Scientific article

Strawberry cultivars performance in contrasting cropping conditions in Tucumán (Argentina)

Comportamiento de cultivares de fresa en condiciones de cultivo contrastantes en Tucumán (Argentina)

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Abstract

Strawberry (*Fragaria* x *ananassa* Duch.) production in Argentina takes place in a wide environmental range, being characterized by the coexistence of different production systems, limitations to technology access by small-scale growers, and by the foreign origin of the cultivars used. In 2021, a study was conducted to evaluate the adaptability of a set of strawberry cultivars to two contrasting cropping conditions in Tucumán, Argentina, in order to increase the current knowledge about genotype response to sub-optimal growing situations. The study included two locations, Padilla (Famaillá, Tucumán) and El Manantial (Lules, Tucumán), that share climate (CWa), soil conditions, and surrounding landscapes. In Padilla, plants were grown under the recommended strawberry farming practices (RSFP), and in El Manantial, plants were subjected to resource-limited cropping conditions (RLCC). The cultivars evaluated were 'Benicia', 'Fronteras', 'Monterey', 'Petaluma', 'Rábida' and 'Rociera'. Fruit number (both total and marketable), % of marketable fruit (%MKTF), average marketable fruit weight, and yield were recorded. There were statistical differences between production systems for all the variables, in favor of RSFP. Not all the evaluated cultivars had the same production pattern in both experimental conditions, showing significant cultivar x cropping condition interactions. 'Rociera' and 'Rábida' had the best performance under RSFP; and 'Rábida' and 'Fronteras' under RLCC. 'Rociera' and 'Benicia' were the most affected cultivars under RLCC. In summary, 'Rábida' was the cultivar that maintained a high relative performance in both growing conditions.

Keywords: Adaptability; *Fragaria x ananassa*; Genotype x environment interaction; Productive systems; Yield.

Resumen

La producción de fresa o frutilla (*Fragaria* x *ananassa* Duch.) en Argentina se desarrolla en un amplio rango ambiental, caracterizándose por la coexistencia de diferentes sistemas productivos, escaso acceso a tecnología por parte de pequeños productores y por el origen extranjero de los cultivares utilizados. En 2021, se evaluó la adaptabilidad de distintos cultivares de fresa a dos condiciones de cultivo contrastantes en Tucumán (Argentina), procurando incrementar el conocimiento actual sobre la respuesta del genotipo a situaciones de cultivo subóptimas. El trabajo incluyó dos localidades, Padilla (Famaillá) y El Manantial (Lules), que comparten clima (CWa), condiciones de suelo y paisajes circundantes. En Padilla, el ensayo se condujo acorde a prácticas recomendadas para el cultivo de frutilla (RSFP). En El Manantial, las plantas se sometieron a condiciones de cultivo restringidas (RLCC). Los cultivares evaluados fueron: 'Benicia', 'Fronteras', 'Monterey', 'Petaluma', 'Rábida' y 'Rociera', registrándose número de frutos totales y comerciales (% frutos comerciales), peso promedio de frutos comerciales y rendimiento. Hubo diferencias estadísticas entre los sistemas productivos para todas las variables analizadas, a favor de RSFP. No todos los cultivares tuvieron el mismo patrón de producción en ambas condiciones experimentales, mostrando interacciones significativas cultivar x condición de cultivo. Se destacaron por mejor desempeño 'Rociera' y 'Rábida' bajo RSFP, y 'Rábida' y 'Fronteras' bajo RLCC. 'Rociera' y 'Benicia' fueron los cultivares más afectados bajo RLCC. En síntesis, 'Rábida' sobresalió por mostrar un desempeño relativo alto en ambas condiciones de crecimiento.

Palabras clave: Adaptabilidad; *Fragaria x ananassa*; Interacción genotipo x ambiente; Rendimiento; Sistemas productivos.

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Introduction

Strawberry (*Fragaria* x *ananassa* Duch.) production worldwide has shown a clear growth in the past 5 years (FAO, 2021) and this trend is expected to continue due to the effects of the COVID-19 pandemic, given that strawberry is one of the foods preferred for their nutraceutical properties, especially for strengthening the immune system (Yadav, 2021). This continuous increase of the crop acreage has encouraged numerous breeding programs to develop new varieties.

Strawberry production in Argentina takes place in a wide range of environments (Kirschbaum and Hancock, 2000), and is characterized for the coexistence of different production systems (Kirschbaum *et al.*, 2019) and for limitations to technology access by small-scale growers (Fernández *et al.*, 2011). In the last 20 years, most of the genotypes of commercially grown strawberries in Argentina, and especially in the northwestern province of Tucumán, were released by United-States or Spain-based breeding programs (Kirschbaum and Hancock, 2000; Kirschbaum *et al.*, 2017), and they are not well adapted to Argentina's diverse edaphoclimatic conditions.

Since the strawberry is a microclimatic crop (Palencia *et al.*, 2009), with a high genotype by environment interaction, cultivars behavior could vary depending on several agronomic and environmental factors (López-Medina *et al.*, 2001), which restricts the selection and recommendation of the same cultivar for contrasting growth conditions. Some cultivars adapt well to a broad range of environments, while others have a limited adaptation, but the major goal for industry and breeding is counting on high-yielding genotypes with good performance in different growing conditions (Lapshin and Yakovenko, 2020).

