Planting date determines the duration of phenological stages and yield of cape gooseberry (*Physalis peruviana* L.) in the subtropics of Argentina

La fecha de siembra determina la duración de las etapas fenológicas y el rendimiento de la uchuva (*Physalis peruviana* L.) en el subtrópico de Argentina

Rolando J. Quiroga[1], Daniel S. Kirschbaum[1, 2], and Gerhard Fischer[3*]

ABSTRACT

To evaluate the effects of different planting dates on the duration of phenological phases and the agronomic yield of cape gooseberry (*Physalis peruviana*), the plants were planted in the province of Tucumán (Argentina). In this province, cape gooseberries have similar day-length requirements to those in other growing regions, suggesting that their production is feasible. Cape gooseberry seeds were sown on three dates, between January 29 and April 3 in 2015, 2016, and 2017, resulting in planting seasons between May and June. The earliest planting date that allowed completion of the phenological phases most closely matches those of other cape gooseberry-producing regions, advancing the phenological stages in calendar terms. Planting date significantly affected yields, as the crop was exposed to variations in environmental conditions, including temperature, photoperiod, and solar radiation throughout the production cycle. The first sowing/planting date yielded the highest total yield in the three years. This response was associated with plants with a greater number of leaves, higher maximum production rate (MPR) and MPR duration, and a longer production cycle that allowed for greater radiation accumulation and favorable temperatures for flower and fruit production. This was positively correlated with the photothermal coefficient for this stage.

Keywords: goldenberry, temperature, photoperiod, solar radiation, production rate.

RESUMEN

Para evaluar el efecto de diferentes fechas de siembra sobre la duración de las fases fenológicas y el rendimiento agronómico de la uchuva (*Physalis peruviana*), se sembraron plantas en la provincia de Tucumán (Argentina). En esta provincia, las uchuvas tienen requisitos de duración del día similares a los de otras regiones productoras, lo que fomenta la idea de que su producción sea viable en esta región. Las semillas de uchuva se sembraron en tres fechas, entre el 29 de enero y el 3 de abril, en 2015, 2016 y 2017, lo que dio lugar a temporadas de trasplante entre mayo y junio. La fecha de trasplante más temprana permitió completar las fases fenológicas de forma más similar a otras regiones productoras de uchuva, adelantando las etapas fenológicas en términos de fechas del calendario. La fecha de trasplante afectó significativamente a los rendimientos, ya que el cultivo estuvo expuesto a variaciones en las condiciones ambientales, como la temperatura, el fotoperíodo y la radiación a lo largo del ciclo de producción. En los tres años, la primera fecha de siembra/trasplante resultó en el mayor rendimiento total. Esta respuesta se asoció con plantas con un mayor número de hojas, una mayor tasa de producción y duración de la misma, y un ciclo de producción más largo que permitió una mayor acumulación de radiación solar y temperaturas favorables para la producción de flores y frutos, relacionándose positivamente con el coeficiente fototérmico para esta etapa.

Palabras clave: uvilla, temperatura, fotoperíodo, radiación solar, tasa de producción.

Introduction

The cape gooseberry (*Physalis peruviana* L.), also known as goldenberry, grows wild and semi-wild at an altitude between 800 and 3,000 m and is widely distributed in the Andean region (Fischer *et al.*, 2011). This plant is found in almost all tropical highlands and in several parts of the subtropics, where it behaves as an annual or perennial plant (Mora-Aguilar *et al.*, 2006; Moura *et al.*, 2016).

In addition to Colombia, goldenberry cultivation has spread throughout South America, especially in Ecuador, Peru, Chile, and Brazil (Fischer *et al.*, 2014). Production

Received for publication: August 27, 2025. Accepted for publication: December 11, 2025. Doi: 10.15446/agron.colomb.v43n3.122431

[1] Estación Experimental Agropecuaria Famaillá, Instituto Nacional de Tecnología Agropecuaria, Tucumán (Argentina).
[2] Facultad de Agronomía, Zootecnia y Veterinaria, Universidad Nacional de Tucumán, Tucumán (Argentina).
[3] Universidad Nacional de Colombia, Facultad de Ciencias Agrarias, Departamento de Agronomía, Bogotá (Colombia).
[*] Corresponding author: gfischer@unal.edu.co

projects have recently been developed in Argentina (Quiroga & Kirschbaum, 2021). Other producing and exporting countries include Kenya, South Africa, Zimbabwe, New Zealand, Australia, India, Malaysia, and the USA (Hawaii) (Miranda & Fischer, 2021), highlighting its adaptability to varied agroclimatic conditions.

Growing freely (without support), the plant can reach a height of 1.0 to 1.5 m, branching sympodially, often forming four main reproductive branches. When trained, it can reach heights of 2 m (Fischer *et al*., 2014). This plant has an indeterminate growth habit, meaning that new branches, leaves, and flowers develop simultaneously (Ramírez *et al*., 2013).

The fruit develops within 60-80 d after transplanting, depending on the agroecological conditions (Galvis *et al*., 2005). The onset of flowering and fruiting is favored by temperatures between 20 and 22°C (Mora-Aguilar *et al*., 2006).

Cape gooseberry is a cold-climate plant that adapts to different agroecological conditions. In subtropical areas, Rufato *et al*. (2012) report that cape gooseberry crops can produce for 2 to 3 years in Brazil. Fischer, Balaguera-López *et al*. (2024) also report that many cape gooseberry crops obtain their best fruit size and quality during the first two harvest peaks and continue producing for 2 to 3 years, but with increasingly smaller fruits that are no longer exportable.

While Fischer *et al*. (2021) and Ali and Singh (2014) describe optimal temperatures for its development and production as 13°C and 16°C, Rufato *et al*. (2012) and Lima *et al*. (2021) recommend a range of 15 to 25°C for Brazil. Salazar *et al*. (2008) estimated the base (minimum) temperature for longitudinal stem growth at 6.3°C, indicating that temperatures below 0°C damage cape gooseberry plants (Fischer *et al*., 2014).

In Colombia, Fischer and Melgarejo (2020) observed that cape gooseberry sprouted by forming new basal shoots after a frost at -6°C, which occurred within 2 h, but crop development was delayed up to 4-6 months. Temperatures above 30°C damage flowering and fruiting (Wolff, 1991), while 10.8°C is the minimum for flower bud formation (Salazar *et al*., 2008). Among other advantages, the fruit calyx protects the fruit from sudden temperature changes, as observed by Fischer, Balaguera-López *et al*. (2024). Temperatures inside the calyx are 5°C lower than those in the surrounding environment, which favors fruit quality.

Photoperiod is another critical factor for the development of the cape gooseberry. Several studies have shown that it is a facultative short-day plant, as 8-h photoperiods shorten the plant's juvenile phase and induce more intense flowering than 16-h photoperiods, but the plants still flower under long photoperiods if temperatures are permissive (Fischer & Melgarejo, 2020). The quantity and quality of light are essential, particularly for photosynthesis in the calyx and leaves near the fruit, as this directly impacts fruit fill and quality (Fischer, Balaguera-López *et al*., 2024).

Cape gooseberry thrives at sites with direct sunlight of 1,500 to 2,000 h year^{-1}, producing fruits of appropriate size and quality (Mora-Aguilar *et al*., 2006; Rufato *et al*., 2012). This behavior indicates that cape gooseberry is a light-demanding plant (Carillo-Perdomo *et al*., 2015).

Based on the effects of the environmental variables described above on cape gooseberry growth and development, the transplant date is expected to influence yield, as suggested by previous studies in which yields decrease as the transplant date is delayed (Sabino-López *et al*., 2018). Climatic conditions affect genotype expression directly (Pérez Martinez & Melgarejo, 2014), so that providing a better environment for the crop through the correct sowing/transplanting date leads to higher yields. Yamika *et al*. (2019) highlight the importance of further studying crop management to standardize cape gooseberry production technologies and promote its development and production under diverse agroclimatic conditions.

The production of *P. peruviana* can be an alternative for export purposes in Argentina, where there are still no commercial crops of this species (Quiroga & Kirschbaum, 2021), so the information available in the country on this fruit crop is practically nonexistent. It is interesting to note that in the region known as Northwest Argentina (subtropical climate), in addition to *P. peruviana,* there are native species of *Physalis* that produce edible fruits, such as *P. pubescens* (Martínez, 1998), *P. victoriana* (Toledo, 2013) and *P. viscosa* (Arenas & Kamienkowski, 2013), but these plants are not yet cultivated.

Within the described conceptual framework, the objective of this study was to evaluate the effects of different planting dates on the duration of phenological phases and the agronomic performance of *Physalis peruviana* crops, analyzing temperature, photoperiod, and radiation effects. The working hypothesis was that early transplant dates allow for longer fruiting cycles and, consequently, higher yields.

Materials and methods

The trials were carried out at the experimental field of INTA's Famaillá Agricultural Experiment Station (EEA), located in Estación Padilla (27°03' S, 65°25' W, 363 m a.s.l.), Famaillá Department, Tucumán Province, Argentina. The work was repeated for three consecutive years of annual planting and harvesting cycles: 2015, 2016, and 2017. Each year, the treatments were the first (T1), second (T2), and third (T3) sowing/planting dates (Tab. 1).

