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Article

Productive diversity and fruit quality of peach and nectarine cultivars

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Abstract

From 2022 to 2023, 15 cultivars with low cold requirements were evaluated in Coatepec Harinas, State of Mexico, in order to select the most outstanding materials for their productive potential and fruit quality. Four-year-old trees were evaluated under forced production management, and growth, productivity and fruit quality were determined. Productive behavior in yield ranged from 3 to 23 kg tree^{-1}, the period from flowering to fruit maturity lasted between 105 and 134 days, and fruit production efficiency ranged from 0.18 to 0.91 kg cm^{-2}. The total soluble solids, content ranged from 11.6 to 19.7 °Brix, titratable acidity, from 0.5 to 0.97% malic acid and the TSS/TA ratio from 15.8 to 36.12. Fruit size ranged from 68 to 168 g, shaped from 64 to 255 and firmness from 1.2 to 4.4 kgF mm^{-1}. 'Oro de San Juan' and 'Cardenal' presented the highest yields; in terms of fruit quality, most cultivars showed excellent attributes in size, shape, firmness and sweeter, more aromatic fruity flavor in white-fleshed fruits. 'Cardenal' presented the earliest fruit ripening, 28 days before 'Diamante'. The introduction and production of the peach cultivars Oro de San Juan, Cardenal, and Robín are real alternatives to increase per-hectare yields and the crop's profitability, as well as to improve per capita consumption with better fruit characteristics in the market.

Keywords:

Prunus persica, genetic improvement, yield.

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Introduction

Peaches and nectarines are the most preferred drupe and stone fruits worldwide due to their attractive colors, aroma and a combination of sugar and acidity that generate a unique and popular flavor among consumers (Veerappan *et al* ., 2021).

In 2023, they were grown in 81 countries, with an area of 2.4 million hectares, with a production of 44 million tons and a yield of 10.8 t ha^{-1}. China, with 36% of the area and 38% of the total production, is the main producer (FAOSTAT, 2025).

In Mexico, peaches are among the sweet seasonal fruits with high consumption and economic value. In 2024, the productive behavior of this fruit was 34 000 ha, 265 000 t and a yield of 8 t ha^{-1}. The main producing states are Zacatecas, Chihuahua, Michoacán, and Mexico with values of 92 000, 37 000, 31 000 and 26 000 t, respectively (SAGARPA-SIAP, 2025).

Peach production in regions of Morelos, Michoacán, and the southern part of the State of Mexico, which have a subtropical climate, is recognized as an important real alternative due to the potential and comparative advantages it presents compared to the temperate zones of Puebla, Tlaxcala, and Zacatecas. Early harvest aligns with a market window, resulting in attractive prices for producers.

This has brought back relevance and interest in continuing to incorporate areas for peach and nectarine cultivation and production. However, the lack of well-adapted cultivars with fruit quality and yield superior to those of traditional varieties has limited their production. As a result, producers have turned to foreign cultivars, including ‘Diamante’.

This particular lack of new cultivars has been one of the main factors driving peach producers and consumers away in Mexico. Raseira and Franzón (2021) note that the introduction of new cultivars with superior productive and commercial attributes could improve yield and that superior-quality fruit can attract end consumers.

In this context, the College of Postgraduates’ genetic improvement program has a collection of genotypes with unique characteristics that are currently of interest to reveal. Therefore, this work aimed to evaluate the yield and fruit quality of 15 peach and nectarine cultivars to assess their potential qualities.

Materials and methods

The study was conducted over two years -2022 and 2023- at the Salvador Sánchez Colín CICTAMEX SC Foundation, ‘La Cruz’ Experimental Center, located in Coatepec Harinas, State of Mexico. The site is located at 18° 48’ north latitude, 99° 42’ west longitude, and an altitude of 2 200 m.

The soil is a Cambisol; the climate is temperate subhumid, with a maximum temperature of 26.1 °C, a minimum temperature of 4.3 °C and an average temperature of 15.8 °C. Rainfall occurs mainly in summer, with the rainiest months being from June to September, with an annual average of 1 162 mm (PDM, 2025).

