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New cropping designs of globe artichoke for industrial use

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Abstract

A two-year experiment was carried-out in order to evaluate the effects of two plant arrangements (single vs. twin rows) and four plant densities (1.0 -1.2 -1.4 and 1.8 plant m^{-2}) on the agronomical behaviour and head characteristics of three globe artichoke genotypes (*Violetto di Sicilia, Harmony F_1* and *Madrigal F_1*). The change of the cultivation format toward a high density stand significantly increase yield and yield synchronicity. The twin rows plant arrangement, although reduced total yield, increased the yield synchronicity. Moreover, the cultivation of seed-propagated genotypes (*Harmony F_1* and *Madrigal F_1*) allowed extending significantly the availability of the heads across the year. On the basis of our results, we can assert that the implementation of a specific scheduling cultivation, based on higher density stands, twin rows plant arrangement and the integration of the traditional early genotypes with the new seed-propagated cultivars, is a promising way to match the requirements of a globe artichoke industrial crop, and to predispose a better mechanization of the cultural practices.

Introduction

Globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] is a perennial herbaceous plant native to the Mediterranean basin, appreciated since ancient times as a tasty food and for its therapeutic effects on human health (Oliaro, 1969). This latter characteristic is mainly due to its high O-diphenolic compounds, flavonoids and inulin content (Lattanzio *et al*., 2001; Di Venere *et al*., 2005; Lombardo *et al*., 2010; Pandino *et al*., 2010). The species represents an important resource for the Mediterranean agricultural economy, since almost 70% of the 129 Kha cultivated worldwide originates from Italy (50 Kha), Spain (20 Kha), North Africa (12 Kha), Turkey (3 Kha) and Greece (3 Kha) (Faostat, 2009). It is also present in the Near East, South America, United States (mainly in California) and recently its cultivation is spreading in China (10 Kha) and Peru (6 Kha). The main product of the crop consists of immature inflorescences (commonly referred as heads or capitula), whose edible fraction consists of the enlarged receptacle and the tender thickened bracts bases, which can be utilized for both fresh consumption and food industry. Each plant produces a variable number of heads, with the earliest and largest one (the main capitulum) formed at the apex of the central stem; several heads are formed later on the lateral branches, and progressively become fibrous, smaller and less appreciated as the season goes on. Throughout the world there are only 11-12 cultivars of globe artichoke, which are important at a commercial level (Basnizki and Zohary, 1994). In Southern Italy, where the majority of the globe artichoke crops are concentrated, only few re-flowering genotypes (e.g. *Violetto di Sicilia* and *Violet de Provence*), well adapted to forcing (summer implantation by dormant offshoots, followed by frequent irrigations), are grown according to traditional techniques (Mauromicale, 1984; Foti and Mauromicale, 1994; Mauro *et al*., 2008). The earliest head productions of such genotypes (from October to February), because of their better quality and higher commercial price, are destined for fresh consumption, while only the late ones (from late March to April) are used for the food industry (Mauromicale, 1987, 1988; Mauromicale *et al*., 2004). Such crop scheduling appears inadequate for both i) matching the needs of the food industry (head yield, quality and temporal availability) and ii) promoting an innovation of the cultural techniques (e.g. increasing yield and reducing the cultural costs). These aspects are of pivotal importance, since the establishment of a specific globe artichoke agro-industrial production process actually appears the only way both to consolidate the economic role of the crop on a national scale, and to better reach the foreign markets (Mauromicale *et al*., 1989; Mauromicale and Ierna, 1995). In the recent decades, the globe artichoke seed-propagated F_1 hybrids are increasing in popularity (Mauromicale and Ierna, 2000; Ierna and Mauromicale, 2004). These genotypes are characterized by high and late yield, contemporary harvests and good quality of heads for processing (Mauromicale *et al*., 1989; Calabrese *et al*., 2004; Mauro *et al*., 2009). Due to the marked bio-agronomical differences, the integration among the traditional cultivated genotypes and the recently released hybrid cultivars could make feasible the enlargement of the temporal availability of heads, so contributing to create a specific globe artichoke chain for the food industry. However, up to date, there is scarce information in literature about the response of these genotypes to those practices (e.g. increased plant densities and different plant arrangements) aimed at

