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Research Report

Consistency of organoleptic and yield related traits of strawberry cultivars over time

M.T. Ariza[a], L. Miranda[c], E. Martínez-Ferri[a], J.J. Medina[b], J.A. Gómez-Mora[c], L. Cervantes[a] and C. Soria[a,*]

[a]*IFAPA Centro de Churriana. Junta de Andalucía. Cortijo de la Cruz s/n, 29140 Churriana, Málaga, Spain*
[b]*IFAPA Centro de Huelva. Junta de Andalucía. Julio Caro Baroja s/n, 21002 Huelva, Spain*
[c]*IFAPA Centro Las Torres-Tomejil. Junta de Andalucía. Ctra. Sevilla - Cazalla Km. 12.2, 41200 Alcalá del Río, Sevilla, Spain*

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Abstract.
BACKGROUND: Strawberry (*Fragaria* x *ananassa* Duch.) is among the most widely consumed fruits in the world and its cultivation is increasing worldwide. This continuous increase in its cultivation acreage is concomitant with the development of new varieties by numerous breeding programs. Due to strawberry is a microclimatic crop, the behaviour of the cultivars could vary depending on many agronomical and environmental factors such as temperature or humidity. Thus, for some traits, data from a single crop season may not be enough to suspect the behaviour of a specific variety.
OBJECTIVE: Generate information that allows knowing the consistency of different characteristics over time.
METHODS: For four consecutive years, organoleptic and yield related traits were analysed in five strawberry cultivars.
RESULTS: The overall result is a significant effect of genotype on all yield relates and organoleptic parameters studied. Our study also inferred an effect of environment, temperature and relative humidity, mainly on yield parameters. However, not all cultivars were similarly affected.
CONCLUSIONS: With the information generated from this work, it will be possible to establish, based on the consistency of the cultivar trials over time, the suitability of using the results of a single season to predict the behaviour of a particular cultivar.

Keywords: Breeding, *Fragaria* x *ananassa*, fruit quality, genotype, harvest, humidity, phenotypic plasticity, temperature

1. Introduction

The commercial strawberry (*Fragaria* x *ananassa* Duch.) is of significant agricultural importance worldwide, and it is among the most widely consumed fruits. Due to the economic and social significance of the strawberry production, there is an increase in various fields of research on this species (i.e. breeding, pathology, agronomy, health, etc.) to give response to the demands of producers and consumers. One of the issues which is receiving more attention is the breeding to obtain new cultivars, using the knowledge generated in these different fields

*Corresponding author: C. Soria, IFAPA Centro de Churriana. Junta de Andalucía. Cortijo de la Cruz s/n, 29140 Churriana, Málaga, Spain. E-mail: maria.soria@juntadeandalucia.es.

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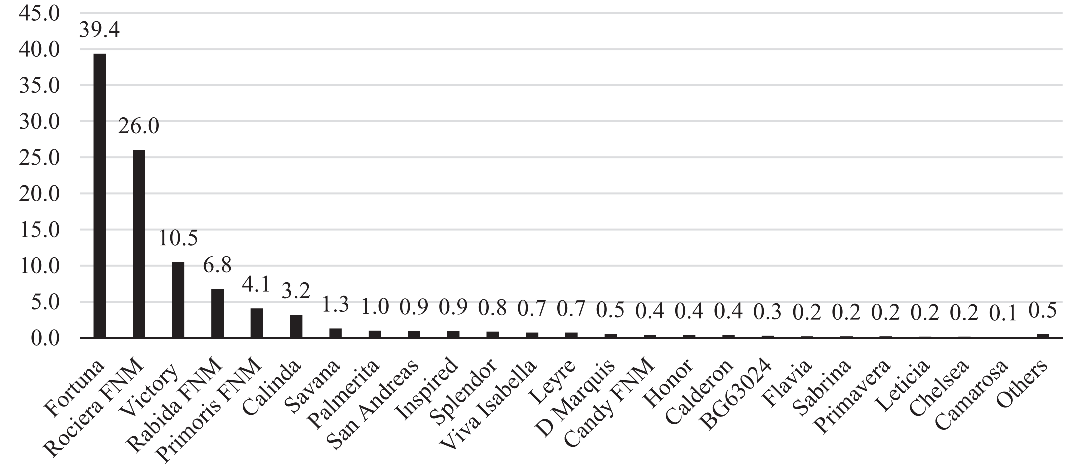

Fig. 1. Varietal distribution (% plants). 2018–2019 crop seasons.

of research. In this sense, are numerous the public and private strawberry breeding programs aiming to develop and release cultivars, well-adapted to the agronomic and environmental conditions of different cultivation areas, with suitable agronomic traits (high yield and fruit quality), and with harvest periods best fitted to the economic interests of the farmers [1–3]. In Huelva (south western coast of Spain), the main strawberry cropping area in Europe, the conventional crop system used can be characterized as an intensive crop in an annual cycle of bare-rooted green plants of short-day cultivars, originating from high-elevation nurseries in autumn planting, on ridges beds with two rows of plants protected by opaque plastic sheets (mulching), with localized fertigation system, under plastic cover formed of macro tunnels. In this area, two different harvest periods can be distinguished within the growing season: a cold early crop season (low temperatures and high relative humidity) between January and March (early production) and a warmer late crop season (high temperatures and low relative humidity) between April and May (late production).