Fifteen peach and nectarine cultivars were evaluated; 14 of which were obtained from the genetic improvement program of the College of Postgraduates (Table 1). The Diamante cultivar was used as a control; it is from EMBRAPA-Brazil’s genetic improvement program and is found on most plantations in the subtropical areas of the states of Michoacán, Morelos and the south of the State of Mexico.

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Table 1. Characteristics of 15 peach/nectarine cultivars with low cold requirements, evaluated in Coatepec Harinas, State of Mexico, cycles 2022 and 2023.

Cultivar	Origin	Type	Cold requirement (CU)	Pulp color
Diamante (control)	Embrapa-Brazil	Peach	200	Yellow
Cardenal	CP	Peach	250	Yellow
Colegio 2005	CP	Peach	200	Yellow
Oro de San Juan	CP	Peach	275	Yellow
Oro Azteca Mejorado	CP	Peach	225	Yellow
Diamante Mejorado	CP	Peach	250	Yellow
Miel Azteca	CP	Peach	250	Yellow
Nuevo Azteca	CP	Peach	250	Yellow
Sol Azteca	CP	Peach	300	Yellow
Granizo	CP	Peach	250	White
Robín	CP	Peach	275	White
Perla Azteca	CP	Peach	200	White
Encanto Azteca	CP	Peach	200	White
Esplendor Azteca	CP	Peach	250	White
Blanquiña	CP	Nectarine	300	White

CP= College of Postgraduates; CU= cold units (García *et al* ., 2018).

The trees were four years old at the start of the study, were growing on a regional ‘Criollo’ rootstock at a planting distance of 5 m between rows and 2 m between trees and had been pruned into a narrow vase shape.

In the ‘Los Postes’ orchard, three trees per cultivar were selected for their respective study. For quality evaluation, during the harvest season from February to June, 10 fruits at maturity for consumption were used for each material and each year (2022 and 2023). Fruit selection was based on discarding fruits that were physiologically immature, malformed or damaged by physical injury, pests or diseases.

Subsequently, the fresh weight of 10 fruits was obtained using an Explorer Pro® gravimetric balance, calibrated to ±0.01 g (Mod. EP114C, Switzerland); the shape was estimated by dividing the value of the polar diameter of the fruit by its equatorial dimeter (cm), measured with a CD-6 ‘CSSX’ vernier (Mitutoyo Corp.), where higher values indicated elongated fruits or fruits with apical protuberance, and lower values indicated a round fruit shape. Firmness was recorded in 10 fruits using a Mc Cormick texture analyzer (F-327) with an 11 mm diameter probe. The probe was inserted into the equatorial section of the fruit, where the peel (exocarp) had previously been removed, following the method of Kader and Mitchel (1989) .

The total soluble solids (TSS in °Brix) content was determined in 10 fruits using a digital refractometer (PR-100 Atago, Tokyo, Japan); the titratable acidity (% malic acid) was determined using the method proposed by the AOAC (1990) ; likewise, the TSS/TA ratio was evaluated and its value was obtained by dividing the amount of total soluble solids by the titratable acidity of each of the 10 samples. To evaluate productive behavior, the trees were subjected to a forced production program (Table 2).

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Table 2. Agronomic management for forced peach production in Coatepec Harinas, State of Mexico, cycles 2022 and 2023.

Season	Stage	Task
September	Full flower	Defoliation with urea (3%; equivalent to 3 kg in 100 L of water) and zinc sulfate (2%); Fruiting pruning; Application of Revent® of 200 g active ingredient per liter (1.25 ml $L^{-1}$of water) plus oil (citrolina) at 2%
October	Dormant tree	Control of peach leaf curl and shothole blight; First fertilization: ½ nitrogen plus all phosphorus and potassium
November-December	Petal drop	Control of brown rot; Control of thrips and red spider mites; Second fertilization: ½ nitrogen; Irrigation; *Weed control
January-February	Fruit thinning and development	Fruit thinning; Control of powdery mildew; Foliar fertilization: zinc, manganese, calcium, boron, and other minor elements (2-3 applications); Control of thrips, red spider mites and fruit flies; Irrigation and weed control
March-April	Harvest	Control of brown rot and fruit flies and *anti-bird netting

+= necessary activities; *= tasks that depend on weather conditions or the presence of the problem.

