traits of globe artichoke to selection and to obtain estimates of realized heritability.

## MATERIALS AND METHODS

Two open-pollinated varieties of artichoke from USA and Argentine were used, one of them, 'Imperial Star' (IS) (California University Desert Research and Extension Center, Holtville, California) with an early production, tronco-conical, and green heads, and very productive (Gil Ortega *et al.*, 1993; Gil and Villa, 2004) and the other, 'Estrella del Sur FCA' (Universidad Nacional de Rosario, Argentine) with sub-spherical, compact and violet heads, later and less productive than IS (García *et al.*, 2006).

The two varieties were inter-crossed and then each  $F_1$  plant was hand selfed and bulked the seeds to obtain  $C_0$  generation. Although the artichoke is a highly heterozygous, both varieties are stables for contrasting traits and do not segregate for the same so that the  $F_1$  generation was uniform. In the  $C_0$  generation, precocity and total yield were the main criterion for selection and the best 20 were selected (18%) with values less than 170 d to harvest and yielding over 700 g per plant. The principal head was harvested and weighed in each  $C_0$  selected plant. The total productive output was estimated based on the total number of heads produced. The heads of unselected plants were completely harvested and weighed.

To generate the  $C_1$  cycle selected  $C_0$  plants were naturally crossed at random by insects using their secondary heads (not harvested).  $C_0$  and  $C_1$  generations were evaluated under the same environmental conditions. Seeds of both parental, their  $F_1$ ,  $C_0$ , and  $C_1$  cycles were sown in speedling in March 2006. In early April 2006 all materials were field transplanted. Three replicates of 30 plants of both varieties and the  $F_1$  generation were used under a complete randomized design.  $C_0$  generation was comprised by 116 plants and the  $C_1$  generation by 103 plants considering each plant as experimental unit. Plant

spacing was 140 cm between rows and 80 cm within rows. In the spring of 2006 the following traits were evaluated: Days to first harvest (FH) measured as the number of days from seed sowing to the harvest of the main head, number of head per plant (NH), weight of the main head (WH), total yield (TY), marketable yield (MY) per plant (TY multiplied by the quality of the heads that were evaluated by visual inspection using a scale ranging from 0.2 to 1, taking in account spineless bracts, tightness, color and general aspect of main head according to Asprelli *et al.* (2001). The length (LH) and diameter (DH) of the main head were also evaluated.

The normal distribution of the traits was tested according to Shapiro and Wilk (1965). The mean values of the traits were compared by ANOVA, and Duncan's multiple range test was used to determine statistical differences among treatments (Sokal and Rohlf, 1969).

The response to selection was calculated by subtracting from the mean of the  $C_1$  generation the mean of  $C_0$  generation. The selection differential was obtained by subtracting the mean of the selected  $C_0$  parents the average of the  $C_0$  generation. Realized heritability was estimated as the selection response divided by the selection differential.

## RESULTS AND DISCUSSION

The mean values for the parental population and selected fraction are shown in Table 1. Except for number of heads, the rest of the traits that define crop productivity showed

highly significant differences between average behavior of  $C_0$  population and selected individuals. Selection differential were positive for all the traits except for FH, which was negative.

The ANOVA showed significant differences between  $C_0$  and  $C_1$  cycles for FH, WH, TY, MY, and LH (Table 2); meanwhile for HH and DH no differences were found between generations. This fact implies that mass selection for increased TY and precocity was particularly successful. The highest responses were obtain for MY (34%), TY (24.1%) and WH (16.8%), meanwhile for the rest of the traits the response was not significant (NH = 9.3%, LH = 11.3% and DH = 1.4%).

Realized heritability estimated for the different traits are presented in Table 3. Heritability estimates ranged from 0.0 to 0.75. Realized heritability for FH, WH, TY, and MY was generally high (overall  $\bar{x}$  = 0.65). In contrast, heritability estimated for the rest of the traits was more variable ranging from 0.0 to 0.52. Heritability estimates smaller than 0.10 are approximately equal to zero. Pacucci *et al.* (1973), De Pace *et al.* (1973) and Asprelli *et al.* (2001) showed that the variability of globe artichoke populations is a result of additive gene effects, although for some traits, such as weight of the first head and some secondary characteristics, dominant or non-additive gene effects prevailed. López Anido *et al.* (1998) working with clones, detected high values of heritability in broad sense and suggested that selection would be effective for yield, weight of secondary artichokes, bottom weight and harvest period. On the

**Table 1. Average values of the  $C_0$  cycle, selected plants, and selection differential for the different traits.**

	FH	WH	NH	TY	MY	LH	DH
$C_0$	169.9 ± 0.9a	140.2 ± 3.9b	4.6 ± 0.2a	547.1 ± 26.9b	424.0 ± 26.9b	8.1 ± 0.08b	6.3 ± 0.06b
Selected plants	159.8 ± 9.74b	190.8 ± 15.5a	5.6 ± 0.67a	903.6 ± 162.2a	903.6 ± 162.2a	9.8 ± 0.31a	7.3 ± 0.27a
Selection differential	-10.1	50.6	1.0	356.5	479.6	1.7	1.0

FH: days to first harvest; WH: weight of the main head; NH: number of heads per plant; TY: total yield; MY: marketable yield; LH and DH: length and diameter of the main head.

Per column, values followed by a same letter do not differ according Duncan's test ( $P < 0.01$ ).