Sowing

The cape gooseberry variety was 'Tarijeña', with seeds provided by small family farmers from Jujuy, Argentina. In the seedbeds, seeds were sown in 35-cell plastic trays containing 100 cc each, using the commercial potting soil Growmix Multipro® (Terrafertil, Argentina), consisting of peat, perlite, vermiculite, and macro- and micronutrients. Sowing (one seed per cell) was carried out on three different dates between January and April (Tab. 1) to ensure different transplant dates in the field. The trays were kept in a glass greenhouse under controlled humidity. The plants were ready to be planted in the field 50-60 d after seed sowing.

TABLE 1. Seed sowing dates of cape gooseberry during three years of evaluation (Famaillá, Tucumán, Argentina).

Treatment	2015	2016	2017
	Sowing date		
T1	January 29	February 11	February 13
T2	February 26	March 01	March 10
T3	March 10	March 31	April 03

Planting, training, and experimental design

Over the three years, field planting was carried out between May and June (Tab. 2), with plants spaced at 1 m, on 0.4-m-wide and 0.5-m-high beds spaced 1.5 m apart.

TABLE 2. Cape gooseberry planting dates during the three years (Famaillá, Tucumán, Argentina).

Treatment	2015		2016		2017	
	Planting date and days after seeding					
T1	May 18	109	May 05	84	May 02	78
T2	June 08	102	May 23	83	May 22	73
T3	June 18	100	June 08	79	June 12	69

As the plants grew, they were trained on trellises, with pine logs placed at each end of the beds and three rows of wire at 0.5 m, 1.0 m, and 1.5 m height.

A completely randomized design was used with three treatments (planting dates) and three replicates (plots), each with nine plants. The number of expanded leaves per plant was recorded weekly as an indicator of growth, from field planting until the appearance of the first open flower (Sánchez, 2002).

Phenological phase records

The following phenological phases were considered: flower bud (Fig. 1A), open flower (Fig. 1B), fruit set (Fig. 1C), and ripe fruit (Fig. 1D) (Sánchez, 2002). Through weekly observations, the start time of each stage was visually recorded and measured in days after planting (DAP).

Additionally, the thermal time (TT) for each stage was calculated, taking 6.29°C as the base temperature (Salazar *et al.*, 2008). Temperature data were provided by INTA Famaillá Agrometeorology Section. The formula used was:

$$\text{Daily thermal time (growing degree days, GDD)} = [(T_{max}+T_{min}) / 2] - T_{base} \quad (1)$$

From the daily TT sums, the total TT was calculated, expressed as accumulated growing degree days (GDD).

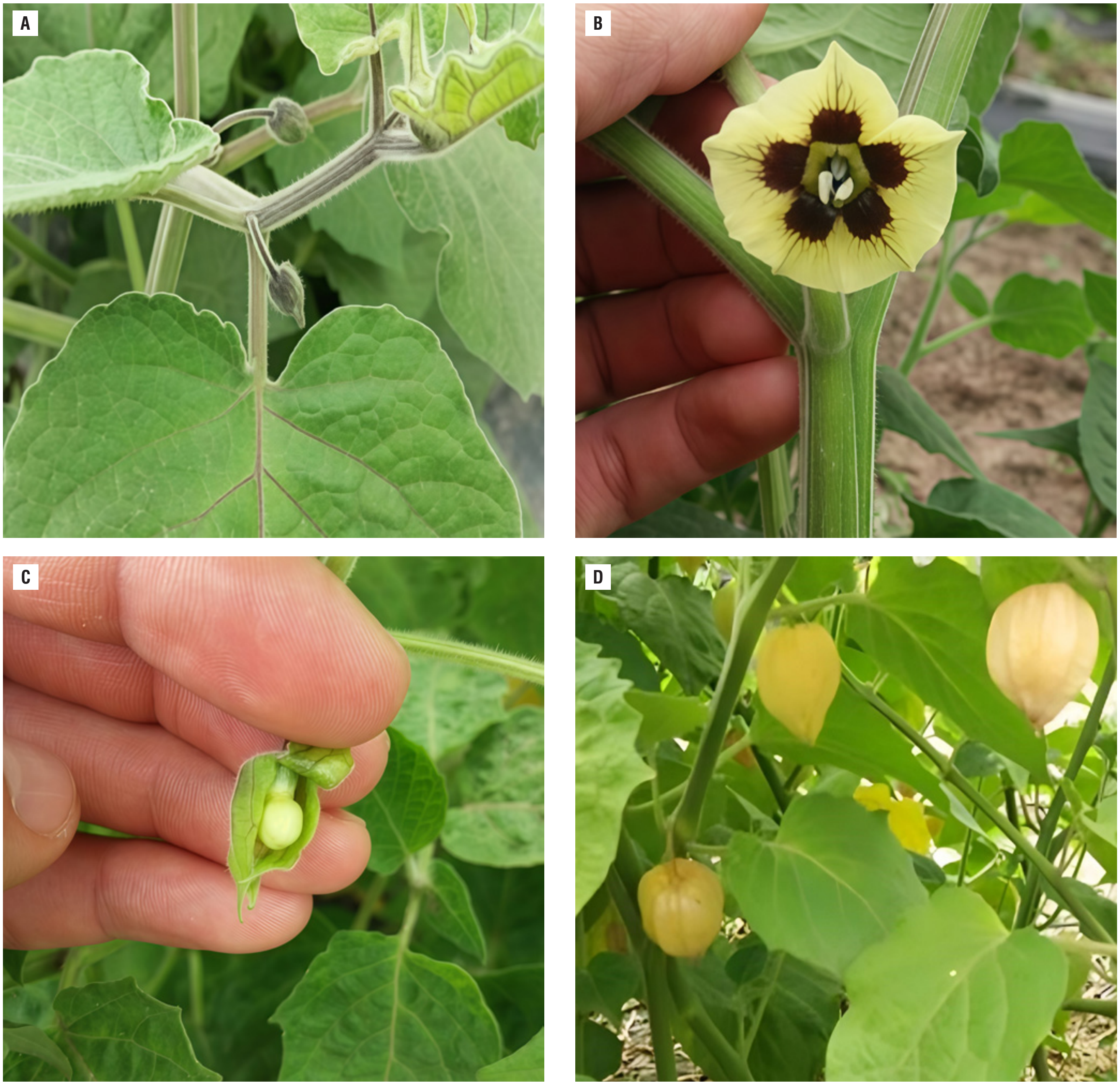

FIGURE 1. Phenological phases of cape gooseberry plants: (A) flower bud, (B) open flower, (C) fruit set, and (D) ripe fruit. The phases correspond to stages 5, 6, 7, and 8 of the BBCH phenological scale (Ramírez *et al*., 2013). EEA INTA Famaillá, Tucumán, Argentina.

Fruit yield evaluation, climatic variables, and statistical analyses

Yield data were recorded at each harvest throughout the production cycle (from ripe fruit to the final harvest), separating fruits into marketable (healthy, undamaged fruit) and non-marketable (with biotic/abiotic damage) grades. The fruits from each plot were weighed on a digital scale. The analyzed variables were marketable yield (MY), non-marketable yield (NMY), and total yield (TY = MY + NMY).

The data were subjected to analysis of variance, followed by the DGC means comparison test with a 95% confidence level, using the statistical program Infostat (Di Rienzo, 2015). From the analysis results, the percentages explained by each source of variation (treatment, year, treatment x year) were manually calculated from the sums of squares. To visualize crop production across treatments over their production cycle during the years, cumulative yield curves were created as a function of time. This allowed to calculate the maximum fruit production rate (MFPR) and the

MFPR duration for each treatment, using linear regressions adjusted for yield as a function of time:

$$Y = a + b*x \quad (2)$$

where "Y" is yield, "a" is the intercept when x = 0, and "b" is the rate of yield increase for the duration interval of that rate. The maximum rate duration was quantified using logistic models in TableCurve Software (Jandel Scientific, 1991) adjusted for yield as a function of time. These data were then used for a multivariate principal components analysis.

Multivariate principal components analysis was performed in Infostat using average data from the three years of study. The variables used were maximum, average, and minimum temperatures, photoperiod, and average radiation. From temperature and radiation, the accumulated radiation and the photothermal coefficient "q" were calculated as q = average radiation/average temperature.

This sought to determine how these variables interacted with the crop during the production cycle. The relationship between variables was evaluated using the angle between the vectors: positive when the angle was less than 90°, null when the angle was 90°, and negative when the angle was greater than 90°.

The agrometeorological information used to determine the influence of climatic variables (maximum, minimum, and average temperature, photoperiod, and average and accumulated radiation) on yield throughout the production cycle was provided by the INTA Famaillá Agrometeorology Section. The influence of each of these variables and the interaction between radiation and temperature (the photothermal coefficient) were analyzed, as this relationship helps explain the yield of some crops in specific environments (Otegui & López, 2012).