In addition, in this area, due to breeding activities, in the last 10 years it has gone from a practically mono varietal cultivation, with more than 80% of the area planted with the cultivar ‘Camarosa’ [4] to a multi varietal culture system; currently there are more than 30 cultivars, developed by different breeding programs, available to farmers; representing, the set of six of them, around 90% (Fig. 1). In these breeding programs, in addition to classical agronomic parameters, other ones related to water requirements, organoleptic and nutraceutic quality, and health benefits have been incorporated [5–9].

Agronomic performance and quality characters of the cultivars depend on both the genotype and growth conditions including environmental factors and cultivation techniques [10]. Climatic differences among cropping areas and inter-annual variations might affect yield and quality characteristics (phenotypic plasticity induced by the agro-environment), to a greater or lesser extent, depending on the genotype. It is known that strawberry species have a micro-climatic adaptation capability [11] and that the use of different cultural practices and production systems allows to improve fruit yields or even crop quality of strawberry cultivars. Considering the micro-climatic adaptation of the strawberry, studies to evaluate the performance (agronomic, quality, etc.) of a cultivar should be carry out in the areas, and with the crop conditions, where they will be grown. Otherwise, it is possible that the cultivar shows a different behaviour.

In recent years, special attention is being paid to traits related to quality [5, 9, 10, 12–15], to the detriment of productive ones. In this paper we want to focus, in addition to quality, in production-related parameters of five cultivars on several crop seasons, so that the information generated in this study allows farmers to know about the consistency of these characteristics over time, in order to make an appropriate choice of cultivars based on their needs (i.e. precocity, fruit firmness, soluble solid content, etc.).

2. Materials and methods

2.1. Plant material and experimental design

During four consecutive crop seasons (2011-2012 (2012), 2012-2013 (2013), 2013-2014 (2014), and 2014-2015 (2015)) plants from high-elevation nurseries of five short-day strawberry cultivars, Candonga®, 'Fortuna', 'Primoris', 'Sabrina', and 'Splendor', were planted at the IFAPA experimental station "El Cebollar" located at Moguer (37°17′N) in the coastal area of Huelva (Spain). This experimental site is a major high-tunnel strawberry production area in Spain with loamy sand soil with an organic matter content of between 0.4–0.6%, and a pH of 6.7 to 7.1. Two planting dates were implemented: an early one at the beginning of October (7th, 9th, 8th and 9th October in the four consecutive seasons respectively), and a conventional one in mid-October (21st, 23rd, 23rd, and 23rd October, respectively). Every year, all cultivars were grown following conventional cropping–practices [4]. Plants were placed in double rows per mulched bed (35 cm high and 50 cm wide) of a sandy soil with 5.8% clay, 5% silt and 89.2% sand, previously biosolarizated [16], and spaced 25 × 25 cm. One month after planting, polyethylene large tunnels were installed over the test area and removed at the end of the cropping season (i.e, end of May) [17]. The plants received: 175 kg N/ha, 77 kg P/ha, 185 kg K/ha, 85 kg Ca/ha, 14 kg Mg/ha, between mid-November and mid-May through the irrigation system.

On each cropping season, the field experiment was setup in a split-plot design with three replicates and 50 plants per plot where the first factor was the planting date and the second factor was the cultivar.

Along the crop season, a set of agronomic variables, organoleptic fruit quality parameters, and vitamin C content were evaluated in order to assess the effect of cultivar, season, planting date, and environmental variation on plant performance.

2.2. Agronomic measurements

Plant vigour was determined as the average of two measurements (north-south and east-west) of the canopy from ten randomly selected plants from each plot. This was done throughout the growing season; at the end-December, end-January, and end-February (i.e. when plant size was established).

Fruit production data from the total number of plants per plot was obtained at least once each week throughout the production season (mid-December to end-May). Fruit was classified into two commercial categories: first and second category. First plus second categories are named commercial or marketable category. First category is defined as healthy fruit well-shaped with a weight above 14–15 g per unit. The second category is defined as healthy fruit that is shaped well and with a weight below 14–15 per unit (and/or healthy fruit lightly misshapen of size above 14–15 g). Non-marketable fruit were rejected without recording (less than 2% of harvested fruit). Yield data were recorded as g/plant. Fruit yield was evaluated for extra-early season production (cumulative yield until end of February), early production (cumulative yield until end of March) and whole season production (cumulative yield until end of the growing season; i.e. end of May). Fruit size was estimated by weighting 40 randomly selected marketable fruits on each harvest. Fruit weight was recorded as gram per fruit. At the end of the production season, yield efficiency was estimated as the ratio between fruit production and vegetative projected area (g fruit cm^{-2}).

Daily, agro-meteorological variables such as temperature (maximum and minimum) and relative humidity were obtained from the Andalucía Institute of Agrometeorological Research for the station located in the same experimental field. In order to estimate the correlation between yield parameters and environmental conditions (minimum and maximum temperature and relative humidity registered), daily yield was estimated by dividing the production of the three harvest periods (from the beginning (i.e. mid-December) until the end of January, from first February until end February, and from first March until the end of the crop (i.e. end-May)) by the number of days in each of those periods.

2.3. Sample preparation to evaluate the organoleptic fruit quality and the vitamin C content

Six times throughout the crop season (mid-February, end-February, mid-March, end-March, mid-April, and end-April) six fruits per plot were evaluated for firmness and soluble solid content. Fruit firmness was measured making two equatorial punctures/fruit using a penetrometer with a 3.5 mm tip; after the homogenization of the samples, soluble solid content was measured using a digital refractometer (PR-32α, Atago, Japan).