Based on the agronomic management, the following was determined: fruit development period (FDP), the time elapsed from anthesis to harvest of the fruit at consumption maturity was recorded (the change of color from green to the predominant color of each cultivar was taken as a maturity criterion); yield in kg tree^{-1}(YT), the total fresh weight was immediately recorded at each of the three cuts during the harvest stage, and the fruit production efficiency per tree (FPE) was calculated by dividing the yield (kg) by the cross-sectional area of the trunk (cm2) of the same tree (kg cm^{-2}).

To calculate the cross-sectional area, the trunk's perimeter was measured at a height of 20 cm from the ground, and the following equality was applied:

$$ATT = \frac{1}{4}\pi d$$

The diameter (d) was calculated using the following function:

$$d = P\pi$$

Where: P= trunk perimeter; π= 3.1416.

The experimental design was completely randomized, with three replications per cultivar, with one peach tree as the experimental unit. The data for the variables described above were subjected to an analysis of variance and tests of means using Tukey's test, with a significance level of ≤0.05. For the variable fruit shape, a non-parametric test was performed using the Kruskal-Wallis test. All these procedures were performed using SAS®, v. 8.0 (SAS Institute, 1999).

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Results and discussion

Physical and chemical properties of fruit quality

Fruit weight varied between 88 g and 168 g for the yellow peaches 'Oro Azteca Mejorado', 'Diamante Mejorado', 'Miel Azteca', 'Sol Azteca', 'Cardenal', 'Diamante', 'Nuevo Azteca', 'Colegio 2005' and 'Oro de San Juan'. In white-fleshed peaches and nectarines, it ranged from 68 g to 149 g, for 'Blanquiña', 'Granizo', 'Esplendor Azteca', 'Perla Azteca', 'Encanto Azteca' and 'Robín'. The potential of 'Robín' and 'Oro de San Juan', white and yellow peaches, respectively, stood out, as they showed higher fruit weight over the two years of evaluation (149 g and 168 g).

Outstanding cultivars could generate preference, acceptance and higher marketing prices. For cultivars weighing less than 90 g to 100 g, thinning can keep weight stable or even increase it due to increased carbohydrate availability for each fruit that remains on the tree (Fanwoua *et al* ., 2014). This thinning task has been suggested to begin at fruiting pruning, during full flowering and before pit hardening; however, the optimal time is at full flowering or immediately after it (Osborne *et al* ., 2005).

Nonetheless, fruit weight will depend largely on harvest time, genotype, number of fruits, and prevailing climatic and agricultural management conditions (Rawandoozi *et al* ., 2020).

For fruit shape, the yellow peaches 'Diamante', 'Sol Azteca', 'Diamante Mejorado', 'Oro de San Juan' and 'Nuevo Azteca', according to analysis and adjustment of means by non-parametric analysis of Kruskal-Wallis, presented the highest values (indicating less roundness), between 183 and 255, which indicate a notable apical protuberance (tip) in their fruits. This is an undesirable trait that makes them prone to bruise during post-harvest handling and shipping and that decreases their commercial quality.

Conversely, some white-fleshed cultivars, such as Encanto Azteca, Perla Azteca and Esplendor Azteca, were statistically different from 'Diamante' in fruit shape, with lower values between 77 and 117, indicating a round fruit profile (Table 3). This genetic improvement in the fruit's round shape favors post-harvest handling and increases consumer preference for the fruit.

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Table 3. Physical properties of fruit quality in 15 peach/nectarine cultivars evaluated in Coatepec Harinas, State of Mexico, during 2022 and 2023.