Results

Temperatures

Each year differed in air temperature (Fig. 2). The first year, 2015, was the warmest in the fall-winter period, while the coolest in the spring-summer period. Regarding 2016, fall-winter temperatures were the coolest, early-spring temperatures were the warmest, and summer temperatures were intermediate. The year 2017 had intermediate temperatures during the fall-winter semester, but the warmest temperatures in late spring and summer. In fact, 2017 was the year with the highest maximum temperatures during the fruit production season. Nevertheless, in any year, winter temperatures were adequate for normal plant growth.

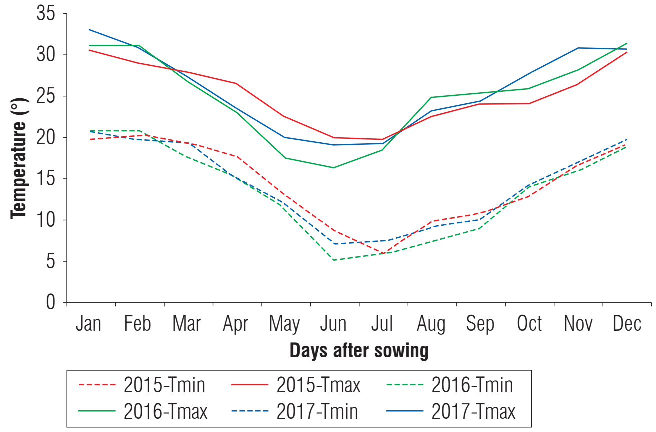

FIGURE 2. Maximum and minimum temperatures during the cape gooseberry crop cycle in 2015, 2016, and 2017 at the INTA Famaillá Agricultural Experiment Station, Tucumán, Argentina.

Number of leaves per plant

The number of leaves per plant (NLP) was recorded at planting and at the onset of the open flower phase. NLP varied each year and each planting date within a range of 2.5 to 7.5 (Tab. 3). NLP decreased from T1 to T3 in 2015, but in 2016 and 2017 it showed opposite behavior. NLP at open flower (OF) varied in each treatment, within a range of 16 to 54, but always with the most significant number for T1, regardless of NLP at planting (Tab. 3). NLP at OF in T1 differed statistically from T3 for all the years. NLP at OF for T2 was sometimes closer to T1 and other times closer to T3.

TABLE 3. Average values of the number of leaves per cape gooseberry plant at the time of transplant and open flower phase for each planting date: first (T1), second (T2), and third (T3), during 2015, 2016, and 2017. Different letters indicate significant differences for $P \leq 0.05$ (DGC means comparison test).

Year	Treatments (sowing date)	Leaf number at planting	Leaf number at open flower
2015	T1 (January 29)	4.59 a	54.74 a
	T2 (February 26)	3.93 b	42.81 c
	T3 (March 10)	3.78 b	46.00 b
2016	T1 (February 11)	3.19 c	34.11 a
	T2 (March 01)	7.52 a	19.19 b
	T3 (March 31)	6.23 b	16.74 b
2017	T1 (February 13)	2.52 b	51.07 a
	T2 (March 10)	3.22 a	42.52 a
	T3 (April 03)	4.41 a	27.67 b

The onset of the flower bud (FB) phase in 2015 occurred at 44, 23, and 49 days after planting (DAP) for the first (T1), second (T2), and third (T3) planting dates, respectively (Tab. 4). In the second year (2016), the onset of FB occurred at 25, 60, and 57 DAP, for T1, T2 and T3, respectively. In 2017, FB was delayed compared to both previous years: 59, 85, and 79 DAP for T1, T2, and T3, respectively. The average FB onset time across all years and treatments was 53.4 (±21.2) DAP, indicating considerable dispersion around the mean, with a coefficient of variation (CV) of 40%.

Regarding the onset of the open flower (OF) phase, in 2015 it occurred at 77, 56, and 76 (DAP) for the first (T1), second (T2), and third (T3) planting dates (Tab. 4). In the second year (2016), the onset of OF occurred at 78, 70, and 72 DAP, for T1, T2 and T3, respectively. In 2017, OF onset was recorded at 71, 93, and 98 DAP for T1, T2, and T3, respectively. Considering the three years and treatments, the average OF onset time was 76.8 (±12.5) DAP, showing less dispersion than the previous phase (CV=16%).

The onset of the next phenological phase, fruit set (FS), in 2015 was recorded at 95, 77, and 81 (DAP) for the first (T1), second (T2), and third (T3) planting dates, respectively (Tab. 4). In the second year (2016), the onset of FS occurred at 88, 88, and 82 DAP, for T1, T2 and T3, respectively. In 2017, FS onset was recorded at 86, 100, and 112 DAP for T1, T2, and T3, respectively. Considering the 3 years and treatments, the average FS onset time was 89.9 (±10.9) DAP, with a CV of 12%.

The first ripe fruit (FRF) phase onset in 2015 was recorded at 114, 93, and 133 (DAP) for the first (T1), second (T2), and third (T3) planting dates (Tab. 4). In the second year (2016), the onset of FRF occurred at 124, 142, and 126 DAP, for T1, T2 and T3. In 2017, FRF onset was recorded at 139, 144, and 133 DAP for T1, T2, and T3. Considering the 3 years and treatments, the average time to FRF was 127.6 (±16.1) DAP with a CV of 13%. This stage indicates the beginning of the harvest season.

The last ripe fruit (LRF) stage in 2015 occurred at 206, 185, and 205 (DAP) for the first (T1), second (T2), and third (T3) planting dates (Tab. 4). In the second year (2016), LRF occurred at 224, 206, and 190 DAP, for T1, T2 and T3. In 2017, it was recorded at 230, 210, and 189 DAP for T1, T2, and T3. Considering the three years and treatments, the average onset of LRF was 205 (±15.4) DAP, CV = 7.5%. This stage marks the end of the fruit production season.

In the first year of evaluation, T2 was the earliest (FRF), followed by T1 at 114 DAP and T3 at 133 DAT. In 2016, T1 and T3 required practically the same number of days (124 and 126 DAP) to FRF, while T2 required 142 DAP. In 2017, T2 required the most extended period (144 DAP) to reach FRF, as in the previous year. In contrast, T3 was the earliest at 133 DAP, followed by T1 at 139 DAP. However, the trend in three-year crop cycle length shows that the first sowing/planting date (T1) had the most extended cycle, followed by T2 and T3 (Tab. 4).

For the FRF phase (beginning of harvest), T1 was always the earliest, except in the first year (2015), where no difference with T2 was observed. The first harvest was recorded on October 9 for T1 and T2, and on October 29 for T3. In 2016, T1 reached this stage on October 6, that is 6 d earlier than T2 and T3. In 2017, T1 began producing ripe fruit earlier than in the previous years, with FRF on September 18, and earlier than T2 and T3.

Thermal time (TT) differed across treatments and phases within each year (Tab. 4). For example, in 2015, the onset of the FB phase required 384 growing degree days (GDD) in T1, 156 GDD in T2, and 322 GDD in T3, from the planting date. In 2016, the onset of FB required 181 GDD for T1 and 292 GDD for both T2 and T3. In 2017, the TT was 463, 604, and 622 GDD for T1, T2, and T3, respectively.

Accumulated TT at each phenological phase onset did not show a clear trend between treatments for FB and OF in 2015 and 2016; however, in 2017, the accumulated TT increased progressively from T1 to T3 at all the phenological phases (Tab. 5). The accumulated TT had a large dispersion from the mean, considering the three years and three treatments in phenological phases FB (CV 45%), OF (CV 28%), and FS (CV 23%). Nonetheless, that dispersion decreased drastically in FRF (CV 7%) and LRF (CV 10%), as if the accumulated TT dispersion becomes progressively smaller from one phenological phase to the next. According to these data (Tab. 5), we might expect the cape gooseberry harvest season to start with an average accumulated thermal time (TT) of 1180 ± 88 GDD and finish at an average accumulated TT of 2180 ± 223 GDD in the location and conditions where the experiments were conducted.

TABLE 4. Date of occurrence of each phenological phase, days after planting (DAP), days after the previous phenological phase (DAPPP), and thermal time (TT, in growing degree days: GDD) of each phenological phase in cape gooseberry plants (Famaillá, Tucumán, Argentina).