Additionally, in three periods in the course of the crop season (mid-February, mid-March, and mid-April), ∼250 g samples of randomly chosen ripe fruits per replication were taken and homogenized with a blender immediately after harvesting, and the purees obtained were then placed in polyethylene bags and frozen and stored at –20°C until processed accordingly to the following assays at the laboratory:

For titratable acidity (TA) determination, the puree was filtrated and diluted with distilled water (1 g: 100 mL). Titration to pH 8.1 with 0.01 M NaOH was done at room temperature with Titroline Easy (Schott Instruments®, GmbH) portable pH meter. Total acidity was expressed as grams of citric acid per 100 grams FW [5].

For ascorbic acid quantification, puree samples were diluted with distilled water (1 g: 10 mL) and homogenized. Reagent test strips were used with the reflectometer set of Merck Co (Merck Rqflex 10). Results were expressed as milligrams of ascorbic acid per 100 grams of FW.

2.4. Effect of environmental variation

To estimate the correlation between the organoleptic parameters and the environmental conditions, since these parameters have been affected by previous environmental factors, not by those recorded at the time of harvest, the average minimum and maximum temperatures and the average relative humidity from two weeks before to the harvest of the fruits (fruit ripening period) were considered at each sampling date in order to be correlated with the different parameters.

2.5. Index of phenotypic plasticity

For each parameter, the phenotypic plasticity index of the different cultivars was calculated as the absolute value of the difference between the minimum value and the maximum value, for all the data obtained in the different samplings, divided by the maximum value [18]. This index, ranging from zero to one, allows an estimation of the magnitude of the phenotypic change under contrasting environmental conditions (i.e. different temperatures) on each genotype. The higher the plasticity index, the higher the phenotypic change in one trait.

2.6. Statistical analysis

Statistical analyses were performed with the analytical software STATISTIX 9.0 (Analytical Software, Florida, USA). Data were subjected to analysis of variance (ANOVA; complete randomized block design). Mean comparisons were done by Least Significant Difference Test (LSD). Pearson's correlation analyses were performed to identify the environmental effects on the studied traits.

3. Results

The overall result (Table 1), evidenced a significant effect of crop season and cultivar on all yield relates and organoleptic parameters studied. Also, a significant effect of the harvesting period on all organoleptic parameters was observed.

In the case of the planting date, this had a significant effect on all yield related parameters but fruit weight. However, this did not show a significant effect on organoleptic parameters.

For each parameter related to yield, and for organoleptic ones, the differences among cultivars, planting dates, crop seasons, and harvest periods are shown in Tables 2 and 3, respectively. For yield related parameters (Table 2), plant vigour was significantly different among cultivars; being ‘Sabrina’ the most vigorous, and between planting dates; cultivars were most vigorous when planted on the conventional date (i.e. mid-October). Among crop seasons, plants reached largest size in 2013 and 2014.

Considering yield, ‘Splendor’, ‘Fortuna’ and ‘Primoris’ had the higher extra-early yield; ‘Fortuna’, as well as ‘Sabrina’ and ‘Primoris’, showed the higher early yield, and ‘Sabrina’ stood out for having the highest total yield. In general, plants were more productive (extra-early, early and total yield) when planting early. Differences among season were also observed; in 2012 plants showed a high yield (extra-early, early, and total yield); although, the highest value of early yield was recorder in 2015, no significantly different from 2012 season; and the highest value of total yield was recorder in 2014, also no significantly different from 2012 season.

The average fruit weight was higher in ‘Splendor’ (28.2 g) and ‘Sabrina’ (28.0 g), and no differences were detected between planting dates. According to the season, the weightiest fruits were observed in 2012, and among harvesting periods, the fruits with greater weight were collected at the beginning of the crop season (until mid-March).

Cultivars studied exhibited different yield efficiency; the cultivars with higher value for this parameter were ‘Splendor’ and ‘Fortuna’. Differences were also observed between planting dates; yield efficiency being higher when planted early, and among seasons; 2012 was the one in which the highest values of yield efficiency were recorded.

The results of the organoleptic parameters are shown in Table 3. For fruit firmness (kg/cm^2), values ranged from 4.4 of ‘Splendor’ to 6.0 of ‘Sabrina’, and no differences were detected for this parameter between the two planting dates. Regarding the season and the harvest period, the fruits were firmer in 2014, and in mid-February.

Considering soluble solid content (°Brix), it ranged from 7.0 of ‘Splendor’ to 7.9 of ‘Candonga’ and ‘Primoris’; according to the planting date, it was higher when conventional planting date was performed. As for the seasons, the higher soluble solid contents were observed in 2013 and 2015 (7.6 °Brix). Concerning harvest periods, the mean highest values were detected at the beginning and at the end of the crop season (mid-February and end-April); although throughout the growing season the values were quite stable, ranging from 7 to 8.

Regarding the acidity, ‘Fortuna’ had the lowest value (0.66 g/100 g FW), whilst ‘Candonga’ showed the highest one (0.77 g/100 g FW). Between planting dates, differences were no detected. Among crop seasons and harvest period, acidity was higher in 2014 and 2015 (0.77 and 0.76 %, respectively), and at the end of the harvest season (0.79% at mid-April).

For vitamin C, among the cultivars studied, ‘Candonga’ was the one with higher amount (58.04 mg/100 g FW). No differences were detected between planting dates, while differences were observed among season (it was higher in 2015) and among harvest periods (it was higher in mid-February).