Strawberry growers usually have to deal with several issues that could limit the achievement of adequate yields. Some of the most important limiting factors are a) initially low plant carbohydrate reserves due to extended cold storage periods (Lieten, 1995), b) late planting (Menzel and Smith, 2012), c) short in-row distance (higher competition between plants; Al-Ramamneh *et al.*, 2013), d) low winter temperatures (Anderson *et al.*, 2019), e) deficient water supply (Ariza *et al.*, 2021), f) insufficient fertilization (Deng and Woodward, 1998), g) delayed stolon removal (Ahmed *et al.*, 2017), and h) pests (MacKenzie *et al.*, 2003; Torrico *et al.*, 2017; Carisse and Fall, 2021; Kirschbaum, 2021a). Under this conceptual frame, a study was carried out to evaluate the adaptability of a set of strawberry cultivars to two contrasting cropping conditions in Tucumán, Argentina, in order to increase the current knowledge about genotype response to sub-optimal growing situations.

Materials and methods

The study was carried out in 2021, in two locations, Padilla and El Manantial, 24-km apart. They share the same climate (CWa, Koppen-Geiger classification, Kottek *et al.*, 2006), similar soil conditions (texture, pH, organic matter and macronutrients content), and agroecologically similar surrounding landscapes (sugarcane plantations, citrus orchards and forest patches). In Padilla (Famaillá, Tucumán), plants were grown under the recommended strawberry farming practices (RSFP), and in El Manantial (Lules, Tucumán) plants were subjected to resource-limited cropping conditions (RLCC) (Table 1).

The RSFP plot was located at INTA's Famaillá Agricultural Experiment Station, in Estación Padilla (27°03'S, 65°25'W; 363 m elevation; Famaillá department, Tucumán province, Argentina), agroecological region of the non-saline depressed plain (Zuccardi and Fadda, 1985). Aquic Argiudol soil, imperfectly drained, silty loam textural type, pH 6.47, organic matter 2.0%, total N 0.12%, soluble P 28.4 ppm, exchangeable K 1.01 me.100 g^{-1} and EC 0.53 $dS.m^{-1}$. Climate CWa (Funes *et al.*, 2020).

The RLCC plot was located at Finca El Manantial (Facultad de Agronomía, Zootecnia y Veterinaria, Universidad Nacional de Tucumán; 26°55'S, 65°20'W, 426 m elevation; Lules department, Tucumán province, Argentina), agroecological region of the subhumid-humid Chacopampean Plain (Sanzano and Fernández de Ullivarri, 2020). Typical Argiudol soil, silty loam textural type, pH 5.9, organic matter 2.89%, total N 0.15%, soluble P 32.3 ppm, exchangeable K (K) 0.9 me.100 g^{-1} (Sal Paz *et al.*, 2014). Climate CWa (Rodríguez and D'urso, 2005).

The strawberry cultivars evaluated in this study were 'Benicia', 'Fronteras', 'Monterey', 'Petaluma' (University of California, USA), 'Rábida' and 'Rociera' (Fresas Nuevos Materiales, Spain). Except for 'Monterey', which is a day-neutral cultivar, all the rest are short-day cultivars.

Table 1. Characterization of the cropping conditions imposed to both strawberry experimental plots.

Conditions	Recommended strawberry farming practices (RSFP)	Resource-limited cropping conditions (RLCC)
Plant storage at 10°C (days)	1-3	40-50
Planting date	19 April-12 May	11 June
Plant density (plants.m-2)	50000	80000
Winter cold protection	Yes	No
Fertilizer supply	Full dose	1/3 full dose
Water supply (field capacity)	3-5/week	1-2/week
Stolon removal	Weekly	Once (26 October)

Fresh dug bare root transplants from a high latitude nursery (42°03' S, 71'10' W; 680 m altitude; El Maitén, Chubut province, Argentina) were used in both experimental fields. All the planting material was cold stored at 10 °C immediately after arrival. In RSFP, each variety was planted the day after the plants arrived. Therefore, planting dates were: 'Monterey' 19 April, 'Fronteras' 23 April, 'Benicia' 6 May, 'Petaluma' 10 May, 'Rociera' and 'Rábida' 12 May. All the planting material for the RLCC plot remained cold stored (10 °C) and were planted all together at the same date: 11 June.

Plants were established in standard offset 2 row beds (0.5 m in width, 0.30 m in height, 1.25 m apart), covered with a 24µ thick black polyethylene mulch, using a 0.3 m in row plant spacing (50000 $plants.ha^{-1}$) in RSFP, and a 0.2 m in row plant spacing in RLCC (80000 $plants.ha^{-1}$). Water and fertilizers were applied through a drip tape with a 0.20 cm hole spacing. Irrigation frequency was 3-5 times per week in RSFP, and 1-2 times per week in RLCC. Fertilization (in $kg.\ ha^{-1}$) under RSFP consisted of 120 N, 70 P_2O_5, 220 K_2O, 40 CaO and 20 MgO (Agüero and Kirschbaum, 2015), while under RLCC the dose was reduced to 1/3. Fertilizers were applied three times a week in the RSFP plot and once a week in the RLCC plot.

In the RSFP plot, low tunnels were erected over each individual cropping bed on 15 June, to protect plants from low winter temperatures. They were supported by hoops (made of stainless steel rods, 6 mm in diameter × 3 m long) spaced every 3 m, providing vertical support for the transparent 100µ thick polyethylene film along each bed. The height of the hoops was 0.6 m above the bed centers. The RLCC plot was not protected by tunnels nor any other covering material.