Year	Treatment	Flower bud				Open flower				Fruit set				First ripe fruit				Last ripe fruit			
		Date	DAP (d)	DAPPP (d)	TT (GDD)	Date	DAP (d)	DAPPP (d)	TT (GDD)	Date	DAP (d)	DAPPP (d)	TT (GDD)	Date	DAP (d)	DAPPP (d)	TT (GDD)	Date	DAP (d)	DAPPP (d)	TT (GDD)
2015	T1	July 07	44	44	374	August 13	77	43	207	August 21	95	18	143	October 09	114	19	551	December 10	206	92	891
	T2	July 07	23	23	156	August 03	56	33	207	August 24	77	21	174	October 09	93	16	520	December 10	185	92	891
	T3	August 06	49	49	322	September 02	76	27	258	September 07	81	5	54	October 29	133	52	598	December 10	205	42	643
2016	T1	May 30	25	25	181	July 22	78	53	251	August 01	88	10	66	September 06	124	36	697	December 15	224	100	1063
	T2	July 22	60	60	292	August 01	70	10	66	August 19	88	18	185	October 12	142	54	594	December 15	206	64	982
	T3	August 04	57	57	292	August 19	72	15	160	August 29	82	10	87	October 12	126	44	507	December 15	190	64	981
2017	T1	June 30	59	59	463	July 12	71	12	88	August 27	86	15	91	September 18	139	53	508	December 18	230	91	1445
	T2	August 15	85	85	604	August 23	93	8	70	August 30	100	7	83	October 13	144	44	498	December 18	210	66	1129
	T3	August 30	79	79	622	September 18	98	19	182	October 02	112	14	175	October 23	133	21	290	December 18	189	56	980
Mean			53.4	53.4	367.3		76.8	24.4	165.4		89.9	13.1	117.6		127.6	37.7	529.2		205.0	74.1	1000.6
±SD			21.1	21.1	166.9		12.5	15.8	74.7		10.9	5.4	51.5		16.1	15.4	110.0		15.4	20.1	215.3
CV%			39.6	39.6	45.4		16.3	64.6	45.2		12.1	41.5	43.8		12.6	40.8	20.8		7.5	27.1	21.5

TABLE 5. Accumulated thermal time (in growing degree days: GDD) at the onset of each phenological phase in cape gooseberry plants (Famaillá, Tucumán, Argentina).

Year	Treatment	Phenological phase				
		FB*	OF	FS	FRF	LRF
		Thermal time (GDD)				
	T1	374	581	724	1275	2166
2015	T2	156	363	537	1057	1948
	T3	322	580	634	1232	1875
	T1	181	432	498	1195	2258
	T2	292	358	543	1137	2119
2016	T3	292	452	539	1046	2027
	T1	463	551	642	1150	2595
2017	T2	604	674	757	1255	2384
	T3	622	804	979	1269	2249
Mean		367	533	650	1180	2180
±SD		167	148	152	88	223
CV%		45	28	23	7	10

*FB: flower bud, OF: open flower, FS: fruit set, FRF: first ripe fruit, LRF: last ripe fruit.

In Table 6, photoperiods for each phenological phase and the occurrence dates are shown. Due to the experiment geographical localization, photoperiods decreased from December 22 to June 21 (summer and fall) and increased from June 22 to December 21 (winter and spring). During the flower induction period, which occurs between planting (P) and the onset of the first flower bud (FB), photoperiods decreased for T1, the first planting date, but increased for the following planting dates (T2 and T3), except for 2015 T2, where photoperiods did not change much between P and FB.

Based on the results obtained for the best treatment (T1), a crop stage calendar was developed (Fig. 3). Planting in May, the crop had a two-month vegetative growth period, the first flowers (reproductive growth) emerge in July, and fruiting starts in September and finishes by the end of December.

Similarly, a chronothermal schedule of the phenological phases was developed for the first transplant date (T1), showing the degree days required for each phenological phase to be completed in Famaillá (Fig. 4). The open flower and fruit set phases required the fewest degree days to advance to the next phase.

Total marketable and non-marketable fruit yields

No interaction was found between treatments and years, so the yield values obtained did not depend on a particular year, following a production trend related to the transplant date (Tab. 7). The first date (T1) was significantly higher

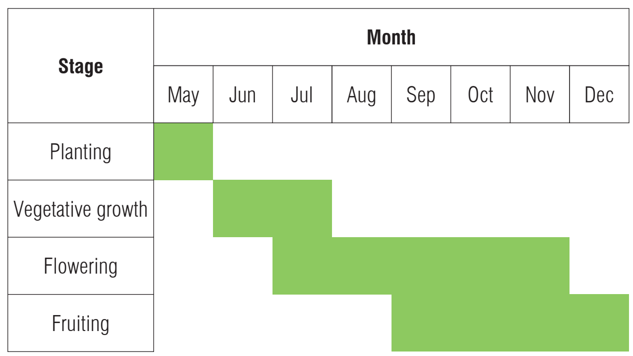

FIGURE 3. Phenological calendar for the first transplant date (T1) from field transplant to the start of production of cape gooseberry at EEA Famaillá, Tucumán, Argentina.

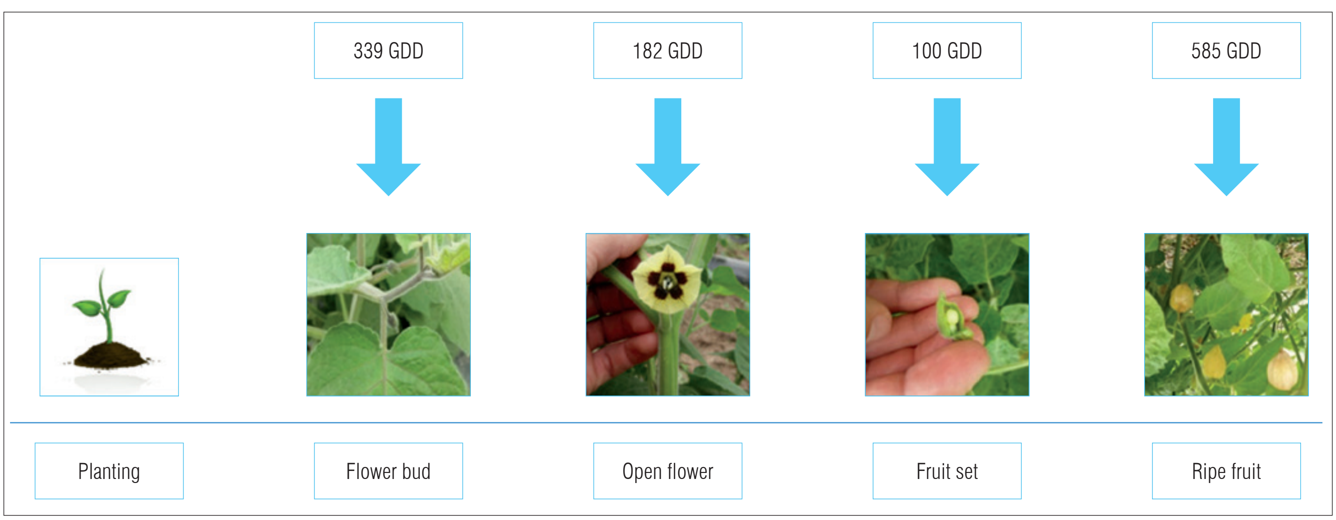

FIGURE 4. Thermal time and phenology of cape gooseberry. Number of accumulated growing degree days (GDD) at each phenological stage using the first transplant date (T1) as a model. Famaillá, Tucumán, Argentina.

TABLE 6. Photoperiod (PP, in h:min:s) of the date of occurrence of the two true leaves (2TL) stage, the planting stage, and the onset of each phenological phase of cape gooseberry (Famaillá, Tucumán, Argentina).

Year	Treatment	Sowing	2nd true leaf		Planting		Flower bud		Open flower		Fruit set		1st ripe fruit		Last ripe fruit	
		Date	Date	PP	Date	PP	Date	PP	Date	PP	Date	PP	Date	PP	Date	PP
2015	T1	January 29	February 23	12:47:58	May 18	10:44:50	July 01	10:28:38	August 13	11:07:21	August 21	11:37:16	October 09	12:32:45	December 10	13:47:12
	T2	February 26	March 26	11:58:41	June 08	10:29:38	July 01	10:28:38	August 03	10:54:52	August 24	11:21:51	October 09	12:32:45	December 10	13:47:12
	T3	March 10	April 29	11:07:54	June 18	10:27:03	August 06	10:58:27	September 02	11:35:47	September 07	11:42:38	October 29	13:03:48	December 10	13:47:12
2016	T1	February 11	March 03	12:27:53	May 05	11:59:11	May 30	10:34:28	July 22	10:42:27	August 01	10:52:51	September 06	11:42:14	December 15	13:48:57
	T2	March 01	March 28	11:54:21	May 23	10:39:56	July 22	10:42:27	August 01	10:52:51	August 19	11:15:50	October 12	12:38:35	December 15	13:48:57
	T3	March 31	April 29	11:06:55	June 08	10:29:31	August 04	10:56:21	August 19	11:15:50	August 29	11:30:13	October 12	12:38:35	December 15	13:45:57
2017	T1	February 13	March 10	12:23:30	May 02	11:03:19	June 30	10:28:19	July 12	10:34:12	July 27	10:47:08	September 18	12:00:25	December 18	13:49:28
	T2	March 10	April 07	11:39:08	May 22	10:41:02	August 15	11:10:01	August 23	11:21:07	August 30	11:31:18	October 13	12:39:44	December 18	13:49:28
	T3	April 03	May 03	11:02:02	June 12	10:28:12	August 30	11:31:18	September 18	12:00:25	October 02	12:22:29	October 23	12:55:00	December 18	13:49:28

Phenological phase: columns from 2nd true leaf through Last ripe fruit.