Results of the correlations between parameters and environmental conditions are shown in Table 4. Significant correlations between yield and the environmental parameters (temperature and humidity) were detected for all cultivars. These correlations were positive with the temperatures (maximum and minimum) and negative with the relative humidity. For yield efficiency, only slight significant negative differences were detected for ‘Primoris’ and ‘Sabrina’ with minimum temperature, and for ‘Candonga’ and ‘Sabrina’ with relative humidity.

Table 1

Analysis of variance (ANOVA) between the main factors for each of the yield related and organoleptic parameters

Yield related parameters

Source[z]	Plant vigor				Extra-early yield				Early yield				Total yield				Fruit weight				Yield efficienc			
	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level
CS	3	81	13.72***	0.000	3	37909	53.2***	0.000	3	134835	50.9***	0.000	3	73746	4.4**	0.006	3	64.1	50.2***	0.000	3	0.11148	65.33***	0.000
PD	1	45	7.63**	0.0072	1	127545	179.1***	0.000	1	385848	145.6***	0.000	1	71992	4.3*	0.041	1	0.1	0.08^{ns}	0.774	1	0.16791	98.40***	0.000
C	4	349	59.2***	0.000	4	44852	62.9***	0.000	4	92601	34.9***	0.000	4	216366	13***	0.000	4	45.5	35.6***	0.000	4	0.12309	72.13***	0.000
CS x C	12	26	4.43***	0.000	12	4864	6.8***	0.000	12	5283	2*	0.036	12	24505	1.5^{ns}	0.154	12	2.6	2.1*	0.029	12	0.01788	10.48***	0.000
PD x C	4	6	1.08^{ns}	0.3738	4	3942	5.5***	0.0006	4	8131	3.1*	0.021	4	30359	1.8^{ns}	0.133	4	1.2	0.9^{ns}	0.463	4	0.008079	4.73**	0.002

Organoleptic parameters

Sources	Firmness				Soluble Solid content (SS)				Titratable acidity (TA)				Vitamin C			
	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level	df	MS	F	*p*-level
CS	3	27486	36.5***	0.000	3	10104.1	202.05***	0.0000	3	0.3	78.8***	0.000	3	10104.1	202.05***	0.0000
HP	5	377384	501.6***	0.000	5	757.3	15.14***	0.0000	2	0.5	127.1***	0.000	2	757.3	15.14***	0.0000
PD	1	510	0.7^{ns}	0.410	1	19.09	0.38^{ns}	0.5373	1	0.005	1.5^{ns}	0.225	1	19.09	0.38^{ns}	0.5373
C	4	277206	368.4***	0.000	4	676.12	13.52***	0.0000	4	0.1	40.2***	0.000	4	676.12	13.52***	0.0000
CS x C	12	2692	3.6***	0.000	12	126.581	2.53**	0.0037	12	0.02	4.4***	0.000	12	126.581	2.53**	0.0037
C x HP	20	3230	4.3***	0.000	20	89.92	1.8^{ns}	0.0781	8	0.01	3.1**	0.003	8	89.92	1.8^{ns}	0.0781
PD x C	4	5347	7.1***	0.000	4	180.927	3.62**	0.007	4	0.03	6.9***	0.000	4	180.927	3.62**	0.007

[z]CS: Crop Season; PD: Planting date; C: Cultivar; HP: Harvest period. ^{ns}, *, **, ***Non significant or significant at $p < 0.05$ or 0.01 or 0.001.

Table 2
Yield related parameters of five strawberry cultivars grown at Huelva (Spain) in two planting dates, during the crop seasons 2012, 2013, 2014 and 2015

	Plant vigor^{z} (cm)		Extra-early yield^{y} (g/plant)		Early yield^{x} (g/plant)		Total yield^{w} (g/plant)		Fruit weight (g/fruit)		Yield efficiency (g/cm^{2})	
Cultivar												
Candonga	36.3	c	114	c	354	c	933	c	25.6	c	0.2038	c
Fortuna	32.9	d	210	a	507	a	1066	b	27.1	b	0.3473	a
Primoris	38.2	b	204	a	490	ab	1036	b	25.1	c	0.3024	b
Sabrina	41.6	a	156	b	491	ab	1194	a	28	a	0.2072	c
Splendor	32.3	d	212	a	469	b	1015	b	28.2	a	0.3462	a
Planting date												
Early	35.6	b	212	a	519	a	1073	a	26.8	a	0.3188	a
Conventional	36.9	a	146	b	405	b	1024	b	26.9	a	0.2440	b
Crop Season												
2012	34.2	c	232	a	507	a	1071	ab	28.5	a	0.3722	a
2013	37.6	a	154	b	393	b	1033	bc	27.2	b	0.2420	b
2014	37.5	a	163	b	417	b	1103	a	25.1	d	0.2591	b
2015	35.6	b	167	b	531	a	988	c	26.3	c	0.2523	b
Harvest period												
Mid February									29.9	b		
End February									33.3	a		
Mid March									32.1	a		
End March									26.8	c		
Mid April									24.0	d		
End April									21.3	e		

Within columns, means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test. ^{z}Average of maximum diameter reached by the plant. ^{y}Extra-early yield: up to end of February; ^{x}Early yield: up to end of March; ^{w}Total yield: up to the end of the crop.

According to fruit weight, a significant negative correlation was observed, for all the cultivars, with minimum and maximum temperatures. Otherwise, no significant correlations were detected with the relative humidity registered (Table 4).

A highly significant negative correlation was recorded for all cultivars between fruit firmness and maximum temperature (Table 4). Meanwhile no significant correlation was detected between fruit firmness and minimum temperature or relative humidity.