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further increasing yield and yield synchronicity of the crop. On the other hand, previous studies conducted by Elia *et al*. (1994) indicated the twin-rows plant arrangement as a suitable way to overcome some problems related to seed-propagated artichoke (e.g. easier access to the plants along the rows) without negatively influencing the production. Based on these considerations, the goal of this study was to investigate the effects of plant arrangement and plant density on some yield characteristics of three globe artichoke genotypes, in order to design a specific crop model for globe artichoke industry.

Materials and Methods

Experimental site and plant material

A two-year experiment was carried out during 2006-07/2007-08 seasons at Gela Plain, Sicily, Italy (37°11' N 14° 11' E), on a Chomoxererts soil (USDA, soil taxonomy). The area is highly representative for globe artichoke cultivation in Italy. The local climate is semiarid-Mediterranean, with mild winters, and hot, dry summers. A split-split-plot experimental design with four replications was adopted to test the effects of two plant arrangements (single vs. twin rows) and four plant densities (1.0, 1.2, 1.4 and 1.8 plant m^{-2}) on three globe artichoke genotypes (the traditional varietal type *Violetto di Sicilia*, and the seed-propagated cultivars *Harmony F_1* and *Madrigal F_1*). Both cultivation formats consisted of a main inter-rows distance of 1.4 m, in order to facilitate mechanical weeding. For twin rows arrangement, simple rows belonging to the same hedge were spaced 0.6 m. In order to realize the different plant densities, plants within each row were spaced from 0.7 to 0.4 m (single rows) and from 0.82 to 0.55 m (twin rows). Plantings were done on August 10, 2006, starting from pre-sprouted ovoli (*Violetto di Sicilia*) or 50 days-old plantlets (*Harmony F_1* and *Madrigal F_1*), which were sprinkler irrigated until early October, when accumulated daily evaporation (measured from an unscreened class A-Pan evaporimeter near the crop) reached 40 mm (corresponding to 40-50% of available soil water content at 0.30 cm depth); each experimental unit consisted of 80 plants. Starter fertilization was done before planting (or awakening) with 70, 150 and 120 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Further two N applications (as ammonium nitrate) were effected at a rate of 65 kg ha^{-1} on late-November and late-February, respectively. In the second season, plants were awakened on August 7, 2007 by means of sprinkler irrigation, while the fertilization and irrigation programmes were the same of the first season. Lateral offshoots were removed two times, in September and November, leaving only one shoot per plant. On both seasons subsequent pest management practices were performed as per local customs, and in the same way for all the experimental units.

Data collection

At the end of each cropping season, the following variables were calculated: number of days between planting (or awakening) and first harvest, total yield (expressed as number of heads per ha), number of harvests, mean yield per harvest (as number of heads per ha per harvest), harvest period (as number of days between first and last harvest). The end-use quality of capitula (main and secondary) was assessed by weighing those collected at commercial maturity (stage D, when the central flower buds are 3-4 mm long) (Foury, 1967), and then reweighing them after outer bracts and inner bracts tips (~4 cm) removal (the edible fraction after processing).

Data analysis

Data were firstly submitted to the Bartlett's test to check the homoscedasticity, then to a three-way Analysis of Variance for split-plots, as a combination of *plant arrangement x plant density x genotype*, considering the growing season as a random variable (Gomez and Gomez, 1984). Means comparison was performed through Fisher's protected LSD test ($P \leq 0.05$). The pooled values of the agronomical variables in response to plant density were subjected to polynomial regression analysis.