TABLE 7. Means and standard errors (SE) obtained using the DGC statistical test, Mean Square Error (MSE) and *P* value, for the sowing/transplant dates treatments (T1, T2, T3), years (2015, 2016, 2017) and treatment × year interaction, for the variables total yield, marketable yield and non-marketable (non-mkt) yield expressed in t ha^{-1}. Different letters indicate significant differences at $P \leq 0.05$.

Source of variation	Total yield (t ha^{-1})	SE	Marketable yield (t ha^{-1})	SE	Non-mkt yield (t ha^{-1})	SE
T1	3.50 a	± 0.11	3.42 a	± 0.11	0.08	± 0.018
T2	2.07 b	± 0.11	1.99 b	± 0.11	0.07	± 0.018
T3	1.65 c	± 0.12	1.53 c	± 0.11	0.11	± 0.019
MSE	12245587		12516630		4764.00	
P	P<0.0001		P<0.0001		P=0.371	
2015	2.49 a	± 0.10	2.39 a	± 0.09	0.09	± 0.016
2016	2.76 a	± 0.12	2.65 a	± 0.11	0.11	± 0.019
2017	1.97 b	± 0.12	1.90 b	± 0.12	0.06	± 0.020
MSE	1849244		1625306		7586.60	
P	P=0.0004		P=0.0005		P=0.212	
T1 2015	3.49	± 0.17	3.33	± 0.16	0.10	± 0.027
T1 2016	3.84	± 0.21	3.74	± 0.20	0.10	± 0.034
T1 2017	3.17	± 0.21	3.12	± 0.20	0.04	± 0.034
T2 2015	2.12	± 0.17	2.08	± 0.16	0.03	± 0.027
T2 2016	2.67	± 0.21	2.54	± 0.20	0.10	± 0.034
T2 2017	1.42	± 0.21	1.35	± 0.20	0.07	± 0.034
T3 2015	1.85	± 0.17	1.71	± 0.16	0.13	± 0.027
T3 2016	1.78	± 0.21	1.65	± 0.20	0.12	± 0.034
T3 2017	1.32	± 0.24	1.24	± 0.23	0.08	± 0.039
MSE	211364.43		200548.99		4869.26	
P	P=0.347		P=0.337		P=0.400	

than the second (T2) and third (T3), with the third date having the lowest average. The lowest yield values were obtained in 2017, coinciding with the highest maximum temperatures recorded during the production cycle that year (Fig. 2). This condition is restrictive for this crop's flowering.

The "treatment" effect explained approximately 85% of the statistical model, and the "year" effect 12%, both of which were significant (total and marketable yield). The treatment × year interaction accounted for only 3% of the yield (Tab. 8).

Non-marketable fruit was mainly due to phytophagous insect damage, and no significant differences were found between treatments, nor was there any interaction between treatments and years.

Table 9 was constructed with data from the last fruit ripe (LFR) stage taken from Table 4 and total yield data from Table 7. The LFR stage was practically the harvest season of the present study. As mentioned before, the first planting date (T1) had top yields for the three years of the experiment, which we linked to three essential factors: days after planting (DAP), days after the previous phenological phase (DAPPP) and thermal time (TT) (Tab. 9). Therefore, treatment 1 met three requirements at the end of the fruiting season: ≥ 206 DAP, ≥ 91 DAPPP, and ≥ 891 GDD, which could explain its best performance. The treatments with lower yields, for example, T2 met two of the three requirements, or T3 met just one.

TABLE 8. Sum of squares (SS) from the ANOVA and percentage explanation of the independent variables' treatment (sowing/planting dates), year, and treatment × year, for the dependent variables total yield (TY), marketable yield (MY), and non-marketable yield (NMY) in t ha^{-1}. * Significant for $P \leq 0.05$. ns: not significant.

Source of variation	SS (TY)	SS (MY)	SS (NMY)
Treatment	24491174.24 (84.35 %) *	25033260.00 (86.07 %) *	9527.99 (21.57 %) ns
Year	3698489.54 (12.74 %) *	3250613.78 (11.18 %) *	15173.21 (34.35 %) ns
Treatment × Year	845457.74 (2.91 %) ns	802195.96 (2.76 %) ns	19477.04 (44.09 %) ns

The plants from the first planting date (T1) yielded the highest values, indicating higher productivity rate and duration than plants from the second and third sowing/planting dates (T2 and T3, respectively). The cumulative yield curves tended to be sigmoid, with a low production rate initially, then increasing to a maximum, forming a plateau. In the first and second years, a clear difference was observed between the production curves of each treatment, with the same behavior. In the third year, there was a notable difference between T1, T2, and T3 (Fig. 5), with T1 significantly superior to T2 and T3.

The total yield showed a positive relationship with the number of leaves recorded during the open flower phenological phase (Fig. 6). Delayed planting dates resulted in fewer leaves per plant at this stage and, simultaneously, lower yields. It may be that the number of leaves at this stage determined the crop productivity.

Total yield, maximum fruit production rate (MFPR) duration, and accumulated radiation were negatively associated with maximum, minimum, and mean temperatures and with photoperiod (Fig. 7), and positively associated with MFPR, MFPR duration, photothermal coefficient, and accumulated radiation.

TABLE 9. Relationship between days after planting (DAP), days after the previous phenological phase (DAPPP), thermal time (in growing degree days: GDD), and yield at the end of harvest (last ripe fruit stage, LRF) in cape gooseberry plants (Famaillá, Tucumán, Argentina).

Treatment	Year	DAP	DAPPP	Thermal time (GDD)	Total yield (t ha^{-1})
T3	2017	189	56	980	1.32
T2	2017	210	66	1129	1.42
T3	2016	190	64	981	1.78
T3	2015	205	42	643	1.85
T2	2015	185	92	891	2.12
T2	2016	206	64	982	2.67
T1	2017	230	91	1445	3.17
T1	2015	206	92	891	3.49
T1	2016	224	100	1063	3.84

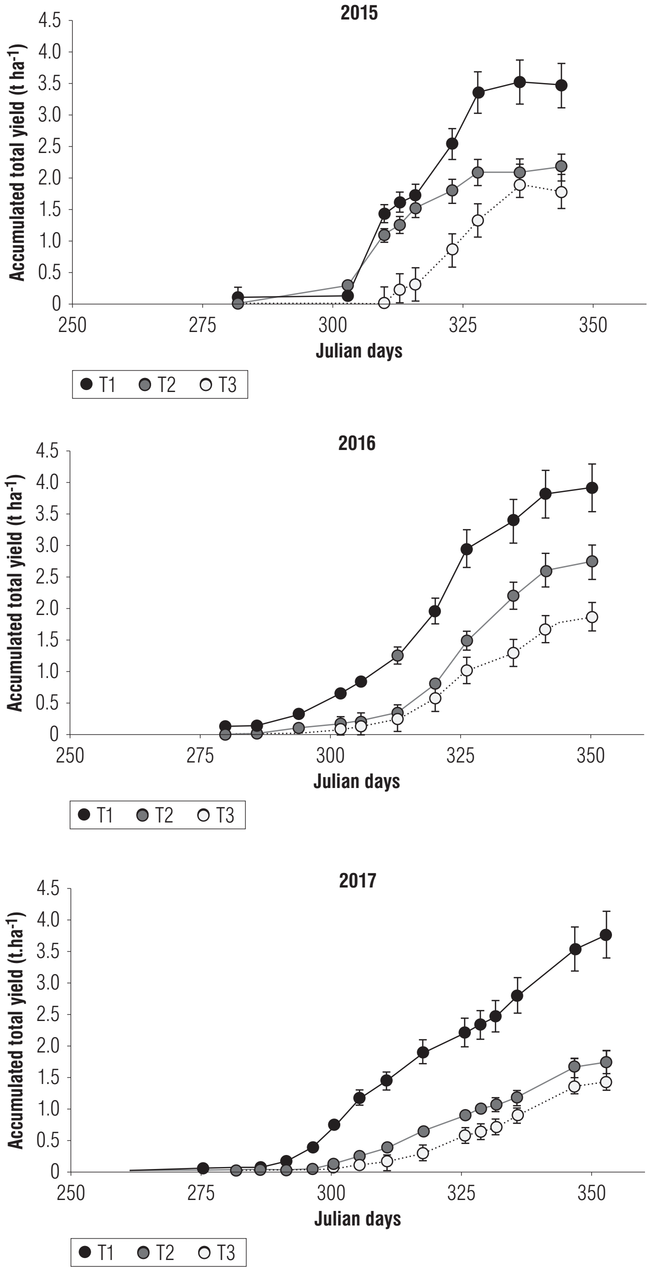

FIGURE 5. Total yield (marketable yield + non-marketable yield) accumulated in the first (T1), second (T2), and third (T3) planting dates, in three annual production cycles (2015, 2016, and 2017) of cape gooseberry in Famaillá, Tucumán, Argentina. The bars represent the standard error.

