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FULL-LENGTH RESEARCH ARTICLE

Agronomic Characterization of the 'Trompito INTA' Persian Walnut Cultivar

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Abstract 'Trompito INTA' is a walnut cultivar of Argentine origin, developed at the Catamarca Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA). It was produced in 1984 by controlled pollination between the Persian walnut cultivars 'Lompoc' x 'UC 56–224'. It has a very early to early sprouting and flowering, and it is protandrous with 30–70% overlap between pollen shedding and pistillate flower receptivity. Its harvesting occurs 28 days earlier than that of 'Chandler'. The tree has weak vigor, semi-upright growth habit, medium density of branches and lateral fructification. The nut is of very large size (37.12 mm), the shell is thin, the kernel color is very light, and kernel percent is very high (> 53.5%). 'Trompito INTA' has early harvesting, high-quality nut and kernel attributes and better agronomic performance than 'Chandler', mainly at lower elevations. This cultivar is allowing the expansion of the crop in the province of Catamarca, lowering the limit of altitude for walnut cultivation.

Keywords Early harvesting · Walnut · Nut breeding · *Juglans regia* L

Introduction

Walnuts are indigenous to Turkey, a country that reached an annual nut production of 225,000 t in 2019 [7]. Walnut global production is over three million tons, mostly provided by China, the USA and Iran [3]. In Argentina, walnut production reached 18,488 t in 2019 [7], being Catamarca the main producing province, with 5,850 t [5].

In Argentina, the Catamarca Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA) began the walnut variety breeding program in the 1980s [4]. Germplasm diversity is commonly evaluated with the help of morphological descriptors [3], as those provided by the International Union for the Protection of New Varieties of Plants [17] and the International Plant Genetic Resources Institute [9]. The Catamarca Experimental Station of INTA has developed a new walnut cultivar called 'Trompito INTA'. The aim of this work is to describe the main agronomic characteristics of this new walnut cultivar.

Materials and Methods

'Trompito INTA', whose name is due to its particular trapezoidal fruit shape similar to a spinning top ("trompo" in Spanish), was produced from controlled pollination, carried out by Antonio Prataviera in 1984, between the Persian walnut cultivars 'Lompoc' x 'UC 56–224'. 'Lompoc' was selected for crossing due to its tree productivity, large nuts with good seal and high kernel percentage, whereas 'UC 56–224' was selected due to its high fruiting capacity on lateral buds (80%), early harvesting, large nuts and weak shell [16]. Selection was aimed at the production of high-quality nuts as well as desirable phenological, vegetative and reproductive traits, resulting in 23 preselected genotypes. These genotypes were clonally

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propagated and planted in four farms of the province, at elevations ranging from 889 to 1700 m above sea level (m a.s.l.), together with the traditional walnut cultivars 'Chandler' and 'Criolla' as controls. Table 1 describes some characteristics of the farms located at the extremes of altitude. After 22 years of observations by farmers, researchers and breeders, the best ten selections were subjected to three growing seasons (2009/2010 to 2011/2012) of field and laboratory evaluations, which were conducted according to IPGRI [9] and UPOV [17] standards. Observations included some descriptors of plant growth, inflorescence and fruiting habit, phenological occurrence, and leaf, shoot and nut characteristics.

Plant growth descriptors included: tree vigor (3 = weak, 5 = medium, 7 = strong, 9 = very strong); growth habit (1 = upright, 2 = semi-upright, 3 = spreading); and density of branches (1 = very sparse, 3 = sparse, 5 = medium, 7 = dense, 9 = very dense).

Inflorescence and fruit habit descriptors included: dichogamy (1 = protandrous, 2 = protogynous, 3 = unknown); predominant location of fruit buds (1 = terminal, 2 = mainly terminal, 3 = lateral); and number of male catkins (3 = few, 5 = medium, 7 = many).

Phenological descriptors included: time of fruit maturity (3 = early, 4 = early to medium, 5 = medium, 6 = medium to late, 7 = late); time of leaf fall (3 = early, 5 = medium, 7 = late); time of leaf bud burst (1 = very early, 2 = very early to early, 3 = early, 4 = early to medium, 5 = medium, 6 = medium to late, 7 = late, 8 = late to very late, 9 = very late); and time of male and female flowering, following the same scale as that for time of leaf bud burst.

Leaf descriptors included: leaflet shape (1 = narrow elliptic, 3 = elliptic, 5 = broad elliptic).

Shoot descriptors included: color of one-year-old shoots (1 = dark yellow, 2 = light brown, 3 = green brown, 4 = blackish).