The experimental setup was a completely randomized design with three replications. Fruit were harvested weekly, from June to November in the RSFP plot, and from August to December in the RLCC plot, according to commercial fruit maturity standards. Fruit yields (total and marketable; TOT and MKT, respectively) and fruit numbers (TOT and MKT) were determined for each plot (on a per plant basis), as well as % of marketable fruit by weight (%MKTF) and average marketable fruit weight (AMFW). The percentage of plants with stolon (%PWS) and the rate of stolon production per plant (RSP) were recorded in RLCC on 26 October. Afterwards, all stolons were removed. Meteorological data for two key months, July (winter) and October (spring), were provided by remote agrometeorological stations located nearby the experimental plots. Data were subjected to analysis of variance and means were separated (DGC test) using INFOSTAT (Di Rienzo *et al.*, 2020).

Results and discussions

Meteorological data. In July, both locations showed very similar meteorological data (Table 2), with some differences in terms of thermal amplitude and days with frosts (both higher in Padilla). In October, besides precipitations (higher in El Manantial), the rest of El Manantial meteorological data was much alike Padilla´s.

Cropping conditions. The restrictions imposed had a highly significant impact on the yield and quality of the strawberry crop, which allowed to differentiate clearly both cropping conditions. There were statistical differences between production systems for all the variables studied, in favor of RSFP (Figure 1a, b, c).

The greatest drops due to the imposed limitations were in yield and fruit number (between 64 and 82%), with lower impact on %MKTF and on AMFW (between 19 and 31%). These drops could be potentially explained by cumulative negative effects of the conditions imposed in the RLCC plot, summarized in Table 3.

Table 2. Meteorological variables in both strawberry experimental plots: resource-limited cropping conditions plot (RLCC; department of Lules) and recommended strawberry farming practices plot (RSFP; department of Famaillá).

Month	Meteorological data	Plot	
		RLCC	RSFP
	Absolute maximum temperature (°C)	26.7	27.9
	Average maximum temperature (°C)	21.0	21.8
	Average temperature (°C)	12.9	12.5
	Average minimum temperature (°C)	4.8	3.2
July	Absolute minimum temperature (°C)	-0.7	-1.7
	Thermal range (°C)	16.3	18.5
	Days with frost (days)	2.0	6.0
	Total precipitation (mm)	0.3	0.5
	Days with precipitation (days)	1.0	2.0
	Absolute maximum temperature (°C)	39.4	40.0
	Average maximum temperature (°C)	30.0	30.1
	Average temperature (°C)	21.4	21.5
	Average minimum temperature (°C)	12.8	12.8
October	Absolute minimum temperature (°C)	5.0	3.7
	Thermal range (°C)	17.2	17.3
	Total precipitation (mm)	49.0	27.9
	Days with precipitation (days)	5.0	6.0

Source: EEAOC, Sección Agrometeorología (https://agromet.eeaoc.gob.ar/).

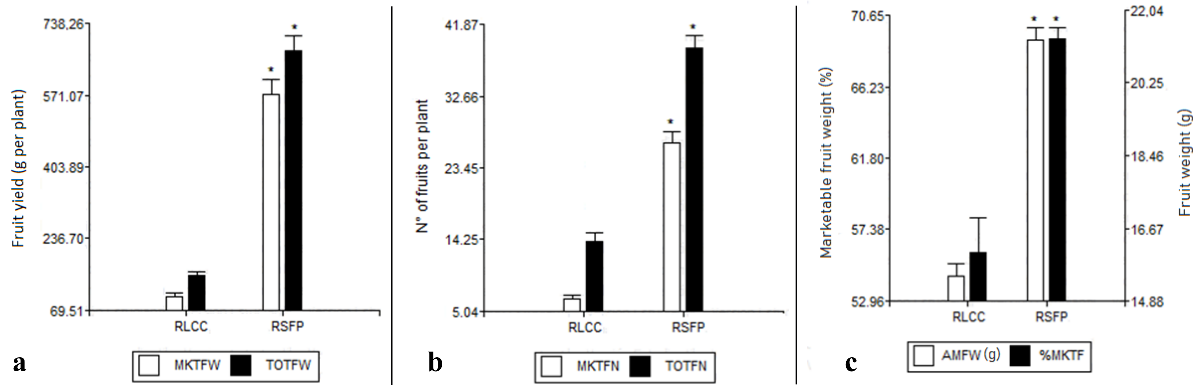

Figure 1: Effects of two contrasting cropping conditions (RSFP; RLCC) on a) total and marketable yield (TOTFW, MKTFW); b) total and marketable fruit number (TOTFN, MKTFN); and c) on the average marketable fruit weight (AMFW) and % of marketable fruit in weight (%MKTF), of six strawberry cultivars. RSFP: recommended strawberry farming practices; RLCC: resource-limited cropping conditions. *Significant differences at $p < 0.0001$.

Similar results were obtained by Gabriel *et al.* (2018), who compared the performance of various strawberry cultivars in two production sites named by the authors as favorable and unfavorable, in Brazil. The average total yield dropped by 51% from favorable to unfavorable. The same trend was observed in %MKTF and AMFW.