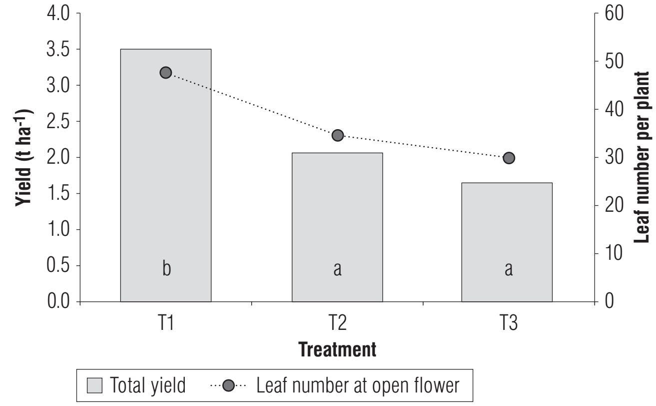

FIGURE 6. Average of the total accumulated yield and the number of leaves recorded in the open flower phenological phase of cape gooseberry during a 3-year evaluation (2015, 2016, and 2017) for the first (T1), second (T2), and third (T3) planting dates. Famaillá, Tucumán, Argentina.

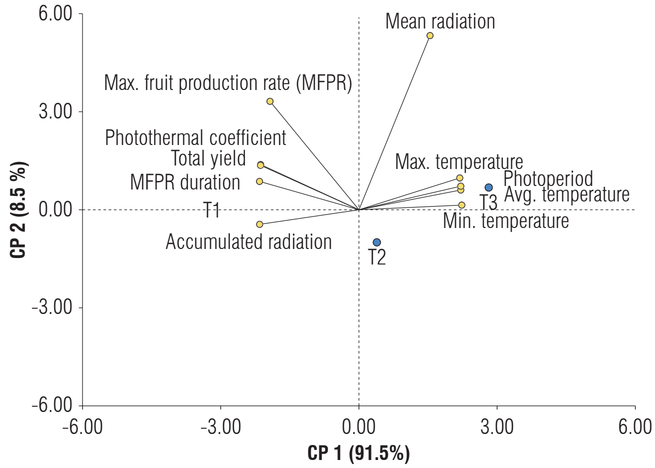

FIGURE 7. Principal component analysis biplot for three evaluation years (2015, 2016, and 2017), analyzing the first (T1), second (T2), and third (T3) sowing/planting dates based on total yield, maximum fruit production rate (MFPR), MFPR duration in days, and climatic variables (accumulated and mean radiation, photoperiod, maximum, mean, and minimum temperatures, and photothermal coefficient).

Discussion

Phenological phases

The seeds were of good quality, as the germination percentage obtained 25 days after sowing (DAS) was between 97 and 98%, similar to that reported in Peru (Willyam, 2013) and in Honduras (Sánchez, 2002) at 22 DAS. Regarding the number of leaves per plant, in Mexico, 54-67 leaves were recorded at 64 DAS in a greenhouse trial with controlled conditions and fertigation (Mora-Aguilar *et al*., 2006). In Brazil, Rodrigues *et al*. (2013) report 4 leaves at 27 DAP, reaching 109 leaves at 72 DAP, under suitable conditions for vegetative growth. On the other hand, Sánchez (2002) report 350-400 leaves per plant at 180 DAP, with an average temperature of 24.2°C at an altitude of 800 m a.s.l. in Honduras. In Tucumán, we recorded between 16 and 54 leaves per plant, on average, between 56 and 98 DAP, with average minimum and maximum temperatures during the 3 years of 6°C and 22°C, respectively, in the evaluation months (May to September); this coincides with what Mora-Aguilar *et al*. (2006) report, but is lower than those of other studies (Rodrigues *et al*., 2013; Sánchez, 2002). This difference in leaf number can be explained by the adverse effect of extreme temperatures on vegetative growth (Fischer *et al*., 2016) of this Andean plant and, consequently, on the development of new leaves.

The first planting date (T1) had the highest number of leaves per plant until the first open flower in the three years of evaluation, close to the values that Mora-Aguilar *et al*. (2006) obtain, mentioned above. This would indicate that by transplanting at early dates, the plants reach the open flower phase earlier (the first weeks of July) than at later planting dates (between August and September), advancing their phenological phases and leading to earlier fruit production, since the number of leaves and productivity are closely related, as a flower grows from each leaf axil of the reproductive branches (Ramírez *et al*., 2013). Therefore, the greater the number of leaves, the greater the number of flowers and fruits (Fischer *et al*., 2014). This has a visible impact on yield, as the first sowing (T1) yielded the highest total and marketable yield in this research. The start times of the flower bud, open flower, fruit set and ripe fruit phases in T1 in the present work: 43, 75, 89 and 126 DAP, respectively, was similar to the results of Mora-Aguilar *et al*. (2006), except for fruit set, since they report 42 DAP for the flower bud phase, 52 DAP for fruit set and 146 DAP for the first harvest or ripe fruit. They also agree with Almeida (2017), who report that flowering (flower opening) occurrs at 68 DAP and that harvest begins at 122 DAP. However, our results differed from those that Sánchez (2002) report for Honduras and Willyam (2012) in Peru, who indicate that flower bud emergence and flower opening occurres between 19 and 25 DAP and 27 and 35 DAP. In contrast, Betemps *et al*. (2014) observe, under the climatic conditions of Rio Grande do Sul, Brazil, that it takes 106 DAP to produce flower buds. The plants planted at mid (T2) and late (T3) planting dates require more days than those mentioned above to reach the flower bud, open flower, and ripe fruit phases. This could be because plants experience different temperatures and photoperiods, which lengthen or shorten the phenological phases (Otegui & López, 2012).

When planting dates are delayed, the growth cycle is exposed to a greater number of photoperiods of increasing duration, also accompanied by higher temperatures, which is detrimental to flowering because the cape gooseberry is a facultative short-day plant (Heinze & Midash, 1991). Since the cape gooseberry is a very plastic crop in terms of environmental requirements, mainly temperature (Mora-Aguilar *et al*., 2006), it adapts to different environments by shortening or lengthening its cycle (Fischer *et al*., 2007), being able to reach the reproductive phase in a few days when conditions are favorable, as occurrs in Trujillo (Peru), where it reaches harvest at 87 DAT (Willyam, 2013). This shortening of the phases in Peru may be due to the plant's photoperiod. Similarly, in southern Brazil, cape gooseberry harvest begins 42 d after open flower, with a total crop cycle of 150 d (Betemps *et al*., 2014).

The Famaillá region experiences a wide temperature range during fall and winter, with warm days and cool nights, conditions that do not favor proper plant growth and development (Wolff, 1991). The crop cycle is shortened by long days in December and rising temperatures, both of which limited cape gooseberry's potential productivity.

Regarding the calendar date, the first sowing (T1) is found to be the earliest, producing up to 35 d earlier than the latest sowing date (T3). This could be because the thermoperiodic conditions of May and June are more favorable for growth, floral induction, and early plant development than those at later transplant dates, as evidenced by the July flower buds in the years evaluated. By delaying planting, the entry into production is delayed as well. Additionally, temperatures in October, November, and December often exceed 30°C, which can affect flowering and fruiting (Wolff, 1991).

Fruit yield

The total yields obtained in this research ranged from 1.65 t ha^{-1} for the third planting date (T3) to 3.5 t ha^{-1} for the first planting date (T1), respectively, higher than those of Willyam (2013) in Peru, who report a yield of 1.2 t ha^{-1}, with a production cycle of approximately 120 d, much shorter than that of Tucumán. However, for Colombia, where harvesting begins 4 to 7 months after planting (Galvis *et al*., 2005) and with a production cycle of 7 to 12 months, yields between 9.8 and 14.5 t ha^{-1} are reported (Fischer *et al*., 2014), and, for 2022, an average yield of 13.49 t ha^{-1} for the entire country is reported (Agronet, 2025). The average reported yield in Chile is 6 t ha^{-1}, with a production cycle from January to March (approximately 100 d), which cannot be extended beyond this period due to severe frosts (Fischer *et al*., 2014). Brazil (Moura *et al*., 2016) obtained yields (5.97 t ha^{-1}) very similar to those obtained in Chile. Notably, all these yield values are higher than those obtained in our research, except for that of Peru, possibly due to the difference in the length of the production cycle, the particular climatic conditions for the plants in Tucumán, the fact that no fertilizer was applied in the trials in this study, and the genetic material used. The difference in yield between treatments during each year was influenced by the maximum fruit production rate (MFPR), since the earliest planting date had a higher MFPR than later dates (Fig. 5), and also a longer MFPR duration, which would have allowed more radiation to accumulate in this period, which would become a greater source for future landfills (fruits) (Smith *et al*., 2018).

Although the yield of many crops rarely reaches its full production potential (Smith *et al*., 2018), plants from the first planting dates (T1) also had a greater number of leaves at the open flower phase, which would translate into a larger leaf area (D'Angelo *et al*., 2017) and a greater area for radiation capture, accumulating more photosynthates, with a direct impact on yield. Fischer *et al*. (2012) concluded that high yields and fruit quality require a precise leaf-to-fruit ratio (leaf area per fruit and number of leaves).

