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Potential of local varieties and their hybrids for the improvement of eggplant production in the open field and greenhouse cultivation

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Abstract

Eggplant (*Solanum melongena* L.) is cultivated both in the open field and greenhouse. F_1 hybrids, which have been mainly developed for greenhouse cultivation, are being increasingly used for open field cultivation. Given that these two growing environments present many differences, we hypothesize that local varieties, adapted to open field cultivation, can be used for developing hybrids that are competitive under these conditions with present commercial hybrids. We have grown 12 local varieties (LV), 12 experimental hybrids (EH) obtained by crossing local varieties, and three commercial hybrids (CH) under open field and greenhouse conditions and evaluated them for yield, fruit weight, earliness and fruit shape. Results show that local varieties and experimental hybrids are as uniform as commercial hybrids. Yield was higher in open field than in greenhouse, although significant differences were found among the materials in the performance. In open field conditions, commercial and experimental hybrids gave higher yield than local varieties (more than two-fold higher as a mean). No significant differences were found among the best accessions of commercial and experimental hybrids. In greenhouse conditions, commercial hybrids outperformed local varieties and experimental hybrids, and none of the latter materials gave yields similar to those of the best commercial hybrid. Commercial hybrids entered into production earlier than local varieties and experimental hybrids, especially under greenhouse conditions. Yield and harvest of the first fruit were negatively correlated in both environments. For all traits there is an important genotype x cultivation conditions interaction, suggesting that breeding programmes specific to each cultivation environment should be established. Also, hybrids between local varieties could be competitive with commercial hybrids in the open air cultivation, but not for greenhouse cultivation.

Key words: Earliness, eggplant, genetic resources, genotype x environment interaction, greenhouse cultivation, hybrids, local varieties, open field cultivation, *Solanum melongena*, yield.

Introduction

In regions of subtropical climate, eggplant (*Solanum melongena* L.) is cultivated both in the open field (warm season) and under greenhouse (cold season) [1]. Differences among these environments are important [2]. For example, conditions under greenhouse are suboptimal for fruit set and for obtaining high yields [3]; also, in the main greenhouse producing areas of Europe, like the region of Almería in Spain, soilless culture is frequently used for greenhouse cultivation [4]. The final destination of the produce may be different too; while fruits produced under greenhouse are sent to fresh vegetable markets, those produced in the open air are also destined to the processing industry.

Another great difference in the eggplant cultivation between these two different cultivation environments concerns the type of varieties used. The open field production has traditionally been based on non-hybrid varieties [5], while the greenhouse production relies on F_1 hybrids, which have been developed and selected under greenhouse conditions and have the ability to give a high load of fruits under suboptimal conditions for fruit set [6].The differences in the economic return per plant obtained by the farmer is much higher in greenhouse cultivation and compensates the higher cost of the hybrid seed. However, during the last years, there is a trend to use these F_1 hybrids also for open field cultivation. Reasons argued for the use of F_1 hybrids under open field cultivation are their higher yield and greater uniformity when compared to local materials and non-hybrid varieties [5].

Genotype x cultivation environment interactions are important in other Solanaceae vegetable crops [2, 7-9]. Therefore, materials with optimum performance under greenhouse cultivation are not necessarily the most suited for open field production and vice versa. In consequence, we hypothesize that local varieties of eggplant, which have been subjected to natural and artificial selection for adaptation to open field conditions, could be useful for the development of hybrids adapted to this environment and these materials could represent an alternative to present commercial F_1 hybrids used at present in open field conditions. On the other hand, local varieties that demonstrate an acceptable performance under greenhouse conditions could allow broadening the genetic base of breeding programmes for greenhouse cultivation and lead to genetic advances in the future.

Here we studied the performance, both in the open field and in greenhouse, of local materials of eggplant and experimental hybrids obtained from the crossing of these local materials, and compared them with commercial F_1 hybrids. Our objective was to obtain information relevant for developing materials adapted to different cultivation environments, and in this way contribute to improving the eggplant production.

Material and Methods

Plant material and growing conditions: A total of twelve local varieties from Spain (LV1 to LV12), which is a secondary center of diversity for eggplant [10], twelve experimental hybrids obtained by crossing Spanish local varieties of different types (EH1 to EH12) and three control commercial hybrids (CH1 to CH3) were used in the experiment (Table 1). Local varieties of eggplant LV1 and LV12 were obtained from the germplasm bank of the Instituto de Conservación y Mejora de la Agrodiversidad Valenciana (COMAV). The experimental hybrids were obtained after crossing Spanish local varieties from a group of local varieties which included LV1 to LV12. Materials were evaluated in Valencia both in a field plot in the open air and in a greenhouse of the Universidad Politécnica de Valencia.