No significant correlation between soluble solid content, acidity and vitamin C, and environmental parameters were recorded. Only in 'Fortuna' a slight correlation ($p < 0.05$) was detected between acidity and the minimum temperature.

The behaviour over time of the yield and fruit firmness, both parameters of greatest interest to the producers, were analyzed in more detail and the cultivars were highlighted based on their consistency over the years. As seen above, the planting date (early or conventional) had a significant impact on production (Table 2), so the data were analyzed independently for each plantation date.

In the case of an early planting date, only 'Candonga' showed stability for extra-early yield throughout the crop seasons; in this case showing the lowest values. The rest of the cultivars showed greater variability, their response not being stable over time. For early yield, significant differences between cultivars were observed in

Table 3

Organoleptic parameters of five strawberry cultivars grown at Huelva (Spain) in two planting dates, during the crop seasons 2012, 2013, 2014 and 2015

	Fruit firmness (kg/cm^2)		Soluble solids (ºBrix)		Titratable Acidity (%)		Vitamin C (mg/100 g FW)	
Cultivar								
Candonga	5.56	c	7.9	a	0.77	a	58.04	a
Fortuna	5.23	d	7.1	bc	0.66	e	49.71	c
Primoris	5.76	b	7.9	a	0.7	d	55.64	b
Sabrina	6.0	a	7.3	b	0.74	b	53.47	b
Splendor	4.40	e	7.0	c	0.72	c	53.93	b
Planting date								
Early	5.38	a	7.4	b	0.71	a	54.39	a
Conventional	5.40	a	7.5	a	0.72	a	53.93	a
Crop Season								
2012	5.33	c	7.3	b	0.65	c	50.93	b
2013	5.19	d	7.6	a	0.69	b	49.87	b
2014	5.62	a	7.3	b	0.77	a	46.09	c
2015	5.43	b	7.6	a	0.76	a	69.74	a
Harvest period								
Mid February	6.75	a	8	a	0.71	b	56.82	a
End February	5.62	b	7	c				
Mid March	5.33	d	7.2	c	0.66	c	53.83	b
End March	5.43	c	7.2	c				
Mid April	4.47	f	7.5	b	0.79	a	51.83	c
End April	4.75	e	7.9	a				

*: Within columns, means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test. SS: soluble solids; TA: titratable acidity.

all years, with ‘Fortuna’ ‘Primoris’ and ‘Sabrina’ standing out with a higher and more stable production. In terms of total yield, differences between cultivars were also observed in all study crop seasons, and it can be concluded that ‘Candonga’, in a stable manner, is the least productive of the five cultivars tested (Fig. 2).

Otherwise, with a conventional planting date, ‘Splendor’, followed by ‘Fortuna’ and ‘Primoris’ stood out as the most stable cultivar with the highest extra-early yield along the four crop season studied, while ‘Candonga’ showed, also stably, the lowest production. From this moment on, all cultivars except ‘Candonga’ began to stand out clearly with a greater early and total yield; behaviour that was repeated in the different crop season (Fig. 3).

For fruit firmness, no significant differences were observed between planting date (Table 2), so the data were analyzed considering the two planting dates together (Fig. 4). For this parameter, Sabrina, followed by ‘Primoris’ and ‘Candonga’ were the varieties with the best response; high stable fruit firmness throughout the four seasons, while ‘Splendor’ showed the lowest values (Fig. 4).

The magnitude of the phenotypic change, under contrasting temperature conditions (plasticity index), of each genotypes and traits are showed in Table 5. Considering the different characteristics, yield had the highest plasticity indexes, while, soluble solids content and acidity showed the lowest values (i.e. most stable parameters). Among cultivars, significant differences were only detected for yield and vitamin C content. ‘Candonga’ and ‘Sabrina’ were the most plastic for yield, and regarding the vitamin C content, highlighted ‘Primoris’, with the highest plastic response, followed by ‘Candonga’. Considering global plasticity (average of the plasticity

Table 4
Pearson correlation coefficients obtained between yield related and organoleptic parameters, and environmental parameters for five strawberry cultivars