**Table 2. Analysis of variance of the  $C_0$  and  $C_1$  cycles for the different traits.**

	FH		WH		NH		TY		MY		LH		DH		
	df	MS	F	MS	F	MS	F	CM	F	CM	F	CM	F	CM	F
Cycles	1	1977.1	31.5**	74186.4	29.6**	31.93	2.8ns	3197927	16.7**	4311543	24.4**	50.2	111.4**	0.42	1.0ns
Error	215	62.7		2511.8		11.4		191700.4		176427		0.45		0.41	

\* $P < 0.05$ ; \*\*  $P < 0.01$ ; ns: non significant.

FH: days to first harvest; WH: weight of the main head; NH: number of heads per plant; TY: total yield; MY: marketable yield; LH and DH: length and diameter of the main head.

**Table 3. Average values of the cycles C<sub>0</sub>, C<sub>1</sub>, selection response (SR), selection differential (S), realized heritability (h<sup>2</sup>) and for the different traits.**

	FH	WH	NH	TY	MY	LH	DH
ES	203.2 ± 1.2	278.3 ± 11.5	8.3 ± 0.3	1167.7 ± 88.4	978.4 ± 68.8	8.7 ± 0.1	7.4 ± 0.1
IS	181.1 ± 0.9	340.9 ± 14.6	9.8 ± 0.5	1619.6 ± 83.0	1443.1 ± 96.3	7.8 ± 0.1	8.4 ± 0.1
F <sub>1</sub>	188.3 ± 0.8	318.7 ± 4.3	10.9 ± 0.3	1780.5 ± 43.1	1641.4 ± 43.2	8.5 ± 0.06	8.2 ± 0.04
C <sub>0</sub>	199.6 ± 0.8a	227.5 ± 5.4b	8.6 ± 0.4a	1052.6 ± 49.6b	867.8 ± 48.7b	8.0 ± 0.06b	7.2 ± 0.07a
C <sub>1</sub>	193.5 ± 0.7b	265.7 ± 4.2a	9.4 ± 0.3a	1306.0 ± 32.0a	1162.7 ± 30.5a	8.9 ± 0.06a	7.3 ± 0.04a
RS	-6.1	38.2	0.80	253.4	294.9	0.9	0.1
S	-10.1	50.6	1.0	356.5	479.6	1.7	1.0
h <sup>2</sup>	0.60	0.75	-	0.71	0.61	0.52	-

FH: days to first harvest; WH: weight of the main head; NH: number of heads per plant; TY: total yield; MY: marketable yield; LH: length of the main head; DH: diameter of the main head.

Per column, values followed by a same letter do not differ according Duncan's test ( $P < 0.01$ ).

other hand, Cravero *et al.* (2004) in a study with a diallel analysis found that additive genetic effects primarily control most of the evaluated variables, as deduced by the large magnitude of the general combining ability effects (associated to additive gene actions) compared to the specific combining ability effects (related to non-additive gene actions).

The estimates for the realized heritability for yield and precocity are specific for the populations, selection procedures, and environmental circumstances used. The observed values for realized heritability in this experiment, however, indicate that a substantial part of the observed phenotypic variance is of additive nature because the narrow sense heritability is a measure of the genetic component that is contributed by the additive genetic variance. Therefore, in general, selection for these traits in globe artichoke should be effective.

This is the first report of heritability estimates for different traits in a segregating globe artichoke population.

## CONCLUSIONS

The additive variance is the principal component of genetic variation in this population, which suggest that the selection for quantitative traits in other globe artichoke populations should be effective.

Significant differences between the C<sub>0</sub> and C<sub>1</sub> cycles for days to first harvest, weight of the main head, total and marketable yield and length of the main head was found and this fact implies that the selection was effective.

Realized heritability for days to first harvest, weight of the main head, total and marketable yield and length of the main head were generally high (overall  $\bar{x} = 0.65$ ). In contrast, heritability estimated for the rest of the traits was more variable.

## RESUMEN

**Respuesta de rasgos productivos y morfovegetativos de alcachofa (*Cynara cardunculus* var. *scolymus*) a selección masal y estimación de su heredabilidad.** Existe a nivel mundial poca información sobre parámetros genéticos o de selección artificial para caracteres relacionados a la producción en el cultivo de alcachofa, por lo que el estudio de los efectos de un ciclo de selección masal y estimaciones de la heredabilidad sería útil para la planificación de estrategias de mejoramiento en esta especie. Las estimaciones de la importancia relativa de la variación genética y de la heredabilidad son fundamentales en la toma de decisiones en todas las etapas de los programas de mejoramiento. Una población segregante (C<sub>0</sub>) se formó de la hibridación de dos cultivares contrastantes multiplicados por semillas 'Imperial Star' y 'Estrella del Sur FCA'. Se evaluaron caracteres productivos y las plantas seleccionadas se hibridaron para conformar el ciclo C<sub>1</sub>. Esta población, junto con el C<sub>0</sub>, los progenitores, y la F<sub>1</sub> se evaluaron para la obtención de la respuesta a la selección y la estimación de heredabilidad. La selección masal para incrementar el rendimiento y la precocidad fue parcialmente exitosa obteniéndose para el primer carácter un valor de heredabilidad estimada de 0,71 y un valor de 0,60 para el segundo. Para la mayoría de las características los valores observados para la heredabilidad (0,75; 0,61 y 0,52 para peso del capítulo principal, rendimiento de mercado y altura del capítulo principal, respectivamente) en esta experiencia indican que una parte sustancial de la variación fenotípica observada es de carácter aditivo. Por lo tanto, la selección de estas características en materiales de alcachofa multiplicables por semilla en esta cruz será efectiva.

**Palabras clave:** acciones aditivas, programa de mejora, *Cynara cardunculus* var. *scolymus*, heredabilidad estimada.

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