Seeds of the local varieties, experimental hybrids and control hybrids were germinated on moistened filter paper in Petri dishes. Germinated seeds were transferred to seedling trays, and in July 2004 (open air) and February 2005 (greenhouse) five plants per variety were transplanted (sandy loam soil in the open air and 25 litre coconut fiber substrate pots in the greenhouse) in a completely randomized design. Plants were spaced 1 m between rows and 0.4 m apart in the row (open air) and 1.7 m between rows and 0.4 m apart in the row (greenhouse) and were drip irrigated.

Table 1. Plant material used in the open field and greenhouse trials and their fruit shape and primary (predominant) and secondary (background) skin colours.

Variety	Shape	Primary colour	Secondary colour
Local varieties			
LV-1	Oval	Black	-
LV-2	Oval	Black	Green
LV-3	Oval	Black	-
LV-4	Long	Black	-
LV-5	Oval	Purple	White
LV-6	Semi-long	Purple	White
LV-7	Oval	Purple	White
LV-8	Semi-long	White	Purple
LV-9	Round	Black	-
LV-10	Oval	Black	-
LV-11	Round	Green	Purple
LV-12	Semi-long	Purple	White
Experimental hybrids			
EH-1	Oval	Purple	White
EH-2	Oval	Purple	White
EH-3	Oval	Purple	White
EH-4	Oval	Black	-
EH-5	Semi-long	Black	-
EH-6	Oval	Purple	-
EH-7	Oval	Black	-
EH-8	Oval	Black	-
EH-9	Oval	Black	-
EH-10	Oval	Black	Green
EH-11	Oval	Black	-
EH-12	Oval	Black	-
Commercial hybrids			
CH-1	Semi-long	Black	-
CH-2	Oval	Black	-
CH-3	Semi-long	Black	-

The standard horticultural practices for eggplant production in the area of Valencia were followed [4]. Fertilization was applied with the drip irrigation system and phytosanitary treatments were performed when necessary.

Traits studied and analysis of data: For each cultivation environment (open field and greenhouse), total yield, mean fruit weight, date of harvest of each fruit and length/width ratio of the fruits were obtained for individual plants. For each variety and trait, the mean, its standard error (SE) and the coefficient of variation (CV) were calculated. The mean SE and CV were estimated for each combination of varietal groups (local varieties, experimental hybrids and commercial hybrids) and growing cycles (open field and greenhouse) from ANOVA tests. Curves of accumulated production were also obtained for each variety.

In order to test for differences in the uniformity among the three varietal groups (local varieties, experimental hybrids and commercial hybrids), an ANOVA with two factors (varietal group and cultivation environment) was performed on the SE and CV values. Correlation coefficients (r) among the traits studied were also calculated for each cultivation cycle. The coefficients of determination (r^2) for the correlation among growing cycles for each trait were calculated in order to provide an estimate of the significance of the interaction between variety and growing cycle[11].

Results

Uniformity: The analysis of variance for the SE values of each varietal group and cultivation environment shows that the only traits for which there were significant effects on SE values were yield (varietal group and growing cycle) and fruit shape (varietal group) (Table 2). At this respect, experimental and commercial hybrids display a significantly greater variability (higher SE values) than local varieties for fruit yield; also, cultivation in the open air results in a greater variability for yield than cultivation in the greenhouse (Table 3). For fruit shape, there was a greater variation in the fruits cultivated in the open air than in greenhouse. However, a detailed observation of these data indicates that there is a relationship between the mean and the standard deviation [12]. Therefore, in these cases, in order to test the significance of the differences in variation among varietal groups, it is more appropriate to study the significance of the differences in the CV, which

Table 2. ANOVA table for the study of the differences in uniformity among varietal groups (local varieties, experimental hybrids and commercial hybrids) and cultivation environments (open air and greenhouse). Values for each trait represent the mean squares for the effects of varietal group and growing cycle for the standard error (SE) and coefficient of variation (CV).