	Miminum Temperature	Maximum Temperature	Relative Humidity
Candonga			
Yield	0.8888***	0.8981***	–0.6612***
Fruit weight	–0.6971***	–0.7445***	0.2136^{ns}
Yield efficiency	–0.5154^{ns}	0.4899^{ns}	–0.6413*
Fruit firmness	–0.5124^{ns}	–0.6841***	0.1463^{ns}
Soluble solids	–0.2269^{ns}	–0.0143^{ns}	–0.3261^{ns}
Acidity	0.5108^{ns}	0.3468^{ns}	0.2930^{ns}
Vit C	–0.2532^{ns}	–0.1103^{ns}	–0.2980^{ns}
Fortuna			
Yield	0.6387***	0.7388***	–0.6266***
Fruit weight	–0.6700***	–0.5112*	–0.0253^{ns}
Yield efficiency	–0.4583^{ns}	–0.2213^{ns}	–0.1305^{ns}
Fruit firmness	–0.4834^{ns}	–0.6617***	0.1645^{ns}
Soluble solids	–0.2203^{ns}	0.0128^{ns}	–0.3152^{ns}
Acidity	0.6209*	0.5566^{ns}	0.2626^{ns}
Vit C	–0.1757^{ns}	–0.0909^{ns}	–0.1516^{ns}
Primoris			
Yield	0.8402***	0.8270***	–0.5966***
Fruit weight	–0.7471***	–0.5788**	–0.1411^{ns}
Yield efficiency	–0.6943*	–0.0053^{ns}	–0.4400*
Fruit firmness	–0.4848^{ns}	–0.7170***	0.1840^{ns}
Soluble solids	–0.0754^{ns}	0.0620^{ns}	–0.2618^{ns}
Acidity	0.4148^{ns}	0.2604^{ns}	0.0748^{ns}
Vit C	–0.1774^{ns}	–0.0644^{ns}	–0.2473^{ns}
Sabrina			
Yield	0.8922***	0.9264***	–0.6775***
Fruit weight	–0.6350**	–0.5863**	0.1480^{ns}
Yield efficiency	–0.5881*	0.2891^{ns}	–0.6341*
Fruit firmness	–0.5838^{ns}	–0.7164***	0.1082^{ns}
Soluble solids	–0.1848^{ns}	0.2172^{ns}	–0.5409^{ns}
Acidity	0.3321^{ns}	0.1962^{ns}	0.1592^{ns}
Vit C	–0.3666^{ns}	–0.2074^{ns}	–0.3749^{ns}
Splendor			
Yield	0.8293***	0.8571***	–0.6573***
Fruit weight	–0.7582***	–0.6733***	0.1053^{ns}
Yield efficiency	–0.4377^{ns}	0.2570^{ns}	–0.4584^{ns}
Fruit firmness	–0.5993^{ns}	–0.6388***	–0.0123^{ns}
Soluble solids	0.2487^{ns}	0.5716^{ns}	–0.4473^{ns}
Acidity	0.5545^{ns}	0.5682^{ns}	0.2150^{ns}
Vit C	–0.1712^{ns}	–0.0561^{ns}	–0.2200^{ns}

^{ns}, *, **, ***Non significant or significant at $p < 0.05$ or 0.01 or 0.001.

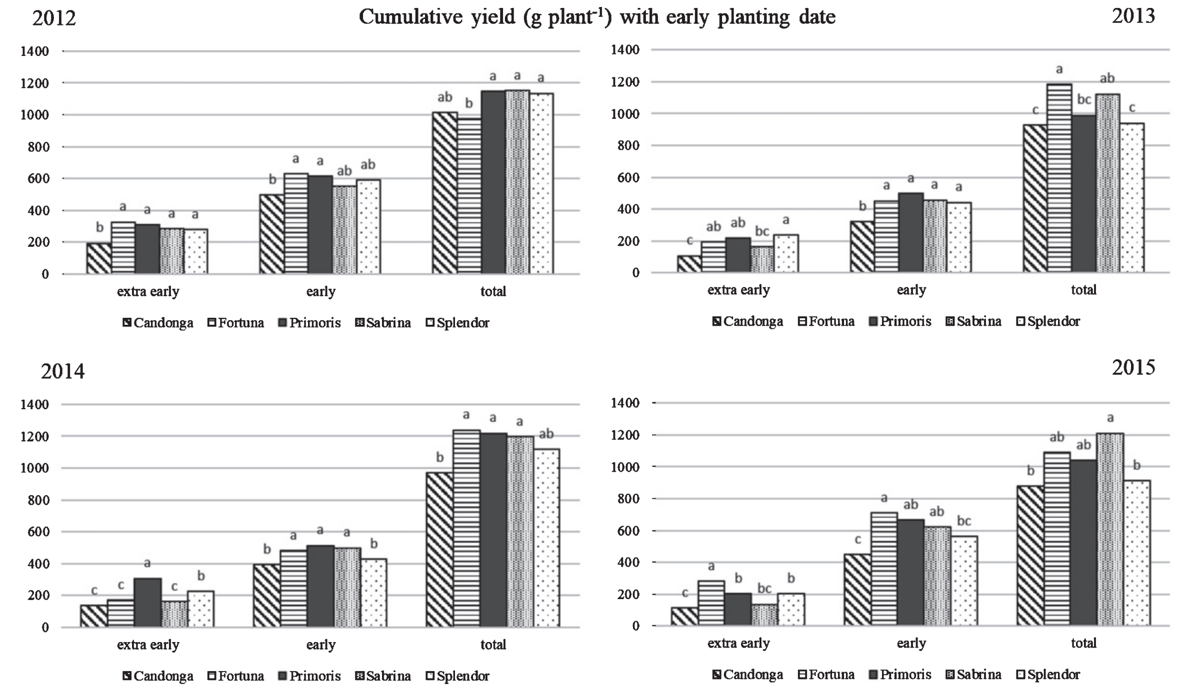

Fig. 2. Cumulative yield (g plant^{-1}) of five strawberry cultivars with early planting date in the 2012, 2013, 2014 and 2015 crop seasons. Means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test.

indexes of all the traits of a variety) [19], all cultivars presented intermediate values of global plasticity varying between 0.606 for 'Primoris' and 0.553 for 'Splendor'. Based on this index the cultivars could be ordered, from more to less plastic: 'Primoris' (0.606) >'Candonga' (0.603) >'Fortuna' (0.600) >'Sabrina' (0.595) >'Splendor' (0.553).

4. Discussion

Many cultivars, coming from several breeding programs, are grown worldwide. However, not all cultivars are well adapted to the different regions where this species is grown; it has been established, that genotype and environmental and agronomical conditions influence fruit characteristics. According to previous works [11, 12, 14, 20, 21], a significant genotypic effect on yield related parameters and on organoleptic parameters have been detected in this study. Furthermore, as it has been pointed by the significant differences in the interactions of season x cultivar and harvest period × cultivar, not all cultivars are affected in the same way for either annual or inter-annual environmental variation (i.e. temperature and/or relative humidity occurring in the different harvest periods and seasons). Therefore, in order to select appropriate cultivars, it is necessary to constantly generate information about the response of cultivars to different production areas and cultural practices. Knowledge of the characteristics of different cultivars, as well as the effect of environmental factors on them can provide valuable information on their adaptability to a specific environment and allow the optimization of the crop.