'Cultivar by cropping condition' interactions. Not all the evaluated cultivars followed the same production pattern in both experimental conditions, showing significant interactions cultivar x cropping condition. Under RFSP (Table 4), the cultivars separated into three groups regarding TOT and MKT yields: 'Rábida', 'Rociera' (high), 'Fronteras', 'Benicia' (intermediate), and 'Monterey', 'Petaluma' (low). In terms of TOT and MKT fruit number, the cultivars separated in two levels, with 'Rábida' and 'Rociera' in the highest, and the rest of the cultivars in the lowest. Performances of 'Rábida', 'Fronteras', 'Benicia' and 'Petaluma' were similar to those previously reported for the same location in 2020 (Kirschbaum, 2021b). Besides, in that report 'Rociera' also had the highest yield as in the present study, but 50%

Table 3. Studies supporting yield and/or fruit quality drops by strawberry crops subjected to different cropping conditions.

Condition	Contribution to yield reduction
Extended plant cold-storage (days)	Crown starch level dropped by almost 50% from lifting time to planting (cultivar ‘Elsanta’), after a cold storage period of 42 days, in Belgium (Lieten, 1995). Plants (‘Sweet Charlie’) with low carbohydrate levels yielded 40% less compared to plants with high carbohydrate levels, in Florida (Kirschbaum *et al*., 1998).
Delayed planting	Delayed planting (from late March to late April) dropped yields by 15-45% depending on the cultivar (‘Festival’, ‘Fortuna’) and the year, in Australia (Menzel and Smith, 2012). Delayed planting from April/May to June, reduced yield by 31-66% depending on the cultivar (‘Albion’, ‘Camarosa’, ‘Festival’), in Brazil (Pereira *et al.*, 2013; Trentin *et al.*, 2021).
Increased plant density (plants.m-2)	Increased plant (‘Albion’) density enhanced competition among plants, reducing number of fruits per plant (22%), yield (31%) and average marketable fruit weight (14%), in Iowa (Portz and Nonnecke, 2010).
Lack of cold protection	Low tunnels improved marketable fruit yield by 8-22% and percentage of marketable fruit by 14-41% compared with the openfield control (‘Albion’, Minnesota) (Anderson *et al.*, 2019).
Low fertilizer supply	Nitrogen deficiency reduced fruit yield by about 50% due to decreases in fruit weight, fruit set and the number of fruits (‘Elsanta’, United Kingdom) (Deng and Woodward, 1998).
Low water supply	Strawberry (‘Sabrina’, ‘Fortuna’, ‘Splendor’, ‘Primoris’, ‘Rabida’, ‘Rociera’) yield decreased up to 40% with deficient irrigation, in Spain (Ariza *et al*., 2021).

Table 4. Mean ± stándar error of yield and fruit number of six strawberry cultivars grown according recommended strawberry farming practices (RSFP).

Cultivar	Total yield (g/plant)	Total fruit number (per plant)	Marketable yield (g/plant)	Marketable fruit number (per plant)
‘Petaluma’	485.56 ± 43.92a	29.28 ± 2.52a	412.97 ± 40.26a	19.52 ± 1.89a
‘Monterey’	567.30 ± 43.92a	35.99 ± 2.52a	443.47 ± 40.26a	21.96 ± 1.89a
‘Fronteras’	643.55 ± 43.92b	34.16 ± 2.52a	554.49 ± 40.26b	24.40 ± 1.89a
‘Benicia’	664.29 ± 43.92b	39.04 ± 2.52a	549.61 ± 40.26b	25.01 ± 1.89a
‘Rábida’	814.96 ± 43.92c	46.97 ± 2.52b	697.23 ± 40.26c	32.94 ± 1.89b
‘Rociera’	869.25 ± 43.92c	47.58 ± 2.52b	778.36 ± 40.26c	35.99 ± 1.89b

Means with the same letter within each column are not significantly different (DGC test, p > 0.05).

greater. Similarly, ‘Monterey’ yielded 50% more in 2020 compared to 2021, but this reduction is attributed to a strong infestation of *Tetranychus ürticae* Koch in 2021. Our results are in agreement with those from Medina Mínguez *et al*. (2019), who reported that ‘Rábida’ and ‘Rociera’ were within the group of the three top producing cultivars in trials conducted in Spain, and that ‘Petaluma’ was in a secondary level, with statistic differences among them.

Under RLCC, the cultivars also separated into three groups regarding TOT yield (Table 5): 'Rábida', ‘Fronteras’ (high), ´Petaluma’, ‘Monterey’, ‘Rociera’ (intermediate), and ‘Benicia’ (low); three groups in terms of MKT yield (p-value <0.0001): ‘Fronteras’ (high), ‘Rábida’, ’Petaluma’ (intermediate), and ‘Monterey’, ‘Rociera’, ‘Benicia’ (low). In TOT fruit number, there were also three levels: ‘Rábida’ (high), ‘Fronteras’, ‘Petaluma’, ‘Monterey’, ‘Rociera’ (intermediate), and ‘Benicia’ (low). However, there were just two groups of cultivars regarding number of MKT fruit: ‘Rábida’, ‘Fronteras’ (high), and ‘Petaluma’, ‘Monterey’, ‘Rociera’ and ‘Benicia’ (low).

In general, yields in the RLCC plot were 25 to 50% below those reported for the same location (but under conventional cropping conditions), where Sal Paz *et al*. (2012) registered 460 and 480 $g.plant^{-1}$ for ‘Camino Real’ and ‘Fortuna’, respectively. However, in other locations of the same department (Lules) subjected to commercial production practices, cultivars such as ‘Benicia’ and ‘Monterey’ reached much higher production values, 684 and 551 $g.plant^{-1}$, respectively (Forns

Table 5. Mean ± stándar error of yield and fruit number of six strawberry cultivars grown under resource-limited cropping conditions (RLCC).