Effect	d.f.[a]	Yield	Fruit weight	Shape	Earliness
		Standard error (SE)			
Varietal group (V)	2	2.335**	3305.73^{ns}	0.137*	0.637^{ns}
Growing cycle (C)	1	10.774***	3203.56^{ns}	0.0008^{ns}	12.608^{ns}
V X C	2	0.928^{ns}	220.80^{ns}	0.005^{ns}	7.110^{ns}
Error	48	0.345	1487	0.038	14.337
		Coefficient of variation (CV)			
Varietal group (V)	2	0.001^{ns}	0.006^{ns}	0.010^{ns}	0.002^{ns}
Growing cycle (C)	1	0.003^{ns}	<0.001^{ns}	0.005^{ns}	0.031**
V X C	2	0.047^{ns}	0.008^{ns}	0.002^{ns}	0.001^{ns}
Error	48	0.028	0.014	0.004	0.002

[a]Degrees of freedom ns,*,**,*** indicate non-significant or significant at P <0.05, 0.01 or 0.001, respectively.

Table 3. Mean values, average standard error (SE) and coefficient of variation for the yield, earliness, fruit weight and fruit shape of the eggplant varieties studied in each cultivation environment (open air or greenhouse), grouped by varietal type.

	Yield (kg m^{-2})		Earliness (d)		Fruit weight (g)		Shape (length/width)	
Variety	Open air	Green-house	Open air	Green-house	Open air	Green-house	Open air	Green-house
				Local varieties				
LV-1	2.46	0.92	65	101	353	342	1.13	2.01
LV-2	1.32	0.98	66	125	203	239	1.93	1.96
LV-3	1.78	0.93	62	111	398	188	1.75	1.86
LV-4	2.17	1.15	55	108	194	220	4.27	4.00
LV-5	2.41	0.98	61	119	368	257	1.59	1.93
LV-6	2.12	1.07	65	125	454	321	1.45	2.02
LV-7	1.26	0.54	78	137	431	248	1.70	1.60
LV-8	2.81	0.92	57	104	226	172	1.93	2.20
LV-9	2.86	1.79	59	129	373	208	0.82	1.17
LV-10	1.02	0.91	78	117	233	180	1.73	1.81
LV-11	3.59	0.96	66	130	394	380	1.00	1.51
LV-12	1.74	0.90	68	114	420	200	2.32	2.75
Mean	*2.13*	*1.00*	*65*	*118*	*337*	*246*	*1.80*	*2.07*
SE	*0.48*	*0.19*	*6*	*6*	*46*	*29*	*0.16*	*0.18*
CV	*0.51*	*0.42*	*0.20*	*0.10*	*0.31*	*0.26*	*0.20*	*0.19*
				Experimental hybrids				
EH-1	1.67	1.10	66	131	420	273	1.52	1.95
EH-2	1.57	1.10	69	115	308	263	1.68	1.82
EH-3	2.88	1.14	64	122	395	464	1.60	1.87
EH-4	5.56	1.59	66	99	458	340	1.33	1.59
EH-5	4.82	1.05	57	121	346	257	1.84	2.03
EH-6	5.90	1.67	56	127	513	263	1.43	1.57
EH-7	5.50	1.31	61	119	452	276	1.39	1.64
EH-8	5.89	1.60	63	116	491	310	1.13	1.78
EH-9	5.21	1.74	57	112	409	246	1.28	1.48
EH-10	6.17	1.88	56	130	444	334	0.93	1.41
EH-11	5.37	1.07	59	124	447	352	0.96	1.74
EH-12	4.34	1.15	62	110	364	320	1.24	1.63
Mean	*4.57*	*1.37*	*61*	*119*	*421*	*308*	*1.36*	*1.71*
SE	*0.91*	*0.29*	*3*	*6*	*44*	*41*	*0.09*	*0.06*
CV	*0.45*	*0.47*	*0.12*	*0.11*	*0.23*	*0.30*	*0.15*	*0.08*
				Commercial hybrids				
CH-1	4.47	1.98	51	61	272	271	2.22	2.32
CH-2	5.81	1.71	51	81	377	282	1.39	1.63
CH-3	4.88	2.46	53	65	275	244	2.35	2.75
Mean	*5.05*	*2.05*	*52*	*69*	*308*	*266*	*1.99*	*2.23*
SE	*1.02*	*0.31*	*4*	*2*	*33*	*21*	*0.14*	*0.11*
CV	*0.45*	*0.34*	*0.17*	*0.06*	*0.24*	*0.18*	*0.16*	*0.11*

compensates the effect of a relationship between the mean and the standard deviation of the mean. In this case, the ANOVA shows that the only trait for which significant differences for the CV were detected is fruit earliness (Table 2), in which a significant difference between environments (higher variation in the open field) was found (Table 3).