According to Costa et al. [22] and Hyun et al. [23], that establish that variations in temperature and relative humidity are among the main factors responsible for the environmental variance for strawberry yield, this study also infers a great effect of temperature and relative humidity mainly on yield related parameters. However,

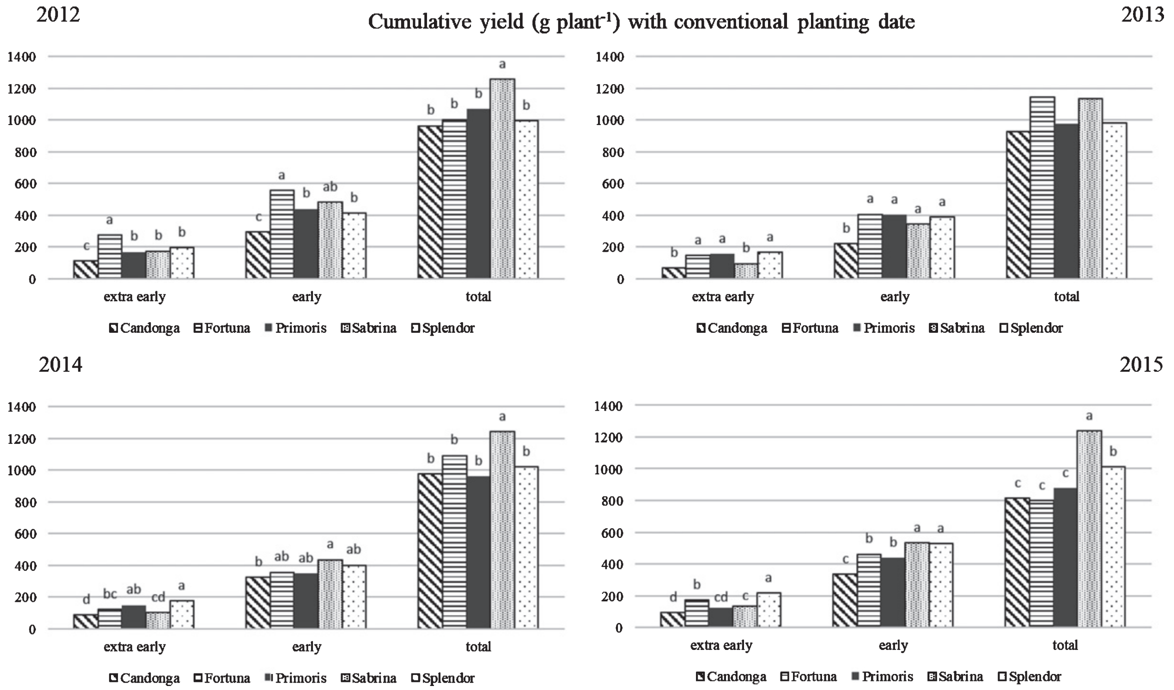

Fig. 3. Cumulative yield (g plant^{-1}) of five strawberry cultivars with conventional planting date in the 2012, 2013, 2014 and 2015 crop seasons. Means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test.

not all the cultivars were similarly affected; thus, yield of ‘Splendor’ was more independent of environmental conditions (temperature and humidity), showing, for this trait, a higher stability than the other cultivars (Table 5).

In our study, no significant effect of temperature and relative humidity on soluble solid content was observed for any of the studied cultivars. In contrast, Wang and Camp [24], working with cultivars adapted to the northeastern U.S. as ‘Earliglow’ and ‘Kent’, point out that increases in temperatures after bloom have the effect of decreasing sugar content. The differences showed among these cultivars and those studied in this work suggest a huge variability among cultivars, and a higher plasticity, for the trait ‘soluble solid content’, of those U.S. cultivars in relation with the cultivars, adapted to Mediterranean climate, studied in this work.

Strawberry shows a high genotypic variability for numerous organoleptic, post-harvest and agronomic characteristics [5, 25, 26], pests and diseases resistance [27, 28], physiological characteristics, or water requirements [7]. This high variability is essential to obtain improved cultivars by breeding programs. Moreover, according to Mishra et al., [26] that establish the environmental influence on the phenotypic expression of characters, and as it has been shown in this work, the interaction of the environment should be taken into account since it carries phenotypic variations; variability that depends on the cultivar, since the degree of modulation of some characteristics by the environment (i.e., phenotypic plasticity) cab be different for each cultivar. Selection of cultivars with greater rusticity (i.e. cultivars with characteristics low dependent of environment; non-plastic) is a factor to be considered in breeding programs in anticipation of climate changes as could be a temperature increase. Moreover, this kind of non-plastic response should also be interesting for cultivars to be grown at different cropping areas (i.e. different regions, countries, etc.) maintaining their original characteristics.