Cultivar	Total yield (g/plant)	Total fruit number (per plant)	Marketable yield (g/ plant)	Marketable fruit number (per plant)
'Benicia'	100.71 ± 18.63a	10.26 ± 1.62a	62.10 ± 15.93a	4.32 ± 1.08a
'Rociera'	146.61 ± 18.09b	16.20 ± 1.62b	82.08 ± 15.39a	5.94 ± 0.81a
'Monterey'	155.79 ± 24.57b	17.55 ± 2.16b	79.38 ± 20.79a	5.67 ± 1.35a
'Petaluma'	170.10 ± 19.98b	14.85 ± 1.62b	102.60 ± 17.01b	5.94 ± 1.08a
'Fronteras'	197.91 ± 17.55c	15.66 ± 1.35b	152.55 ± 14.85c	8.91 ± 1.08b
'Rábida'	230.04 ± 19.71c	24.57 ± 1.62c	123.12 ± 17.01b	8.37 ± 0.81b

Means with the same letter within each column are not significantly different (DGC test, $p > 0.05$).

et al., 2015), which are very similar to those obtained in the RSFP plot. This information confirms the effect of the profound limitations imposed on the RLCC plot. Regarding %MKTF, under RSFP there were no statistic differences among cultivars, but under RLCC 'Fronteras' and 'Petaluma' were on top (Figure 2a, c). In terms of AMFW, 'Fronteras' had the best performance in both cropping conditions, but without significant differences with 'Petaluma' in the RLCC plot (Figure 2b, d).

Similar results were obtained by Gabriel *et al*. (2018), who compared the performance of various strawberry cultivars in two production

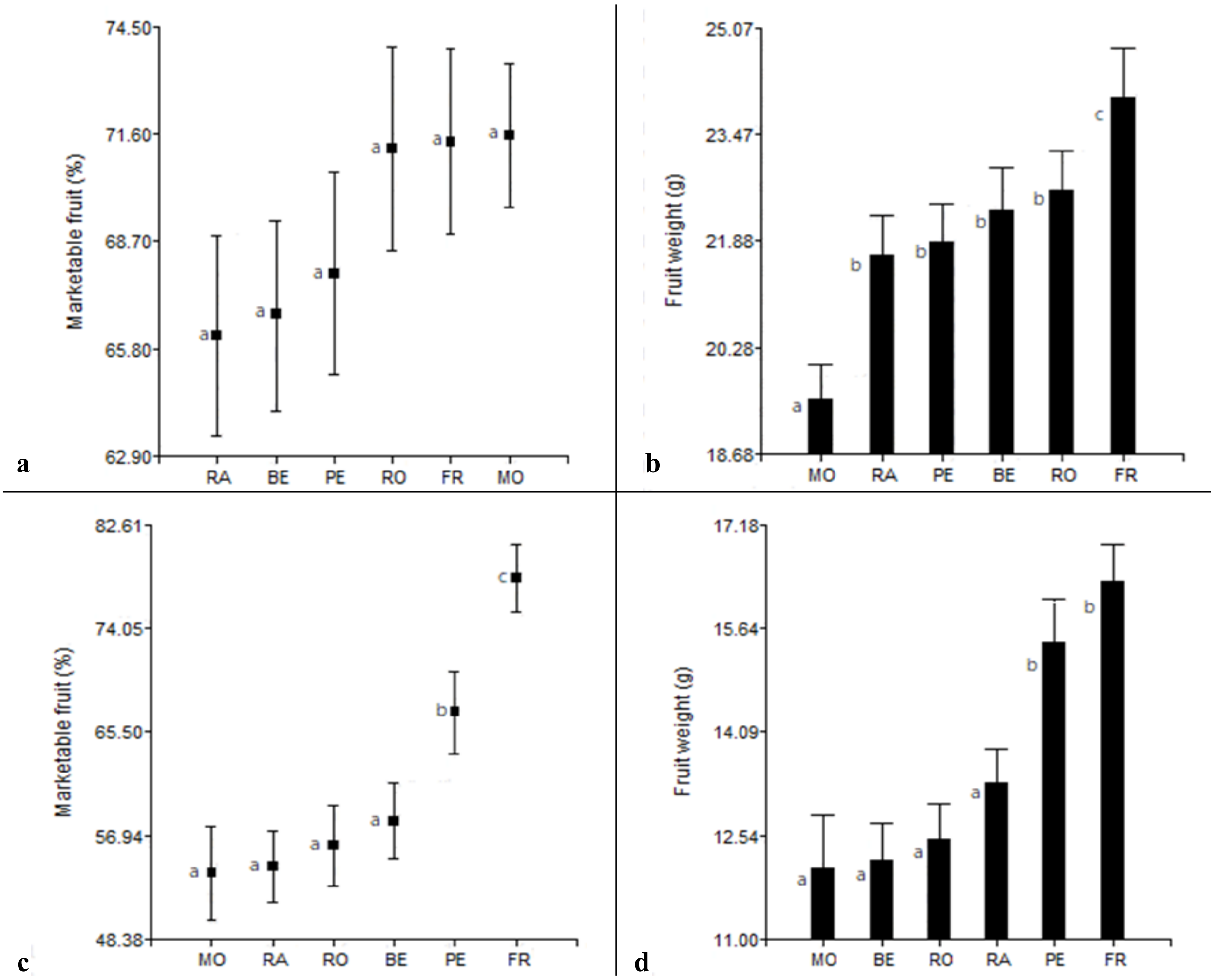

Figure 2: Percentage of marketable fruit and average marketable fruit weight and of six strawberry cultivars ('Benicia', BE; 'Fronteras', FR; 'Monterey', MO; 'Petaluma', PE; 'Rábida', RA; 'Rociera', RO) under recommended strawberry farming practices (RSFP, a and b); and under resource-limited cropping conditions (RLCC, c and d). Means with the same letter are not significantly different (DGC test, $p > 0.05$).