Nut descriptors included: nut size (1 = very small, 3 = small, 5 = medium, 7 = large, 9 = very large); nut width (mm); nut shape in longitudinal section through suture (1 = circular, 2 = triangular, 3 = broad ovate, 4 = ovate, 5 = broad trapezium, 6 = trapezium, 7 = broad elliptic, 8 = elliptic); nut shape in longitudinal section perpendicular to suture (1 = circular, 2 = triangular, 3 = broad ovate, 4 = ovate, 5 = broad trapezium, 6 = trapezium, 7 = broad elliptic, 8 = elliptic, 9 = cordate); nut shape of base (1 = cuneate, 2 = rounded, 3 = truncate, 4 = emarginated); nut shape of apex (1 = pointed, 2 = rounded, 3 = truncate, 4 = emarginated); nut prominence of apical tips (3 = weak, 5 = medium, 7 = strong); roundness index (1 = very low, 3 = low, 5 = medium, 7 = high, 9 = very high); structure of the shell surface (1 = slightly grooved, 2 = moderately grooved, 3 = strongly grooved, 4 = embossed); thickness of primary and secondary dividing membranes (3 = thin, 5 = medium, 7 = thick); thickness of shell (1 = very thin, 3 = thin, 5 = medium, 7 = thick); adherence of shell halves (1 = very weak, 3 = weak, 5 = medium, 7 = strong, 9 = very strong); ease of kernel removal (1 = very easy, 3 = easy, 5 = medium, 7 = difficult); kernel ground color (1 = very light, 3 = light, 5 = medium, 7 = dark); kernel size (1 = very small, 3 = small, 5 = medium, 7 = large, 9 = very large); and kernel percentage (%), obtained by the relationship between the kernel weight and the total nut weight (kernel weight/nut weight $\times$ 100).

At harvesting time, fruits were manually collected and weighed. Tree yield efficiency (kg cm^{-2}) was calculated as the nut yield (kg per tree) per unit of trunk cross-sectional area (cm^2) because plants were of different ages and sizes.

These evaluations were carried out using a completely randomized block design with one-tree plots and eight replications per cultivar (two in each of the four farms). The data were analyzed by analysis of variance for the

Table 1 General soil and meteorological data characterization of two localities of Catamarca province (Argentina), where 'Trompito INTA' was evaluated in comparison with the standard cultivars 'Chandler' and 'Criolla'. Meteorological data are the means of three years (2009–2011)

Characteristic/Location	POZO DE PIEDRA	LA PUERTA
Altitude (m a.s.l.)	1700	889
Land slope (%)	8.6	5.1
Soil pH	8.3–8.7	7.0–7.2
Soil texture	Loam	Sandy Loam
Irrigation system	Surface irrigation	Surface irrigation
Average annual precipitation (mm)	205	452
Frost dates: First	May 10th	May 25th
Last	September 20th	August 25th
Chilling hours below 7.2 °C[z]	1307	714

[z]Calculated from hourly temperature measurement

Table 2 Tree characteristics of the walnut 'Trompito INTA' in comparison with the standard cultivars 'Chandler' and 'Criolla' according to IPGRI [9] and UPOV [17][z]

	'Trompito INTA'	'Chandler'	'Criolla'
Vigor[y]	3	3	7
Growth habit[x]	2	3	2
Density of branches[w]	5	7	6
Leaflet shape[v]	2	1	3
Predominant location of fruit buds[u]	3	3	1
Color of one-year-old shoot[t]	2	3	4
Number of male catkins[s]	7	5	6
Time of fruit maturity[r]	4	5	1
Time of leaf fall[q]	4	5	3
Time of leaf bud burst[p]	2	5	2
Time of male flowering[o]	2	6	1
Time of female flowering[n]	2	6	1

[z]Data are mean ± SD for 3 years (2009–2011)

[y]3: weak; 9: very strong

[x]1: upright; 2: semi-upright; 3: spreading

[w]1: very sparse; 9: very dense

[v]1: narrow elliptical; 2: elliptical 3: broad elliptical

[u]1: terminal; 2: mainly terminal; 3: lateral

[t]1: dark yellow; 2: light brown; 3: green brown; 4: blackish

[s]3: few; 7: many

[r]3: early; 7: late

[q]3: early; 7: late

[p]1: very early; 9: very late

[o]1: very early; 9: very late

[n]1: very early; 9: very late

calculation of yield efficiency, and means were compared using the least significant difference (LSD) multiple range test with 5% significance. Statistical analysis was performed using InfoStat software [11].