Yield: Significant differences between the two cultivation environments were found among the different types of materials studied (Table 3). At this respect, in the open air cultivation, commercial and experimental hybrids presented similar mean yields (5.05 and 4.57 kg m^{-2}, respectively), which were considerably higher than those of traditional varieties (2.13 kg m^{-2}). Under these conditions, all commercial hybrids presented high yields (4.47-5.81 kg m^{-2}); however, for the experimental hybrids there was a wide range of variation (1.57- 6.17 kg m^{-2}). Nonetheless, it is remarkable that most of the experimental hybrids had yields comparable to those of the commercial hybrids (Table 3). Local varieties also displayed a wide range of variation (1.02 - 3.59 kg m^{-2}), but none of them presented yields comparable to those of the best commercial or experimental hybrids (Table 3). Regarding cultivation in greenhouse, in general, yield was much lower than in the open air (Table 3). However, under these conditions, commercial hybrids (2.05 kg m^{-2}) were, as a mean, superior to experimental hybrids (1.37 kg m^{-2}) and to local varieties (1.00 kg m^{-2}). At this respect, all the experimental hybrids and local varieties had a yield significantly lower than the best commercial variety (Table 3).

A comparison of yield between environments for each variety shows that there was a significant variety x cultivation environment interaction for this trait. The coefficient of determination for the correlation for yield between open air and greenhouse can be considered moderate to low (0.463) (Fig. 1).

Earliness: In all cases, earliness was greater in the open air than in greenhouse (means of 59 and 101 days, respectively). However, there were significant differences among the different varietal groups. In open air cultivation, commercial hybrids entered earlier into production (51.7 days as a mean) than local varieties or experimental hybrids (means of 65.0 and 61.3 days, respectively). These differences between the commercial hybrids and local varieties and experimental hybrids increased dramatically in greenhouse cultivation, in which commercial hybrids began to produce much earlier (68.8 days as a mean) than local varieties or experimental hybrids (means of 118.3 and 118.8 days, respectively). Earliness also displayed a significant variety x cultivation environment interaction, and the coefficient of determination between open air and greenhouse for earliness was low (0.274) (Fig. 1).

Fruit weight: Fruit weight ranged between 194 and 454 g in the open air and 172 and 464 g in greenhouse, with the total mean value being greater in the open air (371 g) than in greenhouse (276 g) (Table 3). Experimental hybrids presented mean values greater than those of the local varieties and commercial hybrids, especially in open air cultivation (Table 3). For the fruit weight, the variety x growing cycle interaction was also high, with a value for the coefficient of determination between open air and greenhouse of only 0.194 (Fig. 1).

Fruit shape: All the varieties studied, except a "long" local variety (with a ratio length/width greater than 4) presented round to obovate (ratio length/width in the range 0.8-1.5) or semi-long (ratio length/width in the range 1.5-3) shapes. For this trait, in general, fruits were more elongated in the greenhouse than in the open air (Table 3). Experimental hybrids had a lower value of the length/width ratio than the rest of varieties. Only one of the experimental hybrids had a value for the length/width ratio higher than 2 (H16 in greenhouse cultivation); however, two of the commercial hybrids (in both environments) and five local varieties in greenhouse and two in the open air had values greater than 2 for this ratio. This trait showed the greatest stability among environments, and the coefficient of determination between open air and greenhouse was high (0.867) (Fig. 1).

Relationships among traits: In both environments, a significant negative correlation existed between yield and harvest of the first fruit (Table 4). The representation of the accumulated yield curves for each type of material shows that in open air cultivation there was an effect of earliness on yield (Fig. 2). Although commercial and experimental hybrids display curves with similar shape, the curve of the experimental hybrids is displaced almost 10 days with respect to commercial hybrids. Nonetheless, the results show that the best experimental hybrids present a performance similar to those of the best commercial hybrids. On the contrary, the results for the local varieties show that in open air cultivation, these materials do not only enter into production later than commercial and experimental hybrids, but the yield curve also has a lower degree of steepness (Fig. 2). Under greenhouse cultivation, the materials with the highest yields (commercial hybrids) enter much earlier into production than local varieties or experimental hybrids (Fig. 2). Nonetheless, the comparison of the best varieties of each group of materials shows that among the experimental hybrids there are materials with a yield curve with a greater slope than commercial hybrids. The other significant correlations found are a positive one between yield and fruit weight in the open air, and a negative one between fruit weight and shape also in the open air (Table 4).