sites named by the authors as favorable (F) and unfavorable (U), in Brazil. In that study, for example, 'Camarosa' and 'Oso Grande' were in the top yielding group, 'Dover' was intermediate, and 'Sweet Charlie' was in the lower yielding group, in F. Nevertheless, in U, 'Dover' was in the high yielding group, 'Camarosa' intermediate, and 'Oso Grande' and 'Sweet Charlie' were in a lower yielding group, concluding that the cultivars had different responses to different environments (genotype x environment interaction).
Genotype x environment interactions also occur in different soil moisture situations, since strawberry cultivars respond differentially to deficient irrigation treatments (Ariza *et al*., 2021).
Thus, 'Rabida', 'Rociera' and 'Sabrina' had significant yield decreases with water supply reduction of 20%, but 'Splendor, 'Primoris', and 'Fortuna' were not affected. Further decreases in water supply (35%) resulted in substantial yield reductions in all the evaluated cultivars, but yield losses were comparatively lower in 'Splendor' and 'Primoris'.
There were significant differences among cultivars regarding the percentage of plants with stolon (%PWS; F = 3.24, df error = 13, p-value = 0.0406) and the rate of stolon production per plant (RSP; F = 6.28, df error = 13, p-value = 0.0036; Figure 3). In the first case, the mean separation test showed two groups of cultivars: 'Fronteras', 'Rábida', 'Rociera', 'Monterey' (intermediate to high %PWS), and 'Petaluma', 'Benicia' (null or low %PWS). Regarding RSP, 'Rociera' separated from the rest of the cultivars for having by far the highest rate. The dimension of this particular fact could have been a strong cause of yield reduction in this cultivar. In subtropical annual winter production systems, stolons and flowers often develop simultaneously and stolon removal reduces competition for resources between runnering and flowering, improving yields (Albregts and Howard, 1986). If stolons are not promptly removed, strawberry yield reductions from 11 to 41% can be expected (Ahmed *et al*., 2017; Morrison *et al*., 2018).
Delayed runner removal is not only associated with yield drop but also with decreases of individual berry weight in some cultivars, as reported for 'Albion' in Canada (Hughes *et al*., 2017), where AMFW dropped from 21.1 to 13.8 g under "weekly" versus "never" runner removal. The magnitude of this AMFW reduction is similar to that recorded in our study (Figure 2b, d).
'Rábida' and 'Rociera' are some of the last cultivars registered in Argentina, and are considered very promising because of their high productivity and fruit quality attributes (Medina Mínguez *et al*., 2019; Jerez *et al*., 2021). Their adaptation to different production scenarios of the country is still unknown.

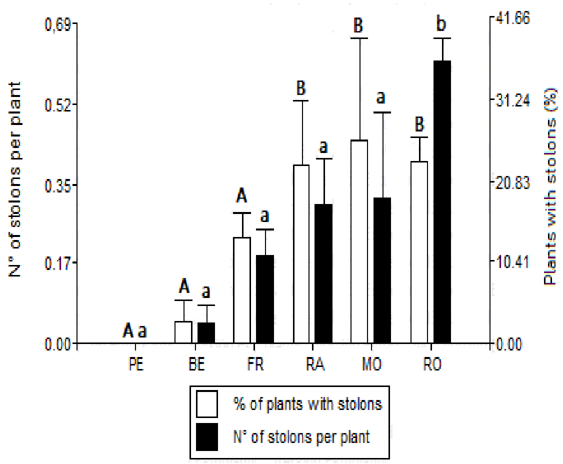

Figure 3: Percentage of plants with stolons (%PWS) and rate of stolon production (RSP), expressed as the number of stolons/plant, of six strawberry cultivars in the resource-limited cropping condition (RLCC) plot. Means with the same letter (upper case for AMFW; lower case for % of marketable fruit) are not significantly different (DGC test, p > 0.05).

Conclusions

The results suggest that the ranking of relative performance of strawberry cultivars might vary depending on the availability of resources or cropping conditions. 'Rociera' and 'Rábida' had the best performance under RSFP. However, under RLCC, the best cultivars were 'Rábida' and 'Fronteras'. Considering the two contrasting cropping conditions, 'Rábida' was the cultivar that maintained a high relative performance in both situations in spite of the limitation of resources. 'Rociera' and 'Benicia' were the most affected cultivars under resource-limited cropping conditions. For more accuracy, it would be necessary to analyze the effect of each individual factor separately.
Continuously, cultivar trials in contrasting environments should be promoted, especially considering that in the last 30 years, 76 strawberry cultivars have been registered in Argentina's National Registry of Cultivars, according to a search that we conducted in the Instituto Nacional

de Semillas (INASE) database.