Results and Discussion

The results showed that the time of leaf bud burst of 'Trompito INTA' ranges from 'very early' to 'early' (Table 2). Flowering is protandrous, with 30 to 70% overlap between pollen shedding and pistillate flower receptivity, depending on the year and the farm´s elevation. Male flowering occurs between September 15th and October 1st in the southern hemisphere (SH) (equivalent to March 15th and April 1st in the northern hemisphere, NH) when plants grow at 1700 m a.s.l., and between September 27th and October 15th in the SH (equivalent to March 27th and April 15th in the NH) when plants grow at 889 m a.s.l. (Fig. 1). Female flowering occurs between September 23rd and October 12th in the SH (equivalent to March 23rd and April 12th in the NH) when plants grow at 1700 m a.s.l., and between September 30th and October 20th in the SH (equivalent to March 30th and April 20th in the NH) when plants grow at 889 m a.s.l. 'Trompito INTA' can be pollinated by 'Criolla' and 'Chandler', covering, between both cultivars, the entire female flower receptivity period at the localities of lower altitude; however, in plantations at higher altitude, the cv. 'Chandler' further delays its flowering, and consequently does not behave as a good pollinator (Fig. 1). 'Trompito INTA' can also be pollinated by 'Argentina INTA' and 'Yaco Tula INTA' [4]. Fruit maturity of 'Trompito INTA' ranges from 'early' to 'medium' and the time of leaf fall is 'medium' (Table 2).

'Trompito INTA' is a tree of weak vigor, a semi-upright growth habit, medium density of branches, and lateral fructification (Fig. 2). Lateral fructification is important in breeding programs because it enhances the early bearing of young trees and is an important factor in determining the yield of mature trees [1, 10]. The nut is of very large size

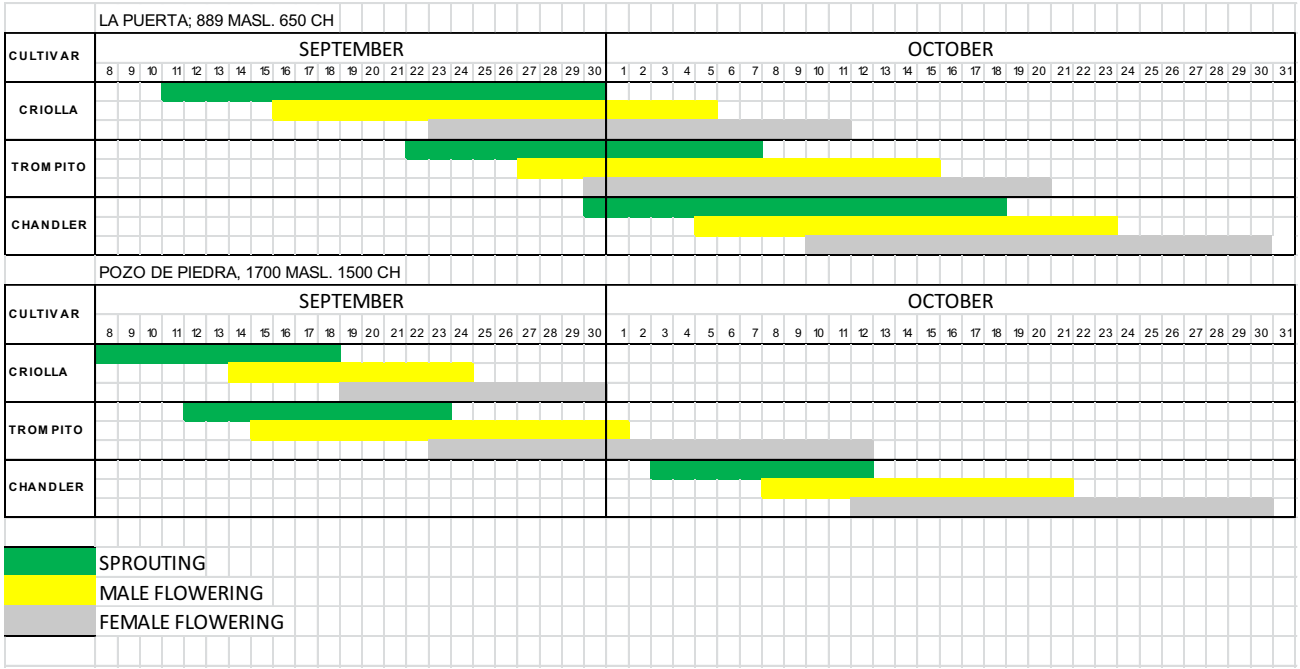

Fig. 1 Phenogram of 'Trompito INTA' in comparison with the standard cultivars 'Chandler' and 'Criolla' at two localities of the province of Catamarca: La Puerta, 889 m above sea level (m a.s.l.) and 650 chilling hours (CH); Pozo de Piedra, 1700 m a.s.l. and 1500 CH. Data are the means of three years of study (2009–2011)