Table 4. Correlations for the traits studied. Values in the upper and lower diagonal correspond to open air and greenhouse cultivation environments respectively.

	Yield	Harvest of 1st fruit	Fruit weight	Shape
Yield		-0.635***	0.452**	-0.338ns
Harvest of 1st fruit	-0.559**		0.071ns	-0.149ns
Fruit weight	0.057ns	0.122ns		-0.617***
Shape	-0.048ns	-0.378ns	-0.285ns	

ns,*,**,*** indicate non-significant or significant at P <0.05, 0.01 or 0.001, respectively.

Discussion

Development of hybrids has been one of the most successful strategies for obtaining high yielding and uniform varieties in many vegetable crops [13]. When combined with the exploitation of genotype x environment interaction, this has been one of the major tools used by breeders and agronomists to increase the yield and quality of crops [14]. Also, the use of elite genetic resources, i.e., materials with good adaptation to the target environmental conditions, has also been proved useful for breeding new improved materials and for broadening the genetic base of modern cultivars [15]. In eggplant, commercial F_1 hybrids have been developed for greenhouse production and present a high adaptation to this environment giving a high yield and early production [5]. Our results show that under these suboptimal conditions they are superior in yield to local varieties or to experimental hybrids between these materials. However, in open field conditions, while commercial hybrids present a higher production than local varieties, many experimental hybrids between local varieties present yields similar to those of the commercial hybrids and some of the experimental hybrids are even superior to the best commercial hybrids.

The results obtained suggest that the exploitation of the heterosis of eggplant hybrids [16-18] obtained using as parent materials with the good adaptation of local varieties to open field conditions can lead to the development of hybrids competitive or superior to present commercial hybrids. This shows that in this species there is ample potential for exploiting the genotype x environment interaction. In fact, the low correlation between the results in greenhouse and open field cultivation suggests that breeding programmes specific for each type of environment should be established.

Commercial hybrids show a greater earliness than the rest of materials, especially under greenhouse conditions. This greater earliness results in a longer time of production and, therefore, a greater total yield. The results suggest that selection for earliness could be useful in the selection of new eggplant varieties with a higher yield. Furthermore, an additional advantage of earliness is that the value of the early production is usually higher than the rest of the harvest. For the fruit weight and shape there are no differences of consideration between the different groups of varieties tested, and for each of these traits there are materials with values similar to those of commercial hybrids.

Commercial hybrids do not show a greater uniformity than experimental hybrids or local varieties for the traits studied. Eggplant is fundamentally autogamous [19], and therefore, local varieties present a high degree of fixation and show a high uniformity. In consequence, experimental hybrids obtained between them will also have a high genetic uniformity.

Differences between environments have been great. The environments affect not only traits like yield and earliness, but also to traits that are usually highly stable, like fruit shape [2], so that fruits in greenhouse are slightly more elongated than in the open air, although this change does not have effects on the marketability of fruits.

Conclusions

Here we show that in eggplant, while commercial F1 hybrids outperform local varieties in yield, experimental hybrids obtained after crossing local varieties can be useful for developing new high yielding varieties adapted to open field cultivation. On the other hand, the utility of these materials is not so promising for greenhouse cultivation, in which commercial hybrids have a better performance than the experimental hybrids. However, as has been suggested for tomato [20], local varieties and the materials derived from them, could be used for broadening the genetic variation of greenhouse commercial hybrids of eggplant.