Weather conditions during the trial

Total rainfall in the 2006-2007 growing season fell mostly between October and March (450 out of 560 mm), as is typical for the Mediterranean climate (Figure 1). The 2007-2008 growing season was rather unusual, in that the rainfall amount was somewhat low (396 mm), and 75% of it fell between October and February (Figure 1). Higher mean maxima temperatures were recorded in the second season than in the first one in August (30.3 vs. 28.6°C), September (27.2 vs. 26.0°C) and April (20.7 vs. 20.0°C), but lower mean minima temperatures, especially in December (9.9 vs. 12.0°C), January (9.7 vs. 10.5°C) and February (8.4 vs. 9.9°C) (Figure 1).

Results

Yield and yield characteristics

All the main factors studied, namely plant arrangement, plant density and genotype, significantly affected the bio-agronomical variables (Table 1). Compared with the single-rows plant arrangement, the twin-rows one delayed the first harvest by 6 days and decreased the total yield (from 152,208 to 147,115 heads ha^{-1}), but showed a strong positive effect on the *emission synchronicity* of the heads (Table 2). Indeed, regardless of the other factors, it significantly reduced the number of harvests (from 11 to 9) and increased the yield per harvest (from 16,443 to 17,502 heads ha^{-1} $harvest^{-1}$) (Table 2). Plant density significantly affected the studied variables as well. Passing from 1.0 to 1.8 plant m^{-2}, it was recorded a significant increase of both total yield (from 118,698 to 173,464 heads ha^{-1}, +46%) and yield per harvest (from 11,246 to 22,287 heads ha^{-1} $harvest^{-1}$, +99%), and a significant decrease of the number of harvests (from 11 to 9) (Table 2). Among the genotypes tested, *Violetto di Sicilia* proved the earliest cultivar, as the first harvest occurred 132 days after the beginning of the crop cycle; moreover, it needed the highest number of harvests (13),

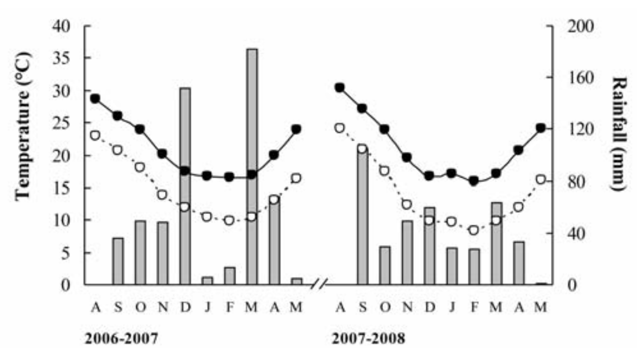

Figure 1. Total rainfall (solid bars), mean monthly maxima (solid circles) and minima (open circles) temperatures at the experimental site during the trial.

accordingly with its longer harvest period (118 days) (Table 2). In contrast, both hybrid cultivars appeared more yielding and contemporaneous. *Madrigal F_1* proved to be the latest and most yielding genotype on the basis of both the number of days to first harvest (231 days) and total yield (181,200 heads ha^{-1}) values, followed by *Harmony F_1*. Moreover, *Madrigal F_1* showed the highest emission synchronicity of heads, due to its lowest number of harvests (8) and its highest yield per harvest (23,600 heads ha^{-1} $harvest^{-1}$) (Table 2). The seed-propagated cultivars showed also the best response to the increased plant density, in terms of both yield and yield synchronicity. Indeed, passing from 1.0 to 1.8 plant m^{-2}, *Harmony F_1* and *Madrigal F_1* showed higher increases of total yield (+68,528 and +53,068 heads ha^{-1}, respectively), and yield per harvest (+14,831 and +12,386 heads ha^{-1} $harvest^{-1}$, respectively) compared to those of *Violetto di Sicilia* (Figure 2A-B). The plotted cultivation scheduling showed a different response between seasons. In the second cropping season, there was an increased earliness and emission synchronicity of the heads, but a decrease in the total yield, whose magnitude was genotype-dependent (Figure 3). Indeed, in the second season, in *Violetto di Sicilia and Harmony F_1* the number of days to first harvest, total yield and number of harvest were all significantly reduced, while in *Madrigal F_1* the same variables showed no significant variations (Figure 3A-C). The harvest period showed also significant *genotype x season* interaction, since in *Violetto di Sicilia* it significantly increased from 114 to 122 days, while in *Harmony F_1* it was reduced from 50 to 36 days (Figure 3D).