Fig. 2 Tree of 'Trompito INTA' walnut selected at the end of the 6th vegetation period, in Pozo de Piedra, Belén, Catamarca province, Argentina. The tree is 4.5 m tall and has 5.0 m of canopy diameter

(37.12 mm of nut width on average), with a broad ovate shape in the longitudinal section through the suture. The base of the nut has a typical trapezoid shape, whereas the apex is pointed with a strong prominence of the apical tip (Table 3; Fig. 3). The roundness index of the nut is high to very high (> 0.82). The structure of the shell surface is slightly grooved, with a thin shell. Although the adherence of the shell halves is strong, the kernel is very easy to remove. The kernel color is very light (Fig. 3) and kernel percentage is very high (> 53.5%).

In comparison with 'Chandler', 'Trompito INTA' has a more spreading growth habit, a lower branch density and more male catkins. On the other hand, 'Trompito INTA' differs from the control cultivar 'Criolla' mainly in its lower vigor and the lateral location of the fruit buds (Table 2). Under the same agroecological conditions, the overlap between pollen shedding and pistillate flower receptivity is higher in 'Trompito INTA' than in 'Chandler' (20–60%), and similar to that of 'Criolla' (25–80%). The female flowering of 'Trompito INTA' occurred 4 to 7 days later than that of 'Criolla' but 11 to 18 days earlier than that of 'Chandler' (Fig. 1). In accordance with the date of flowering, the harvesting of 'Trompito INTA' occurs 28 days earlier than that of 'Chandler' and 7 days later than that of 'Criolla'. Early harvesting is a desirable characteristic for the walnut industry because it allows growers to spread out their harvest and to provide more

Table 3 Inflorescence, nut and kernel traits of 'Trompito INTA' in comparison with the standard cultivars 'Chandler' and 'Criolla' according to UPOV [17][z]

	'Trompito INTA'	'Chandler'	'Criolla'
Dichogamy[y]	1	1	1
Nut size[x]	9	5	3
Nut width (mm)	37.12	35.55	31.15
Nut shape in longitudinal section through suture[w]	3	8	1
Nut shape in longitudinal section perpendicular to suture[v]	5–6	7	1
Nut shape of base[u]	3	2	2
Nut shape of apex[t]	1	2	2
Nut prominence of apical tip[s]	7	5	5
Roundness index[r]	8	3	7
Structure of the shell surface[q]	1	2	1
Thickness of primary and secondary dividing membranes[p]	1/1	1/1	2/2
Thickness of shell[o]	3	3	6
Adherence of shell halves[n]	7	3	7
Ease of kernel removal[m]	1	3	7
Kernel ground color[l]	1	1	6
Kernel size[k]	9	5	3
Kernel percentage (%)	53.52	48.84	39.14

[z]Data are mean ± SD for 3 years (2009–2011)

[y]1: protandrous; 2: protogynous; 3: unknown

[x]1: very small; 9: very large

[w]1: circular; 8: elliptical

[v]1: circular; 9: cordate

[u]1: cuneate; 4: emarginated

[t]1: pointed; 4: emarginated

[s]3: weak; 7: strong

[r]1: very low; 9: very high

[q]1: slightly grooved; 4: embossed

[p]1: 1: thin; 2: medium; 3: thick

[o]1: very thin; 7: thick

[n]1: very weak; 9: very strong

[m]1: very easy; 7: difficult

[l]1: very light; 7: dark

[k]1: very small; 9: very large

Fig. 3 Kernels and fruits of the three walnut genotypes here compared: 'Trompito INTA' (left), 'Criolla' (center), and 'Chandler' (right)