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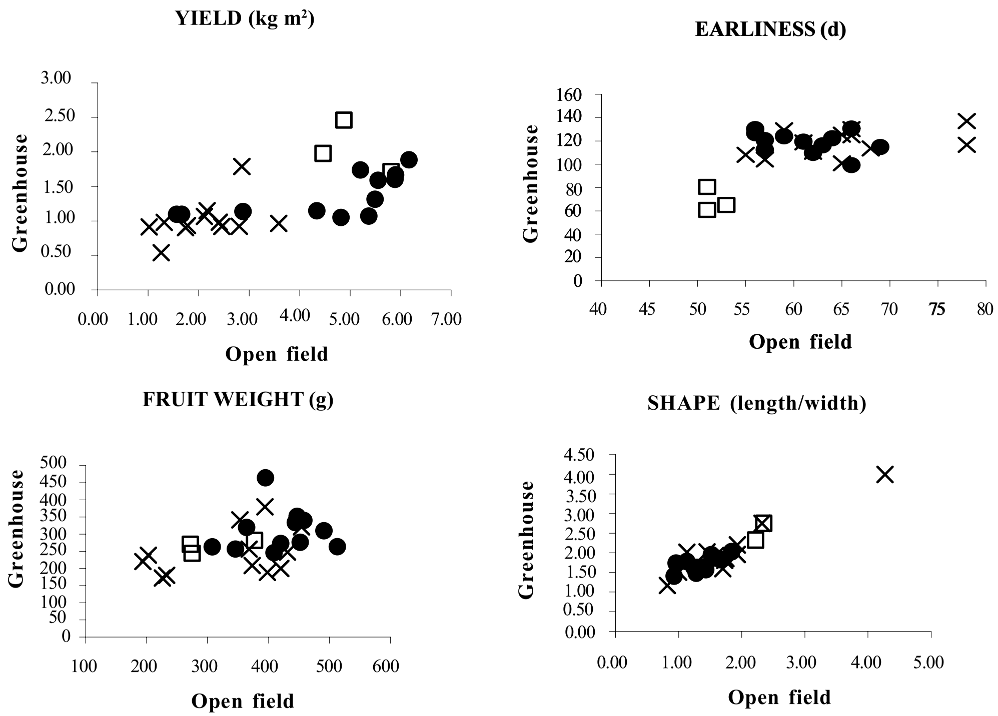

Figure 1. Relationship between the yield, earliness, fruit weight and fruit shape between open air and greenhouse growing systems for a total of 27 varieties of eggplant corresponding to three different varietal groups (local varieties, x; experimental hybrids, ●; and, commercial hybrids, □).

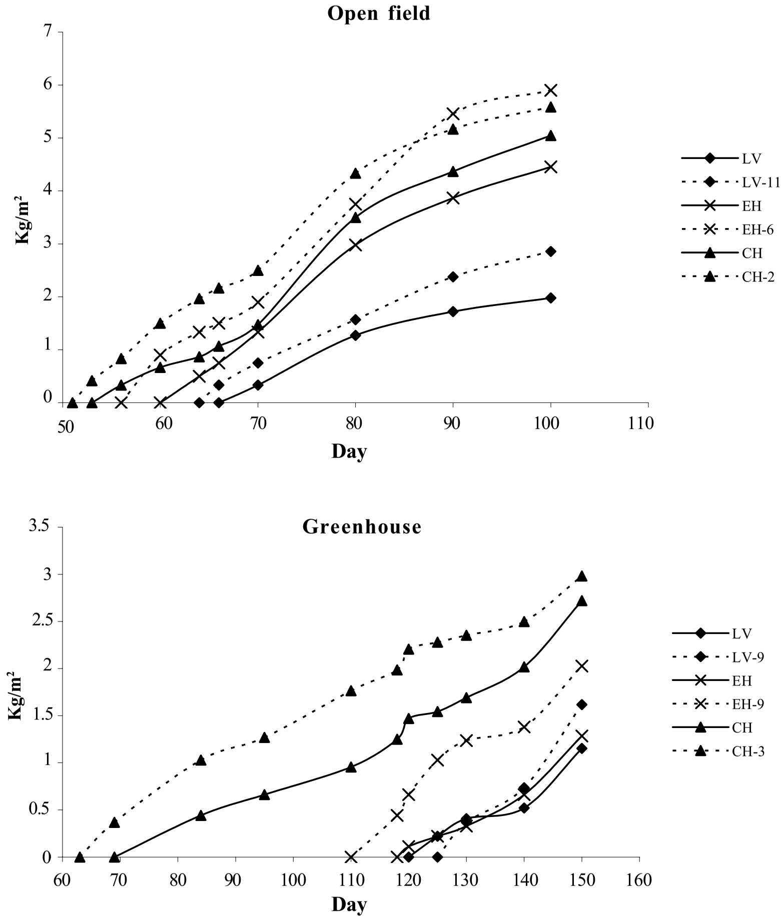

Figure 2. Curves of accumulated production for the mean value (continuous lines) of local varieties (LV), experimental hybrids (EH) and commercial hybrids (CH), and of the highest yielding variety of each of these varietal groups (dashed lines), in the open air (above) and greenhouse (below) cultivation.