Plants with a greater leaf number would have a higher net dry matter assimilation rate than T2 and T3 plants with fewer leaves at flower opening. Similar results are obtained by López-Sandoval *et al*. (2018), who report that plants with higher biomass have a higher net dry matter assimilation rate due to greater radiation by the crop and are the ones with the highest yield. Total yield is positively related to accumulated radiation, fruit production rate, duration, and the photothermal coefficient. These variables are grouped with T1 (Fig. 7), which can explain (together with the number of leaves per plant at the time of open flower) the significant differences in yield on the early date compared to the late ones, since the increase in the acquisition and utilization of light to promote photosynthetic performance is essential to improve yield (Smith *et al*., 2018). In addition, radiation is involved in processes such as floral primordium differentiation and flowering (Rivera *et al*., 2008). Salazar *et al*. (2008) calculate a light-use efficiency of 2.62 g/MJ for the reproductive phase of cape gooseberry (but only 0.46 g/MJ for the vegetative phase), in which 69% of the dry biomass is translocated to the fruits, confirming again what Carrillo-Perdomo *et al*. (2015) state that cape gooseberry is a light-demanding plant.

Production variations between transplant dates could be influenced by the time of year, as plants experience changes in fruiting due to variations in climatic conditions such as temperature, photoperiod, radiation, and precipitation (Menzel & Simpson, 1994). In the present study, temperature, radiation, and photoperiod varied across treatments throughout the production cycle. The first planting date (T1) was positively associated with the photothermal coefficient in the principal components analysis, indicating that an earlier harvest, produced by the early transplant, would provide a better environment for the crop with respect to this variable for fruit production. T1 would have explored better photothermal environments and consequently obtained higher yields (Flórez-Velasco *et al*., 2024; Otegui & López, 2012; Smith *et al*., 2018).

Being a quantitative (facultative) short-day plant, meaning that floral induction is encouraged by short photoperiods (Fischer & Melgarejo, 2020), the photoperiod is negatively associated with yield (Fig. 7). This results in a delay in flowering and production onset at later transplant dates, with T3 being the most affected. Similarly, temperature plays an important role in crop development, since, according to Fischer *et al*. (2014) and Ali and Singh (2014) it requires between 13 and 16°C for optimal crop development and production, conditions that are not present at the late transplant dates due to a delay in fruit set, evidenced by low yields compared to the early planting dates.

The last year of evaluation was warmer than previous years, which impacted yields (Tab. 6). This suggests that temperature could be a key factor for cape gooseberry production in Tucumán. As day length increased toward the end of the crop cycle and, with it, temperatures rose, yield declined, terminating fruit production short in December. Bera *et al*. (2022) also state that due to heat stress in plants, which primarily affects leaves (the potential source), there is always a risk of lower, more unstable yields. Yield was strongly influenced by the photothermal coefficient, which was associated with T1, due to the higher radiation and temperatures conducive to fruit production during the production cycle. This shows that under ideal environmental conditions, there is a very favorable relationship between photosynthesis and crop yield (Smith *et al*., 2018).

The low yield of the last planting date (T3) could be due to exposure to higher-than-optimal photoperiods and temperatures during the crop's productive cycle, which are unfavorable to this crop. The time for the fruit production peak for the first sowing dates was shorter than that of the first and second ones.

Conclusions

Early planting maximizes the duration of the reproductive and harvest stages, providing a production window that is nearly twice as long as that of late planting. The planting date significantly influenced the yield of the cape gooseberry crop, as the plant was exposed to variations in environmental conditions such as temperature, photoperiod, and radiation throughout its production cycle. The earliest planting date yielded the highest total yield. Regarding the crop cycle length, the earliest planting date resulted in the most extended crop cycle, allowing the plant to accumulate greater radiation and take advantage of favorable temperatures for flowering and fruit production, which was positively correlated with the photothermal coefficient at this stage. According to these experiments conducted at INTA Famaillá agricultural research facility, the average accumulated thermal time for the cape gooseberry harvest to begin is 1,180 ± 88 GDD and for the harvest to end is 2,180 ± 223 GDD. Based on the information generated by this experiment, goldenberries could be an alternative for diversification in Argentina's exports. The study shows that early transplant dates allow for longer fruiting cycles and, therefore, higher yields, supporting the working hypothesis.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contributions

RJQ and DSK: methodology design, research, data analysis. DSK: funding acquisition and project management. RJQ, DSK, and GF: writing and correcting preliminary manuscripts. RJQ, DSK, and GF: editing of the final manuscript. All authors have read and approved the final version of the manuscript.

Literature cited

Agronet. (2025). *Reporte: área, producción y rendimiento nacional por cultivo. Uchuva*. https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=1

Ali, A., & Singh, B. P. (2014). Potentials of cape gooseberry (*Physalis peruviana* L.): an under-exploited small fruit in India. *The Asian Journal of Horticulture, 8*(2), 775–777. https://researchjournal.co.in/upload/assignments/8_775-777.pdf

Almeida, F. H. Z. (2017). *El cultivo de uvilla (Physalis peruviana) y su adaptabilidad a las condiciones de clima cálido, con adición de materia orgánica en el cantón Vinces provincia de Los Ríos* [Undergraduate thesis, Universidad de Guayaquil, Ecuador].

Arenas, P., & Kamienkowski, N. M. (2013). Ethnobotany of the genus *Physalis* L. (Solanaceae) in the South American Gran Chaco. *Candollea, 68*(2), 251–266. https://doi.org/10.15553/c2012v682a9

Bera, A., Shukla, V. K., Venkatswarlu, B., Sow, S., Rajan, S., Jaiswal, S., Vishwakarma, G., Murmu, J., Vishwakarma, G., Alipatra, A., & Maitra, S. (2022). An overview of the source-sink relationship. *Indian Journal of Natural Sciences, 13*(72), 44216–44228. https://www.researchgate.net/publication/361809206_An_Overview_of_the_Source-Sink_Relationship

Betemps, D. Z., Fachinello, J. C., Lima, C. S. M., Galarça, S. P., & Rufato, A. R. (2014). Epoca de semeadura, fenología e crescimento de plantas de fisális no sul do Brasil. *Revista Brasileira de Fruticultura, 36*(1), 179–185. https://doi.org/10.1590/0100-2945-292/13

Carrillo-Perdomo, E., Aller, A., Cruz-Quintana, S. M., Giampieri, F., & Alvarez-Suarez, J. M. (2015). Andean berries from Ecuador: A review on botany, agronomy, chemistry and health potential. *Journal of Berry Research, 5*(2), 49–69. https://doi.org/10.3233/JBR-140093

D'Angelo, J. W. O., Bastos, M. C., & Cuquel, F. L. (2017). Maintenance pruning in physalis commercial production. *Bragantia, 76*(2), 214–219. https://doi.org/10.1590/1678-4499.128

Di Rienzo, J. A., Casanoves, F., Balzarini, M. G., Gonzalez, L., Tablada, M., & Robledo C. W. (2015). *InfoStat versión 2015*. Grupo InfoStat, Universidad Nacional de Córdoba, Argentina.

Fischer, G., Almanza-Merchán, P. J., & Miranda, D. (2014). Importancia y cultivo de la uchuva (*Physalis peruviana* L.). *Revista Brasileira de Fruticultura, 36*(1), 1–15. https://doi.org/10.1590/0100-2945-441/13

Fischer, G., Almanza-Merchán, P. J., & Ramírez, F. (2012). Source-sink relationships in fruit species: A review. *Revista Colombiana de Ciencias Hortícolas, 6*(2), 238–253. https://revistas.uptc.edu.co/index.php/ciencias_horticolas/article/view/1980/0

Fischer, G., Balaguera-López, H. E., & Magnitskiy, S. (2021). Review on the ecophysiology of important Andean fruits: Solanaceae. *Revista U.D.C.A Actualidad & Divulgación Científica, 24*(1), Article e1701. https://doi.org/10.31910/rudca.v24.n1.2021.1701

Fischer, G., Balaguera-López, H. E., & Melgarejo, L. M. (2024). Crop physiology of *Physalis peruviana*. In M. F. Ramadan (Ed.), *Handbook of goldenberry (Physalis peruviana). Cultivation, processing and functionality* (pp. 101–119). Academic Press. https://doi.org/10.1016/B978-0-443-15433-1.00010-8

Fischer, G., Ebert, G., & Lüdders, P. (2007). Production, seeds and carbohydrate contents of cape gooseberry (*Physalis peruviana* L.) fruits grown at two contrasting Colombian altitudes. *Journal of Applied Botany and Food Quality, 81*(1), 29–35. https://www.researchgate.net/publication/256475195_Production_seeds_and_carbohydrate_contents_of_cape_gooseberry_Physalis_peruviana_L_fruits_grown_at_two_contrasting_Colombian_altitudes

Fischer, G., Herrera, A., & Almanza, P. J. (2011). Cape gooseberry (*Physalis peruviana* L.). In E. M. Yahia (Ed.), *Postharvest biology and technology of tropical and subtropical fruits. Acai to citrus* (Vol. 2, pp. 374–396). Woodhead Publishing, Oxford, UK. https://www.researchgate.net/publication/277816442_Postharvest_biology_and_technology_of_tropical_and_subtropical_fruits_Volume_2_Acai_to_citrus