The information on the strawberry crop growth in response to the environment provided by the present study could contribute to developing mathematical crop models, which would allow making yield predictions on specific issues (i.e. the impact of projected climate change scenarios on strawberry production systems). Strawberry growers in Argentina and in many underdeveloped countries, especially small-scale farmers with limitations to technology access, are frequently exposed at least to one of the yield-limiting factors discussed in this study, which results could be useful for reinforcing actions to raise awareness about the consequences of inappropriate crop management practices. All the situations that reduce the capacity of the plant to express its optimal agronomic performance must be rigorously avoided in order to guarantee profitable yields in a frame of sustainable production.

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References

Agüero J.J., Kirschbaum, D.S. (2015). Response to fertilization associated to leaf mineral content in strawberry. Journal of Plant Nutrition 38: 116-126.

Ahmed M., El-Latif A., Al-Ballat I., Salah S. (2017). Effect of gibberellic acid concentrations and runners' removal rates on yield and quality of frigo strawberry plantations. Menoufia Journal of Plant Production 2: 395-406. doi: 10.21608/mjppf.2017.176311

Albregts E.E., Howard C.M. (1986). Effect of runner removal on strawberry fruiting response. HortScience 21: 97-98.

Al-Ramamneh E., Al-Rawashdeh Z., Karajeh M., Abu-Romman S. (2013). Plant response of strawberry to intra-row spacing and growing conditions in south of Jordan. Asian Journal of Plant Sciences 12: 201-207. DOI: 10.3923/ajps.2013.201.207

Anderson H., Rogers M.A., Hoover E.E. (2019). Low tunnel covering and microclimate, fruit yield, and quality in an organic strawberry production system. HortTechnology 29: 590-598, doi:10.21273/HORTTECH04319-19.

Ariza M.T., Miranda L., Gómez-Mora J.A., Medina J.J., Lozano D., Gavilán P., Soria C., Martínez-Ferri E. (2021). Yield and fruit quality of strawberry cultivars under different irrigation regimes. Agronomy 11: 261. https://doi.org/10.3390/agronomy11020261

Carisse O., Fall M.L. (2021). Decision trees to forecast risks of strawberry powdery mildew caused by *Podosphaera aphanis*. Agriculture 11: 29. https://doi.org/748 10.3390/agriculture11010029

Deng X., Woodward F.I. (1998). The growth and yield responses of *Fragaria ananassa* to elevated CO_2 and N supply. Annals of Botany 81: 67-71. https://doi.org/10.1006/anbo.1997.0535

Di Rienzo J.A., Casanoves F., Balzarini M.G., Gonzalez L., Tablada M, Robledo C.W. (2020). Infostat –Software estadístico. InfoStat Versión 2020. Centro de Transferencia InfoStat, FCA, Universidad Nacional de Córdoba, Argentina.

Fernández M.T., Villegas D.R., Alvarado P., Kirschbaum D.S. (2011). Mejoramiento de las condiciones de trabajo y de la rentabilidad de agricultores familiares. VII Jornadas Interdisciplinarias de Estudios Agrarios y Agroindustriales (FCE-UBA). 1-4 November, Buenos Aires, Argentina.

Forns A., Lobo Zavalía R., Mamana R., Zakelj M., Coronel M., Valdez I., Ale J., Berettoni A. (2015). Comportamiento productivo de nuevas variedades de frutilla en el piedemonte tucumano. EEAOC Avance Agroindustrial 36 (4): 38-42.

Funes C., Escobar L., Kirschbaum, D. (2020). First record of *Feltiella curtistylus* Gagné (Diptera: Cecidomyiidae) in Argentina. Revista de la Facultad de Ciencias Agrarias de la Universidad Nacional de Cuyo 52: 314-319.

Gabriel A., Resende J.T.V., Zeist A.R., Resende L.V., Resende N.C.V., Galvao A.G., Zeist R.A., de Lima Filho R.B., Corrêa J.V.W., Camargo C.K. (2018). Phenotypic stability of strawberry cultivars assessed in three environments. Genetics and Molecular Research 17 (3): gmr18041.

Hughes B.R., Zandstra J., Taghavi T., Dale. A. (2017). Effects of runner removal on productivity and plant growth of two day-neutral strawberry cultivars in Ontario, Canada. Acta Horticulturae 1156: 327-332.

Jerez E.F., Heredia A.M., Mariotti Martínez J.A., Kirschbaum D.S. (2021). Nuevas cultivares de frutilla (*Fragaria* x *ananassa*): caracterización de la calidad del fruto en el subtrópico de Argentina. III Congreso Argentino de Biología y Tecnología Postcosecha, 26-30 July. Santa Fe, Argentina. P. 159.

Kirschbaum D.S. (2021a). Fresa: Tendencias y perspectivas en el control de la plaga clave araña roja (*Tetranychus urticae*). Chapter 5. In: Avances en el cultivo de las berries en el trópico. Fischer G., Miranda D., Magnitskiy S., Balaguera-López H.E., Molano Z. (eds.). Edition: 1°. Sociedad Colombiana de Ciencias

Hortícolas. Colombia. Pp. 59-65. https://doi.org/10.17584/IBerries

Kirschbaum D.S. (2021b). Manejo del cultivo de frutilla. Jornada de capacitación para productores. INTA AER Perico, 18 Nov. Jujuy, Argentina

Kirschbaum D.S., Cantliffe D.J., Darnell R.L., Bish E.B., Chandler C.K. (1998). Propagation site latitude influences initial carbohydrate concentration and partitioning, growth, and fruiting of 'Sweet Charlie' strawberry (*Fragaria* x *ananassa* Duch.) transplants grown in Florida. Proceedings of the Florida State Horticultural Society 111: 93-96.