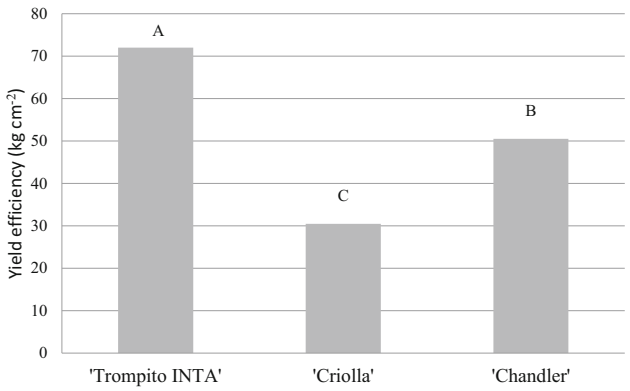

Fig. 4 Yield efficiency (kg cm^{-2} trunk cross-sectional area) of the three walnut genotypes here compared. Data are the averages over three growing seasons (2009/2010 to 2011/2012) and plants were of different ages. Different letters over the columns indicate significant differences by the LSD multiple range test ($P = 0.05$)

efficient use of the harvesting, drying and processing equipments [6]. Besides, early harvesting cultivars than Californian ones would increase the price for the farmer; this is the reason why one of the objectives of the IRTA (Spain) walnut breeding program is to obtain early harvesting cultivars [12]. Furthermore, 'Trompito INTA' differs markedly from the controls with regard to its very large nuts and kernel size, the particular shape according to which it is named, the easiness to remove the kernel and the percentage of kernels; all of them desirable characteristics for new walnut cultivars [13–15]. Fruit yield efficiency is high and regular, and exceeds both control cultivars (Fig. 4). However, data were obtained from trees of different ages (10 years on average). In comparison with 'Chandler', the improved performance of 'Trompito INTA' was more evident on farms located at lower elevations. Preliminary studies with excised shoots exposed to artificial cold (0–1000 chilling hours, CH) showed that the terminal buds of 'Trompito INTA' have a chilling requirement of 500 to 550 CH in comparison with 'Chandler', which has a chilling requirement of 800 CH (unpublished data). Using excised shoots also allowed determining that 'Serr' and 'Z_{30}' are also walnut cultivars with low chilling requirements (650 CH [2]. In comparison with our unpublished data, other studies performed in Iran have estimated that the terminal buds of 'Chandler' have a high chilling requirement (950–1100 CH) [8]. According to our results and after more than 20 years of observations by farmers, researchers and breeders, 'Trompito INTA' is allowing the expansion of the crop in Catamarca province, lowering the limit of altitude for walnut cultivation by 200 m, from 900 to 700 m a.s.l.

In two years of the study, less than 10% of the apical flowers were damaged by frost only above altitudes of 1500 m in Catamarca province, but this did not affect fruit production. However, cultivars with early leafing and flowering can be avoided in areas where late spring frost occurrences are frequent [1]. Thus, 'Trompito INTA' appears well adapted to the local environmental conditions of Catamarca, which is recommended in the context of climate change and global awareness of the ecological impact of chemical inputs [3], but not recommended under climatic conditions with high risk of late frost occurrence.

In conclusion, 'Trompito INTA' was chosen because it strongly fitted the selection goals, displaying early harvesting and lower chilling requirement, as well as other desirable characteristics such as lateral fruiting habit, high-quality nut and kernel attributes and a high kernel percentage. The new cultivar was named according to its trapezoidal fruit shape.

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Author Contributions All the authors have contributed to the study conception and design. Dante Carabajal, Juan Colica, Antonio Prataviera and Eber Delgado prepared the material, collected the data and performed the analyses. Norberto Gariglio wrote the first draft of the manuscript and all the authors commented on previous versions of the manuscript. All the authors have read and approved the final manuscript.

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Data Availability Statements 'Trompito INTA' was released as a public cultivar. Limited quantities of scion wood are available at the Experimental Station of INTA Catamarca, Catamarca province, Argentina. 'Trompito INTA' was registered in the National Registry of Cultivars of the National Institute of Seeds of Argentina (INASE; Instituto Nacional de Semillas) by resolution INASE N° 364 of October 2nd 2013. Register number 14.213. Available at: https://gestion.inase.gob.ar/consultaGestion/gestiones.

Declarations

Conflict of interest The authors declare they have no conflicts of interest/competing interests.

Data Availability Limited quantities of scion wood of the new cultivar are available at INTA Catamarca, Catamarca province, Argentina.

Code Availability InfoStat software (Di Rienzo et al. 2012) was used for statistical analysis.

Ethical Approval The authors declare that the submitted work is original and has not been published elsewhere in any form or language.

Consent to Participate All the authors consent to participate in the manuscript.

Consent for Publication All the authors consent to publish the manuscript.

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