Fischer, G., & Melgarejo, L. M. (2020). The ecophysiology of cape gooseberry (*Physalis peruviana* L.) – an Andean fruit crop. A review. *Revista Colombiana de Ciencias Hortícolas*, *14*(1), 76–89. https://doi.org/10.17584/rcch.2020v14i1.10893

Fischer, G., Ramírez, F., & Casierra-Posada, F. (2016). Ecophysiological aspects of fruit crops in the era of climate change. A review. *Agronomía Colombiana, 34*(2), 190–199. https://doi.org/10.15446/agron.colomb.v34n2.56799

Flórez-Velasco, N., Fischer, G., & Balaguera-López, H. E. (2024). Photosynthesis in fruit crops of the high tropical Andes: A systematic review. *Agronomía Colombiana, 42*(2), Article e113887. https://doi.org/10.15446/agron.colomb.v42n2.113887

Galvis, J. A., Fischer, G., & Gordillo, O. P. (2005). Cosecha y poscosecha de la uchuva. In G. Fischer, D. Miranda, W. Piedrahita, &

J. Romero (Eds.), *Avances en cultivo, poscosecha y exportación de la uchuva (Physalis peruviana L.) en Colombia* (pp. 165–190). Unibiblos. Universidad Nacional de Colombia, Bogotá. https://repositorio.unal.edu.co/handle/unal/81851

Jandel Scientific. (1994). Jandel tablecurve: the fastest curve fitting software on your desktop today [Software advertisement]. *Chemical & Engineering News Archive, 72*(6), pp. 8. https://doi.org/10.1021/cen-v072n006.p008

Lima, J. E., Cruz, M. C. M., Alves, D. A., Santos, N. C., & Guimarães, A. G. (2021). Pruning, training system, and climate conditions for the perennial cultivation of physalis. *Pesquisa Agropecuária Brasileira, 56*, Article e01850. https://doi.org/10.1590/s1678-3921.pab2021.v56.01850

López-Sandoval, J. A., Morales-Rosales, E. J., Vibrans, H., & Morales-Morales, E. J. (2018). Tasa de asimilación neta y rendimiento de *Physalis* bajo cultivo en dos localidades. *Revista Fitotecnica Mexicana, 41*(2), 187–197. https://doi.org/10.35196/rfm.2018.2.187-197

Martínez, M. (1998). Revision of *Physalis* section Epiteiorhiza (Solanaceae). *Anales del Instituto de Biología Universidad Nacional Autónoma de México. Serie Botánica, 69*(2), 71–117. https://www.redalyc.org/pdf/400/40069201.pdf

Menzel, C. M., & Simpson, D. R. (1994). Passionfruit. In B. Schaffer, & P. C. Andersen (Eds.), *Handbook of environmental physiology of fruit crops. Subtropical and tropical crops* (Vol. 2, pp. 225–241). CRC Press. https://books.google.co.ve/books?id=wynac3NvzLsC&printsec=frontcover&hl=es&source=gbs_atb#v=onepage&q&f=false

Miranda, D., & Fischer, G. (2021). Avances tecnológicos en el cultivo de la uchuva (*Physalis peruviana* L.) en Colombia. In G. Fischer, D. Miranda, S. Magnitskiy, H. E. Balaguera-López, & Z. Molano (Eds.), *Avances en el cultivo de las berries en el trópico* (pp. 14–36). Sociedad Colombiana de Ciencias Hortícolas, Bogotá. https://www.researchgate.net/publication/356760922_Avances_en_el_cultivo_de_las_berries_en_el_tropico

Mora-Aguilar, R., Peña-Lomelí, A., López-Gaytán, E., Ayala-Hernández, J. J., & Ponce-Aguirre, D. (2006). Agrofenología de *Physalis peruviana* L. en invernadero y fertirriego. *Revista Chapingo Serie Horticultura, 12*(1), 57–63. https://doi.org/10.5154/r.rchsh.2005.10.011

Moura, P. H. A., Coutinho, G., Pio, R., Bianchini, F. G., & Curi, P. N. (2016). Plastic covering, planting density, and prunning in the production of cape gooseberry (*Physalis peruviana* L.) in subtropical region. *Revista Caatinga, 29*(2), 367–374. https://doi.org/10.1590/1983-21252016v29n213rc

Otegui, M. E., & López, P. M. (2012). Fecha de siembra. In E. H. Satorre, R. L. Benech Arnold, G. A. Slafer, E. B. de la Fuente, D. J. Miralles, M. E. Otegui, & R. Savin (Eds.), *Producción de granos: bases funcionales para su manejo* (pp. 259–274). Editorial Facultad de Agronomía, Universidad de Buenos Aires. Buenos Aires. https://www.calameo.com/books/005884792717a5e52c083

Pérez Martínez, L. V., & Melgarejo, L. M. (2015) Photosynthetic performance and leaf water potential of gulupa (*Passiflora edulis* Sims, Passifloraceae) in the reproductive phase in three locations in the Colombian Andes. *Acta Biológica Colombiana, 20*(1), 183–194. https://doi.org/10.15446/abc.v20n1.42196

Quiroga, R. J., & Kirschbaum, D. S. (2021). *Physalis* (uchuva): especies frutales nativas de las Yungas subandinas con alto potencial de cultivo en Argentina. *Horticultura Argentina, 40*(102), 90–114. http://id.caicyt.gov.ar/ark:/s18519342/b1hh3umjs

Ramírez, F., Fischer, G., Davenport, T. L., Pinzón, J. C. A., & Ulrichs, C. (2013). Cape gooseberry (*Physalis peruviana* L.) phenology according to the BBCH phenological scale. *Scientia Horticulturae, 162*, 39–42. https://doi.org/10.1016/j.scienta.2013.07.033

Rivera, B., Miranda, D., Ávila, L. A., & Nieto, A. M. (2008). *Manejo integral del cultivo de la granadilla (Passiflora ligularis Juss.)*. Editorial Litoas, Manizales. https://www.researchgate.net/publication/315614738_Manejo_integral_del_cultivo_de_la_granadilla_Passiflora_ligularis_Juss

Rodrigues, F. A., Penoni, E. S., Soares, J. D. R., Silva, R. A. L., & Pasqual, M. (2013). Caracterização fenológica e produtividade de *Physalis peruviana* cultivada em casa de vegetação. *Bioscience Journal, 29*(6), 1771–1777. https://seer.ufu.br/index.php/biosciencejournal/article/view/21859

Rufato, L., Muniz, J., Kretzschmar, A. A., Rufato, A. R., & Gatiboni, L. C. (2012). Aspectos técnicos da cultura da fisalis. *Informe Agropecuario, 33*(268), 69–83. https://www.alice.cnptia.embrapa.br/alice/handle/doc/939551

Sabino-López, J. E., Sandoval-Villa, M. S., Alcántar-González, G., Ortiz-Solorio, C., Vargas-Hernández, M., &. Colinas-León T. (2018). Fecha de trasplante, boro, potasio y poda en la producción de frutos de *Physalis peruviana* L. en hidroponía e invernadero. *Agrociencia, 52*(2), 255–265. https://agrociencia-colpos.org/index.php/agrociencia/article/view/1667/1667

Salazar, M. R., Jones, J. W., Chaves, B., Cooman, A., & Fischer, G. (2008). Base temperature and simulation model for nodes appearance in cape gooseberry (*Physalis peruviana* L.). *Revista Brasileira de Fruticultura, 30*(4), 862–867. https://doi.org/10.1590/S0100-29452008000400004

Sánchez Sánchez, J. P. (2002). *Estudios fenológicos de uchuva (Physalis peruviana L.) en El Zamorano, Honduras* [Undergraduate thesis, Universidad El Zamorano, Honduras]. https://bdigital.zamorano.edu/server/api/core/bitstreams/119e0409-9cd4-4540-9edd-bb1262733cb5/content

Smith, M. R., Rao, I. M., & Merchant, A. (2018). Source-sink relationships in crop plants and their influence on yield development and nutritional quality. *Frontiers in Plant Science, 9*, Article 1889. https://doi.org/10.3389/fpls.2018.01889

Toledo, J. M. (2013). *Physalis victoriana* (Solanaceae) a new species from Northern Argentina. *Phytotaxa, 124*(1), 60–64. https://www.mapress.com/phytotaxa/content/2013/f/pt00124p064.pdf

Willyam, E. O. U. (2013*). Fenología y producción de aguaymanto (Physalis peruviana L.) en función de la fertilización N, P, K en pampas de San Juan, Laredo, La Libertad* [Undergraduate thesis, Universidad Nacional de Trujillo, Peru]. https://hdl.handle.net/20.500.14414/7587

Wolff, X. Y. (1991). Species, cultivar, and soil amendments influence fruit production of two *Physalis* species. *HortScience, 26*, 1558–1559.

Yamika, W. S. D., Aini, N., & Waluyo, B. (2019). *Physalis peruviana* L. growth, yield and phytochemical content: A review. *Agricultural Reviews, 40*(4), 324–328. https://doi.org/10.18805/ag.R-130