Kirschbaum D.S., Hancock J.F. (2000). The strawberry industry in South America. HortScience 35: 807-811.

Kirschbaum D.S., Sordo M.H., Adlercreutz E.G., Delmazzo P.R., Cuellas M.V., Lochbaum T., Caminiti A., Miserendino E.E., Escalier C., Choque L. (2019). Panorama del cultivo de frutilla en Argentina 2019. Boletín de Frutas y Hortalizas Nº 99. Corporación del Mercado Central de Buenos Aires. Argentina

Kirschbaum D.S., Vicente C.E., Cano-Torres M.A., Gambardella-Casanova M., Veizaga-Pinto F.K., Correa-Antunes L.E. (2017). Strawberry in South America: from the Caribbean to Patagonia. Acta Horticulturae 1156: 947-955.

Kottek M., Grieser J., Beck C., Rudolf B., Rubel F. (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15: 259-263.

Lapshin V.I., Yakovenko V.V. (2020). An analysis of the inheritance of the density of the pulp of a berry in a number of varieties of strawberries. Agrarian Science 4: 72-74. https://doi.org/10.32634/0869-8155-2020-337-4-72-74

López-Medina J., Vazquez E., Medina J.J., Dominguez F., López-Aranda J.M., Bartual R., Flores F. (2001). Genotype x environment interaction for planting date and plant density effects on yield characters of strawberry. The Journal of Horticultural Science and Biotechnology 76: 564-568.

Lieten F., Kinet J.M., Bernier G. (1995). Effect of prolonged cold storage on the production capacity of strawberry plants. Scientia Horticulturae 60: 213-219x. https://doi.org/10.1016/0304-4238(94)00721-Q.

MacKenzie S.J., Xiao C.L., Mertely J.C., Chandler C.K., Martin F.G., Legard D.E. (2003). Uniformity of strawberry yield and incidence of Botrytis fruit rot in an annual production system. Plant Disease 87: 991-998. https://doi.org/10.1094/pdis.2003.87.8.991.

Medina Mínguez J.J., Miranda Enamorado L., Gómez Mora J.A., Soria Navarro C. (2019). Evaluación de variedades de fresa en cultivo convencional con suelo desinfectado químicamente, campaña 2018-2019. Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible, Instituto de Investigación y Formación Agraria y Pesquera, 16 p. Sevilla, Spain.

Menzel C.M., Smith, L. (2012). Effect of time of planting and plant size on the productivity of 'Festival' and 'Florida Fortuna' strawberry plants in a subtropical environment. HortTechnology 22: 330-337.

Morrison D.M., Blankenship E.E., Read P.E., Paparozzi E.T. (2018). Stolon development and cultural production practices of winter-grown strawberries. International Journal of Fruit Science 18: 138-152. DOI: 10.1080/15538362.2017.1413700

Palencia P., Martínez F., Medina J.J., Vázquez E., Flores F., López-Medina J. (2009). Effects of climate change on strawberry production. Acta Horticulturae 838: 51-54. https://doi.org/10.17660/ActaHortic.2009.838.6

Pereira W.R., de Souza R.J., Yuri J.E., Ferreira S. (2013). Produtividade de cultivares de morangueiro, submetidas a diferentes épocas de plantio. Horticultura Brasileira 31: 500-503. https://doi.org/10.1590/S0102-05362013000300026

Portz D., Nonnecke G.R. (2010). Effect of removal of runners and flowers from day-neutral strawberries on time of harvest and total yields. Iowa State Research Farm Progress Reports, Agricultural Science Commons 9 (36): 325-328.

Rodríguez G.V., D'Urso C.H. (2005). Estudio hidrogeológico y de calidad de agua en el sector oriental de la Sierra de San Javier entre las localidades de Yerba Buena y El Manantial. Provincia de Tucumán, República Argentina. Estudios Geológicos 61: 197-206.

Sal Paz M.I., Salazar S.M., Brandán E.Z. (2014). Rendimiento frutal de plantas de frutilla bajo condiciones de campo en Tucumán, Argentina. Biología en Agronomía 4 (2): 52-58.

Sanzano A., Fernández de Ullivarri J. (2020). Suelos de Tucumán. Guía de estudio. Cátedra de Edafología. Facultad de Agronomía y Zootecnia. Universidad Nacional de Tucumán, Argentina.

Taghavi T., Dale A., Hughes B., Zandstra J. (2016). The performance of dayneutral strawberries differs between environments in Ontario. Canadian Journal of Plant Science 96: 662-669.

Torrico A.K., Salazar S.M., Kirschbaum D.S., Conci V.C. (2017). Yield losses of asymptomatic strawberry plants infected with Strawberry mild yellow edge virus. European Journal of Plant Pathology 150: 983-990.

Yadav R. (2021). Potential benefits of berries and their bioactive compounds as functional food component and immune boosting food. In: Immunity boosting functional foods to combat COVID-19. Giri A. (ed.). CRC Press. Boca Raton, USA.

Zuccardi R.B., Fadda S. (1985). Bosquejo agrológico de la provincia de Tucumán. Facultad de Agronomía y Zootecnia/UNT. Miscelánea 86. Tucumán, Argentina.