Cultivar	Weight (g)	Shape	Firmness (kgF)
Oro de San Juan	168.05 ay	182.4 ad	1.54 ef
Robínx	149.8 ab	168.65 be	2.2 bf
Colegio 2005	134.65 bc	140 ch	1.62 df
Nuevo Azteca	128.8 cd	189.75 ac	2.55 be
Diamante	114.7 ce	255.4 a	2.33 be
Cardenal	110.1 df	74.38 hi	2.68 bd
Sol Azteca	105.75 eg	244.35 a	2.61 be
Encanto Aztecax	102.25 eg	76.75 gi	1.68 cf
Miel Azteca	92.6 fg	63.83 i	1.81 cf
Perla Aztecax	91.3 fg	80.43 fi	2.72 bc
Diamante Mejorado	91 fg	232.48 ab	1.8 cf
Oro Azteca Mejorado	88.36 gh	109.08 ei	2.9 b
Esplendor Aztecax	88.1 gh	116.85 di	1.94 bf
Granizox	86.5 gh	167.75 bf	4.42 a
Blanquiñaxw	68.35 h	155.42 cg	1.2 f
Media	108.02	150.5	2.26
CV (%)	17.8	41.7	42.43

Polar diameter/equatorial diameter ratio with adjustment of means using Kruskal-Wallis non-parametric analysis; y= values with a common letter are not significantly different according to Tukey's test (p≤ 0.05); x= white-fleshed varieties; w= nectarine.

Research such as that by Li *et al* . (2016) reports that the degree of ellipticity and tip prominence tends to increase in subtropical cultivars, mainly due to a lack of cold hours and to high temperatures after flowering.

In firmness, a significantly lower value (1.2 kgF) was obtained for 'Blanquiña'. This can negatively affect quality attributes, increase susceptibility to diseases and lead to greater postharvest fruit deterioration due to lower cell wall resistance (Qiant *et al* ., 2021). The highest value was for 'Granizo', with 4.42 kgF. This peach has a high degree of pulp adherence to the seed, which can classify it as a prospect for the industry.

The yellow peaches 'Oro de San Juan', 'Colegio 2005', 'Diamante Mejorado', 'Miel Azteca', 'Diamante', 'Nuevo Azteca', 'Sol Azteca', 'Cardenal', and 'Oro Azteca Mejorado' showed firmness values between 1.54 and 2.9 kgF. For the white-fleshed peaches 'Encanto Azteca', 'Esplendor Azteca', 'Robín' and 'Perla Azteca', the corresponding values varied between 1.68 and 2.72 kgF, respectively.

In general, the yellow cultivars 'Nuevo Azteca', 'Cardenal', 'Sol Azteca', and 'Oro Azteca Mejorado' showed values that were similar to and higher than those of 'Diamond' (control) and those of white peaches at the time of harvest; this can give them greater resistance during handling, transport and storage.

The total soluble solids (TSS) content for the yellow peaches 'Oro de San Juan', 'Miel Azteca', 'Diamante Mejorado', 'Nuevo Azteca', 'Cardenal', 'Diamante', 'Oro Azteca Mejorado', 'Colegio 2005' and 'Sol Azteca' showed an average of 13.47 and a range from 11.66 to 14.9 °Brix. For the white-fleshed peaches and nectarines 'Robín', 'Perla Azteca', 'Esplendor Azteca', 'Encanto Azteca', 'Granizo' and 'Blanquiña', the average value was 15.83 and varied from 13.57 to 19.75 °Brix. The concentration of TSS in white-fleshed cultivars was higher (Table 4).

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Table 4. Chemical properties of fruit quality in 15 peach/nectarine cultivars evaluated in Coatepec Harinas, State of Mexico, during 2022 and 2023.

Cultivar	TSS (%)	TA (% malic acid)	TSS/TA ratio
Blanquiña	19.75 az	0.95 a	21.72 bc
Granizo	16.59 b	0.97 a	18.05 c
Encanto Azteca	15.46 bc	0.8 ad	20.92 bc
Esplendor Azteca	15.09 bd	0.53 d	36.12 a
Sol Azteca	14.9 bd	0.62 bd	29.89 ab
Perla Azteca	14.54 bd	0.83 ac	18.71 c
Colegio 2005	14.53 bd	0.86 ab	17.95 c
Oro Azteca Mejorado	14.36 bd	0.75 ad	22.99 bc
Diamante	14.31 bd	0.73 ad	20.61 bc
Robín	13.57 ce	0.66 bd	24.67 bc
Cardenal	13.56 ce	0.93 a	15.84 c
Nuevo Azteca	13.2 ce	0.85 ab	17.95 c
Diamante Mejorado	13.06 de	0.74 ad	18.94 c
Miel Azteca	11.66 e	0.57 cd	21.23 bc
Oro de San Juan	11.66 e	0.75 ad	16.67 c
Media	14.41	0.77	21.48
CV (%)	14.74	32.72	42.09

z= Values with a common letter are not significantly different according to Tukey's test (p≤ 0.05).