Biometric profile of capitula

Plant density and genotype significantly affected the characteristics of main and secondary heads (Tables 1 and 3). The mean weight of main head showed a similar value at 1.0 and 1.2 plants m^{-2} (on average, 196.9 g), but it underwent a significant decrease at 1.4 and 1.8 plant m^{-2} (by 9 and 12%, respectively) (Table 3). This was reflected in the weight of edible fraction of the main head (which represents the processable yield) that, passing from 1.0 to 1.8 plant m^{-2}, significantly decreased from 74.2 to 62.1 g (Table 3). The effect of plant density appeared more marked on the biometric profile of secondary heads, as their weight decreased by about 40 g among the extreme plant densities (-26%), and the weight of their edible fraction passed from 51.5 (1.0 plant m^{-2}) to 39.1 g (1.8 plant m^{-2}) (Table 3). Among the tested genotypes, *Madrigal F_1* showed the highest mean weight of both mean and secondary heads and their edible fraction, followed by *Harmony F_1* and *Violetto di Sicilia* (Table 3). However, passing from 1.0 to 1.8 plant

Table 1. F-values of the main factors and their first order interactions for the bio-agronomical variables, with the significance resulting from the ANOVA.

Variable Source of variation	Days to first harvest	Total yield	Number of harvests	Yield per harvest	Harvest period	Weight of main head	Weight of edible fraction (main head)	Weight of secondary heads	Weight of edible fraction (secondary head)
Plant arrangement	5*	8**	9**	6*	22***	ns	ns	8**	ns
Plant density	7***	174***	28***	126***	32***	26***	19***	23***	18***
Genotype	1207***	560***	123***	389***	8864***	401***	123***	50***	29***
(PA) x (PD)	ns	ns	ns	ns	ns	ns	ns	ns	ns
(PA) x (G)	ns	ns	ns	ns	ns	ns	ns	ns	ns
(PA) x (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns
(PD) x (G)	ns	4**	ns	7***	ns	4**	ns	ns	ns
(PD) x (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns
(G) x (S)	9***	32***	6**	ns	93***	ns	ns	ns	ns

PA, plant arrangement; PD, plant density; genotype; S, season; ns, not significant;*P<0.05;**P<0.01;***P<0.001.

Table 2. Productive characteristics of globe artichoke as affected by genotype, plant arrangement and plant density (main effects).

Treatment	Days to first harvest	Total yield (000 heads ha^{-1})	Number of harvests	Yield per harvest (000 heads ha-1 $harvest^{-1}$)	Harvest period (days)
Plant arrangement					
Single rows	182[a]	152.2[a]	11[a]	16.4[b]	61[a]
Twin rows	188[b]	147.1[b]	9[b]	17.5[a]	59[a]
Plant density (plant m^{-2})					
1.0	180[c]	118.7[d]	12[a]	11.2[d]	64[a]
1.2	184[bc]	145.2[c]	11[b]	14.9[c]	61[ab]
1.4	186[ab]	161.3[b]	9[c]	19.4[b]	58[bc]
1.8	191[a]	173.5[a]	9[c]	22.3[a]	56[c]
Trend	L*	Q**	NS	Q*	Q*
Genotype					
Violetto di Sicilia	132[c]	109.3[c]	13[a]	9.0[c]	118[a]
Harmony F_1	193[b]	158.5[b]	9[b]	18.4[b]	43[b]
Madrigal F_1	231[a]	181.2[a]	8[c]	23.6[a]	18[c]
Season					
2006-2007	194	155.4	11	15.3	61
2007-2008	178	143.9	9	18.6	59

[a-d]Different letters within each factor's column indicate significance at Fisher's LSD test (P<0.05). L, linear; Q, quadratic; *P<0.05; **P<0.01.