With this type of studies, it can be established whether a trait of a cultivar is consistent over time, that is, if farmers can rely on the choice of one or another cultivar depending on the results of a given season. For some traits of some cultivars, with the results of a crop season it might be enough to know their expression; since they

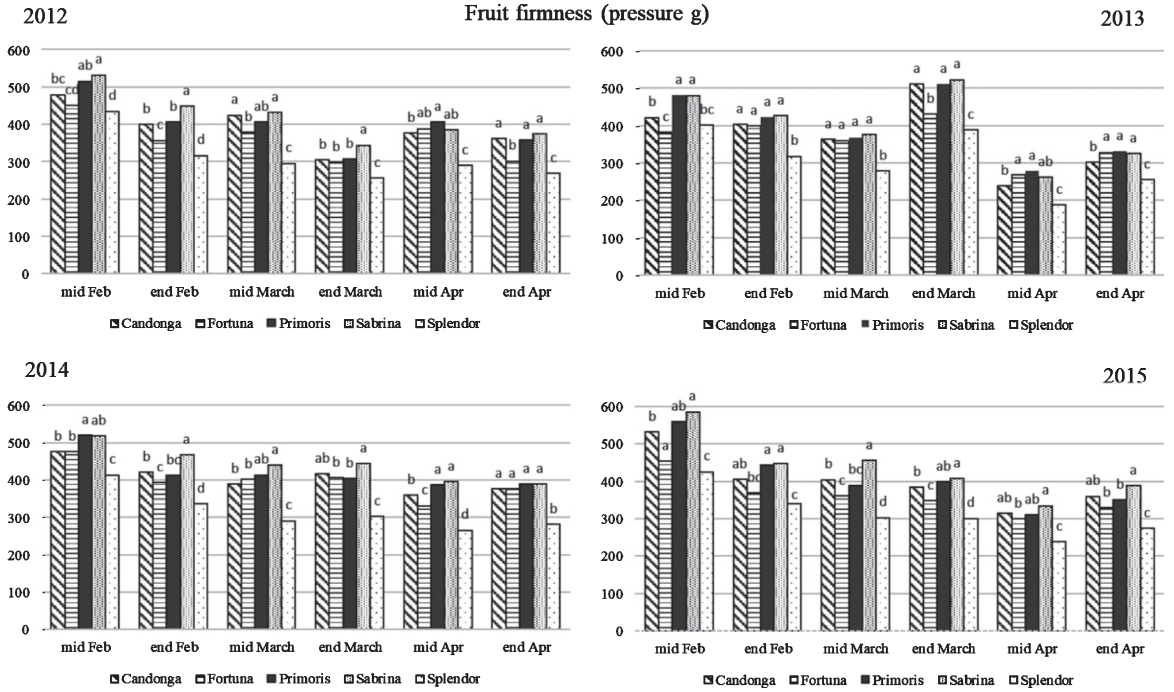

Fig. 4. Fruit firmness (pressure g) of five strawberry cultivars during the 2012, 2013, 2014 and 2015 crop seasons. Means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test.

Table 5
Plasticity index

	Yield	Fruit weight	Yield efficiency	Fruit firmness	Soluble solid	Acidity	Vitamim C
Candonga	0,898 a	0,617	0,567	0,594	0,512	0,415	0,619 ab
Fortuna	0,823 b	0,634	0,644	0,522	0,419	0,602	0,555 b
Primoris	0,817 b	0,581	0,520	0,563	0,486	0,572	0,703 a
Sabrina	0,890 a	0,672	0,489	0,605	0,511	0,424	0,573 b
Splendor	0,773 c	0,621	0,453	0,617	0,461	0,371	0,572 b
	P < *0.001*	*ns*	*ns*	*ns*	*ns*	*ns*	*P* < *0.05*
Average	*0.840 ± 0.053*	*0.625 ± 0.033*	*0.534 ± 0.038*	*0.580 ± 0.038*	*0.478 ± 0.040*	*0.477 ± 0.103*	*0.604 ± 0.060*

Means followed by different letters are significantly different at $P < 0.05$, as determined by the LSD test.

will not be significantly affected by external factors, as can be deduced from their low plasticity index. However, the opposite is true for other traits and cultivars, and the study of one single crop season will not be enough to anticipate their behaviour.

Base on the results of the different cultivars studied, fruit firmness, the soluble solids content, and acidity, for example, were quite stable for all cultivars studied; therefore, data from a single crop season would be enough to predict future behaviour. However, the opposite was observed for the yield; therefore, the results of a single growing season would not be enough to predict the performance of a cultivar and additional evaluations should be carried out in the following growing seasons to establish the behavior of this type of characteristics.

5. Conclusions

Widely consumed strawberry cultivars produced on the main strawberry production area of Europe, differ largely in their organoleptic and yield related characteristics. This variability must be taken into account in order to offer products with the characteristics demanded by the different markets. Also, it is relevant for the choice and selection of parental in breeding programs focused in obtaining new cultivars with specific characteristics.

In addition to genotype, environmental and agronomical conditions have a clear effect on fruit characteristics and, therefore, it is necessary to constantly generated information about the response of new cultivars to different production areas and cultural practices.

To establish the behaviour of a specific cultivar for a specific characteristic, data from a single growing season may or may not be enough; It will depend on both, characteristic and cultivar. Therefore, prior studies should be conducted to find out which traits are more stable to allow them to be properly selected after a single crop season.

This work sheds light on the stability of different characters (i.e. low phenotypic plasticity) such as soluble solids content and acidity (parameters involved in the perception of fruit flavor) that seem to be sufficiently independent of climatic conditions (stable during successive seasons), and can therefore be characterized in a single crop season. Likewise, a classification of the study genotypes based on their phenotypic plasticity is proposed, highlighting 'Splendor' as the most stable cultivar among the study genotypes.

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Conflict of interest

The authors have no conflict of interest to report.

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