The TSS content will depend on genotype, environmental conditions, yield, fruit position in the canopy, ripeness, water available during fruit development, nutrition, thinning and their interactions (Rawandoozi *et al* ., 2020).

The cultivars Cardenal and Miel Azteca, with shorter periods from flower to ripe fruit (105 and 118 days), showed lower TSS values, with 11.66 and 13.56 °Brix, respectively. In yellow cultivars such as Oro de San Juan, Cardenal, and Nuevo Azteca, high fruit production may have affected the total TSS content. Controlling fruit load could reduce competition among fruits for carbohydrates (glucose, fructose and sucrose) and increase TSS levels (Anthony and Minas, 2021).

For titratable acidity (TA), which represents a key quality parameter and an important factor in determining fruit flavor, it generally ranges between 0.07 and 0.14% for low-acid cultivars and between 1.1 and 1.45% for acidic cultivars (Mrázová *et al* ., 2021). For the yellow peaches 'Miel Azteca', 'Sol Azteca', 'Diamante', 'Diamante Mejorado', 'Oro de San Juan', 'Oro Azteca Mejorado', 'Nuevo Azteca', 'Colegio 2005' and 'Cardenal', TA ranged from 0.57 to 0.93% malic acid, respectively.

In the white peaches 'Esplendor Azteca', 'Robín', 'Encanto Azteca', 'Perla Azteca', 'Blanquiña' and 'Granizo', it ranged from 0.53 to 0.97% malic acid.

In the Mexican market, as in most countries, sweet fruits with low acidity have been preferred, which are liked for their flavor balance and are commonly found in most of the available cultivars (Table 4). Peach may contain important organic acids, such as oxalic acid, quinic acid, shikimic acid, citric acid, fumaric acid and malic acid, the latter being predominant (Famiani *et al* ., 2015).

The ratio of total soluble solids to titratable acidity (TSS/TA) is the best indicator to evaluate fruit ripeness and palatability. A high ratio indicates a higher degree of ripeness and a more pleasant taste, due to an ideal balance between sugars and organic acids (Sanches *et al* ., 2017).

'Esplendor Azteca', with white flesh, stood out with a higher TSS/TA ratio value, 36.12. This characteristic indicates high sweetness (15.09 °Brix) and low acidity (0.53% malic acid), reflected in an optimal balance between sweet and acid, desirable for the consumption of fresh fruit.

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In the yellow peaches 'Cardenal', 'Oro de San Juan', 'Nuevo Azteca', 'Colegio 2005', 'Diamante Mejorado', 'Diamante', 'Miel Azteca', 'Oro Azteca Mejorado' and 'Sol Azteca', this ratio varied between 15.84 and 29.89. For the white peaches 'Granizo', 'Perla Azteca', 'Encanto Azteca', 'Blanquiña', 'Robín' and 'Esplendor Azteca', the TSS/TA ratio was between 18.05 and 36.12.

In fruits, this maturity index (MI) ratio is used to classify them as acidic (MI: 5-7), bittersweet (MI: 17-24) and sweet (MI: 31-98) (Ortiz *et al* ., 2008). Therefore, it can be concluded that most cultivars can be classified as bittersweet and 'Aztec splendor' can be classified as sweet (Table 4).

Fruit growth period and production

For the fruit growth period (FGP), 'Cardenal' excelled with only 105 days from flower to ripe fruit, 28 days faster than 'Diamante', which requires 133 days from flower to ripe fruit. Most cultivars exhibited a shorter time to fruit harvest compared to 'Diamante' (Table 5). Nevertheless, this implies that the fruits have less time to accumulate carbohydrates, which often results in smaller sizes.