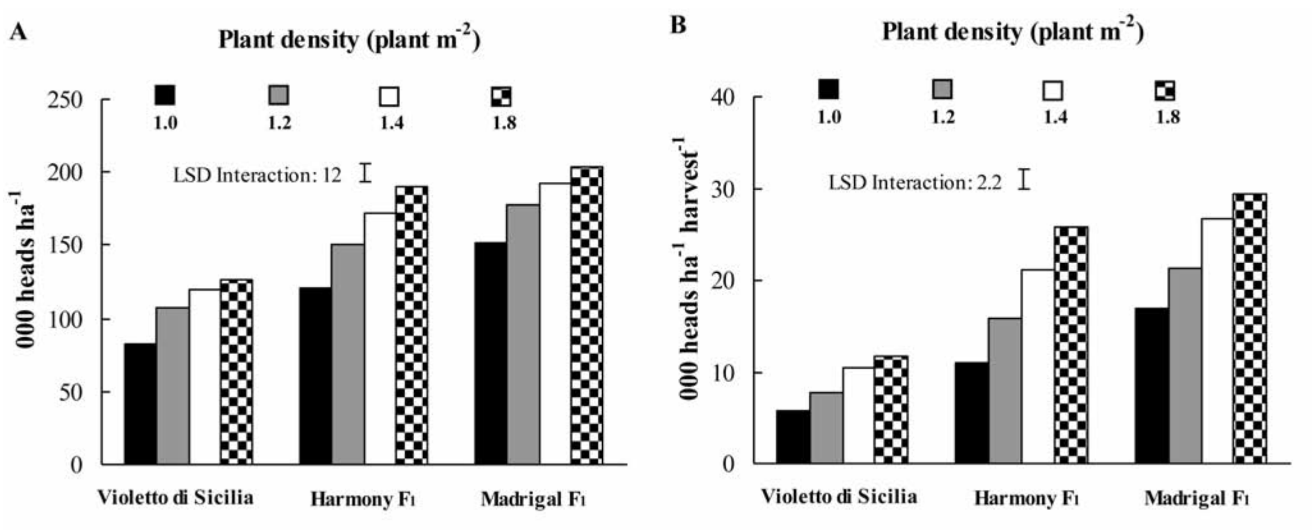

Figure 2. Total yield (A) and yield per harvest (B) as affected by *genotype x plant density* interaction.