Table 5. Average fruit growth period and production of 15 peach/nectarine cultivars evaluated in Coatepec Harinas, State of Mexico, during 2022 and 2023.

Cultivar	FGP (days)	YT (kg)	FPE (kg cm^{-2})
Perla Azteca	133.5 az	14.46 ac	0.28 ac
Diamante	133.17 a	14.4 ac	0.21 af
Granizo	131.67 ab	3.65 c	0.07 f
Oro de San Juan	129.37 ab	23.18 a	0.36 a
Colegio 2005	129.19 ab	9.22 bc	0.11 fe
Diamante Mejorado	128.17 ab	12.33 abc	0.11 fe
Robín	126 ab	14.87 abc	0.24 ae
Sol Azteca	125.67 ab	4.68 c	0.15 cf
Oro Azteca Mejorado	123.25 ab	11.07 bc	0.11 df
Encanto Azteca	122.6 ab	16.32 ab	0.31 ab
Nuevo Azteca	122.25 ab	14.22 abc	0.27 ad
Esplendor Azteca	120.47 ab	10.16 bc	0.2 af
Blanquiña	121.13 ab	11.19 bc	0.2 bf
Miel Azteca	118 bc	8.03 bc	0.09 ef
Cardenal	105.07 c	17.56 ab	0.2 bf
Media	124.55	12.45	0.2
CV (%)	5.67	43.57	37.54

z= values with a common letter are not significantly different according to Tukey's test (p≤ 0.05).

Short FGP materials could take advantage of this quality of early fruit ripening to achieve better selling prices. In addition, production costs would be reduced by achieving a faster fruit harvest. 'Perla Azteca', which matures late (133.5 days), could benefit producers and consumers by prolonging the supply of fresh fruit and increasing economic income from a seasonal offer.

This diversification has been an important breeding trend for extending the harvest season among early- and very late-maturing cultivars in some producing areas (Baccichet *et al* ., 2025). It could also guarantee a fruit harvest from January to June in subtropical areas and help reduce fresh fruit imports to the Mexican market at the beginning of the year, which is the season of low supply. This would be a response to consumer demand for peaches to be available almost all year round.

In yield, the yellow peaches 'Oro de San Juan' and 'Cardenal' were superior, with 23 and 17 kg tree^{-1}, respectively. They did not present alternation in their production during the two years of evaluation, considering that there is often an impact on the source-demand balance of nutrients and carbohydrates, and there is a competition between the vegetative and reproductive parts, which generates a drop in yield in the subsequent season (Bussi et al ., 2016).

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The lower yields of cultivars such as Granizo, Colegio 2005, Sol Azteca and Miel Azteca were influenced by factors such as adaptation, susceptibility to diseases (*Monilinia fructicola*), and low percentage of fruit set, to name a few. Outstanding cultivars could increase orchard productivity and improve the profitability of peach production per hectare.

In fruit production efficiency, for the yellow peaches 'Miel Azteca', 'Colegio 2005', 'Diamante Mejorado', 'Oro Azteca Mejorado', 'Sol Azteca', 'Cardenal', 'Diamante', 'Nuevo Azteca' and 'Oro de San Juan', it varied between 0.09 and 0.36. In the white peaches 'Granizo', 'Blanquiña', 'Esplendor Azteca', 'Robín', 'Perla Azteca' and 'Encanto Azteca', it ranged from 0.18 to 0.78 kg cm^{-2}, respectively.

Oro de San Juan was superior in fruit production efficiency with 0.36 kg cm^{-2}. However, it was observed that, numerically, white cultivars were more stable in total fruit yield than yellow peaches (Table 5).

Conclusions

'Oro de San Juan' and 'Cardenal' excelled in yield; in fruit quality, most cultivars showed excellent attributes in size, shape, firmness and sweeter, more aromatic fruity flavor in white-fleshed fruits.

'Cardenal' presented a fruit harvest 28 days faster than 'Diamante' an advantage to increase supply and profitability.

The introduction and production of the peach cultivars Oro de San Juan, Cardenal and Robín are real alternatives to increase per-hectare yields and the crop's profitability, and to improve per capita consumption with better fruit characteristics in the market.

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