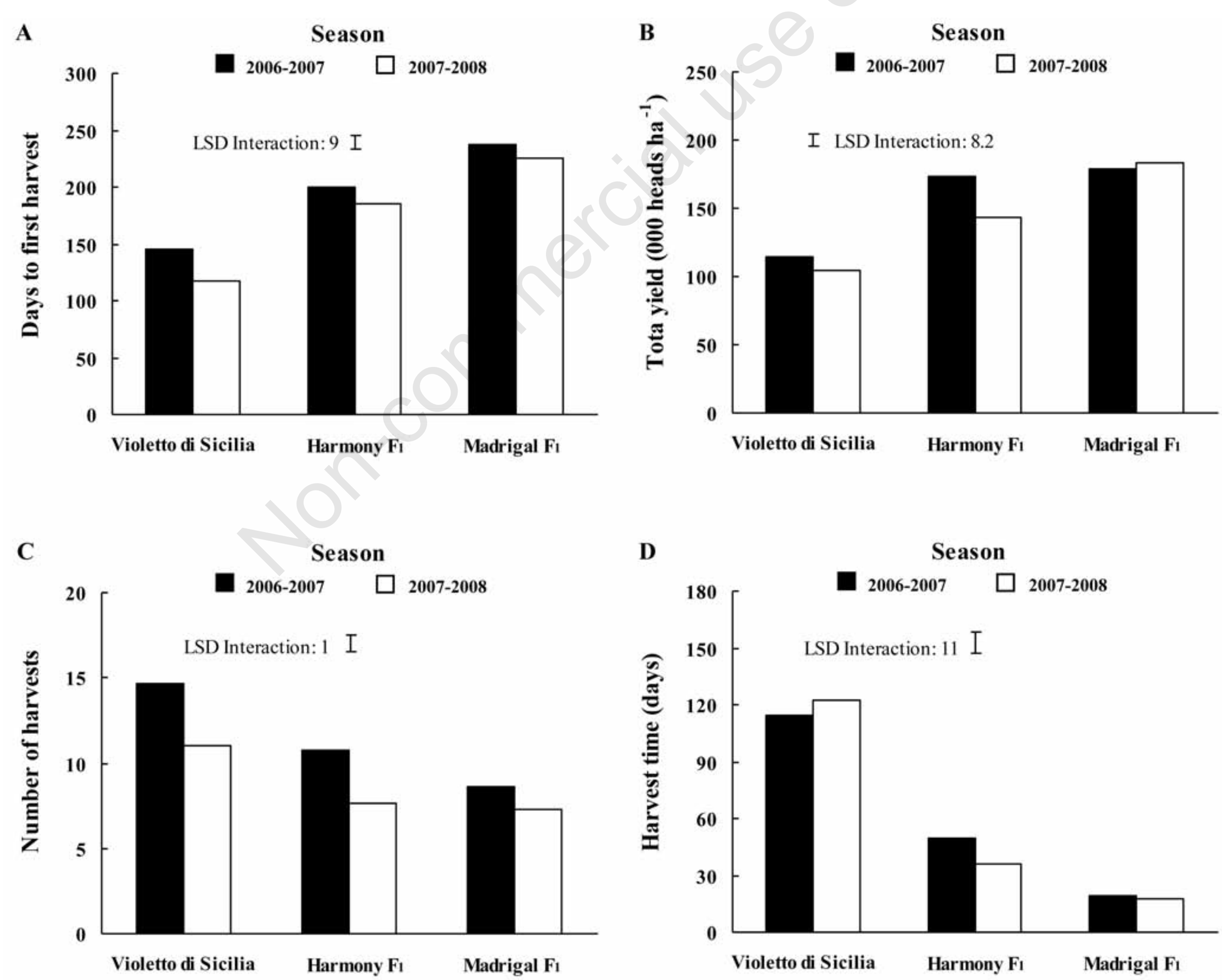

Figure 3. Days to first harvest (A), total yield (B), number of harvests (C) and harvest period (D) as affected by *genotype x season* interaction.

Table 3. Heads characteristics of globe artichoke as affected by genotype, plant arrangement and plant density (main effects).

Treatment	Main head		Secondary heads	
	Weight (g)	Weight of edible fraction (g)	Weight (g)	Weight of edible fraction (g)
Plant arrangement				
Single rows	188[a]	69[a]	132[a]	46[a]
Twin rows	185[a]	67[a]	127[a]	43[a]
Plant density (plant m^{-2})				
1.0	200[a]	74[a]	153[a]	52[a]
1.2	193[a]	71[ab]	129[b]	45[ab]
1.4	179[b]	65[bc]	124[bc]	42[b]
1.8	172[b]	62[c]	113[c]	39[b]
Trend	Q*	Q*	Q*	Q*
Genotype				
Violetto di Sicilia	147[c]	57[c]	108[c]	38[b]
Harmony F1	179[b]	67[b]	132[b]	48[a]
Madrigal F1	234[a]	81[a]	150[a]	47[a]
Season				
2006-2007	187	69	129	45
2007-2008	186	67	130	44

[a-c]Different letters within each factor's column indicate significance at Fisher's LSD test ($P<0.05$); Q, quadratic; *significant at $P<0.05$.

m^{-2}, in *Madrigal* F_1 the mean weight of main heads was reduced from 265.8 to 200.4 g, a difference which was significantly higher than those showed by *Harmony* F_1 (26.2 g) and *Violetto di Sicilia* (12.1 g) (Figure 4).

Discussion

Under the specific conditions of our experiment, the twin rows plant arrangement, although negatively affected the total yield, proved to be an effective tool to improve the yield synchronicity of the tested genotypes, as it reduced both the number of harvests and increased the yield per harvest, with potential positive effects on harvest costs. Moreover, the change of the cultivation format toward a high density stand, allowed to increase the yield and to reduce the number of harvests. Analogous results in response to plant density were found by Santoiemma *et al*. (2004) working with the cultivar *Romanesco* clone C3. As regards the tested genotypes, the integration of cultivars with very different biological characteristics, such as earliness and harvest timing, prolonged the availability of heads until 6 months (from December to May). Indeed, thanks to their different earliness, both seed-propagated genotypes allowed a high temporal availability of heads from February to May, and increased the accumulated yield during spring, i.e. when *Violetto di Sicilia* is usually near the end of its cropping cycle and the quality of its heads starts to decline (Mauromicale and Ierna, 2000; Mauromicale *et al*., 2000). In particular, *Madrigal* F_1 showed good yield stability among seasons, behaviour opposite to that of *Violetto di Sicilia* and Harmony F_1. Indeed, these latter genotypes showed decreased yield in the second season, likely as a consequence of both lower winter temperatures and scarce spring rainfall encountered during their cropping cycle. In this view, the highest yield stability of *Madrigal* F_1 could be explained by its higher tolerance to cold and/or drought stress. Hence the latter traits might be considered in genotypes used for industry, in order to stabilize as much as possible the yield among seasons. On the other hand, this could imply the need to implement and rationalize single irrigation interventions during spring, in order to avoid yield decreases without burden excessively on the cultural costs. With reference to the end use quality of the heads, all the tested genotypes showed a significant decrease in the weight of processed heads at the highest plant densities (namely 1.4 and 1.8 plants m^{-2}); hence medium density stands (up to 1.2 plants m^{-2}) could be considered as the upper limit, since a major intraspecific competition exerts negative effects on the end-use quality of the heads. Alternatively, we must consider that in our experiment the same fertilization was done for all plant densities, and no further offshoots removal was done beyond November, so living plants to accentuate the intraspecific competition during the remaining crop cycle. Taking into account these considerations, the outcome of our experiment suggest the need to define more appropriated fertilization programmes suitable for the highest plant densities, together with the adoption of solutions aimed at lowering the effects of the intraspecific competition (e.g. earlier transplanting times, more appropriated periods for offshoots removal) in order to implement higher density stands, without compromising the end-use quality of the heads.

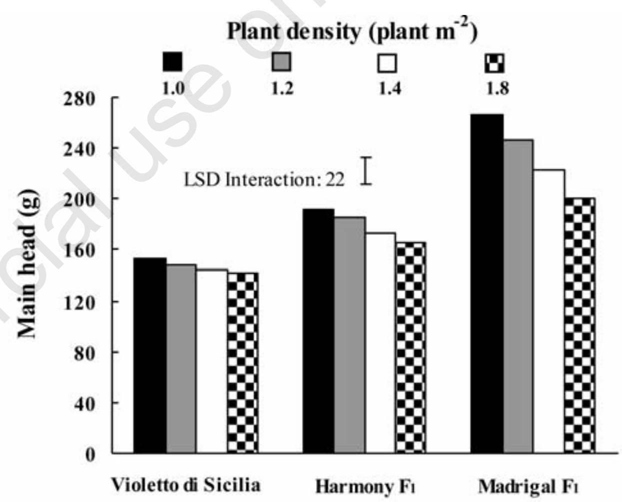

Figure 4. Weight of main head as affected by *genotype x plant density* interaction.

Conclusions

On the basis of these preliminary results, we can assert that the implementation of a specific scheduling cultivation, based on higher density stands (from 1.4 to 1.8 plant m^{-2}, depending on the genotype), twin rows plant arrangement and the integration of the traditional early genotypes with the new seed-propagated cultivars, is a promising way to match the requirements of a globe artichoke industrial crop and to predispose a better mechanization of the cultural practices. However, subsequent investigations are needed to improve the cultural technique (specific irrigation and fertilization programmes, a better management of the plant competition phenomena within the crop), to further expand the temporal availability of the heads (e.g. GA_3 applications, different stands locations) and to better elucidate the effects of these cultural practices on heads quality and suitability for processing.

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