https://doi.org/10.18406/2316-1817v17nunico20251994 e-ISSN 2316-1817

Manual cross-pollination on the profitability of a pitaya orchard with self-compatible and self-incompatible species

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Received in: 08/01/2025
Accepted in: 03/04/2025

Abstract

The high dependence on cross-pollination in self-incompatible pitaya species causes low productivity. The objective, with the accomplishment of this work, was to compare the profitability of the pitaya orchard with the management of manual cross-pollination and natural pollination in self-compatible and self-incompatible species. Data were obtained from an experimental orchard formed with species *Selenicereus monacanthus* (self-incompatible) and *S. undatus* (self-compatible). The flowers of both species were manually and naturally pollinated by native pollinators, in all flowering fluxes of the plants. The profitability assessment considered the established activities from implementation and maintenance to the third productive cycle of the orchard. The management of manual cross-pollination in pitaya orchards increased productivity by more than 150 %, from the first production cycle. Manual cross-pollination made it possible to profitability the capital invested in 1.0 hectare of pitaya in the second productive cycle of the orchard, with a profitability of 76 %. With natural pollination, the profitability on the initial investment occurred in the third production cycle, with a profitability of 72 %. The profitability of pitaya orchard is higher with manual cross-pollination in self-compatible and self-incompatible species compared to natural pollination.

Keywords: *Selenicereus monacanthus*. *Selenicereus undatus*. Open pollination. Production costs.

Introduction

The high dependence on cross-pollination is considered the main cause of low productivity in pitaya species that are self-incompatible, such as *Selenicereus monacanthus* (Lem.) D.R.Hunt (synonym: *Hylocereus polyrhizus* (F.A.C.Weber) Britton and Rose) (LICHTENZVEIG et al., 2000). However, it is questionable whether manual pollination is completely dispensable in self-compatible pitaya species. In species that self-fertilize, such as some clones of *Selenicereus undatus* (Haw.) D.R.Hunt (TRAN, YEN, 2014; MENEZES et al., 2015a; TRAN et al., 2015), there is a discussion about manual pollination is necessary or whether self-pollination and pollination by native pollinators are sufficient to achieve high productivity. For the species *S. undatus*, results were found regarding the production of fruits with more seeds, heavier, when the flowers were pollinated manually, compared to those that were self-pollinated spontaneously or pollinated naturally by insects (MENEZES et al., 2015 a,b).

Even in self-compatible clones, there is a deficiency in self-pollination or in pollination performed by floral visitors in pitaya orchards. This may occur due to the floral morphology, that is, the difference in the height of the stigma and the anthers (GUIMARÃES et al., 2022). In the case of natural pollination, the action of native pollinators in transporting pollen grains to the stigma of flowers may be insufficient. In addition, natural pollination can be influenced by the climatic conditions of the place of cultivation, since the occurrence of rain, for example, during anthesis, reduces the visitation of pollinators. In addition, the presence of some floral visitors, such as bees (*Trigona spinipes*), a very common species in pitaya orchards in Brazil, can negatively interfere with pollination (MUNIZ et al., 2019). Other factors, such as species diversity in the growing area and orchard size, may also affect pollination.

The efficiency of pollination depends on the number of pollinated flowers and the number of fertilized ovules, as this will increase the number of seeds in the fruit, with a direct consequence on its size and mass. This aspect is highly desirable for the production of pitaya on a commercial scale, since larger fruits command better market prices, while fruits weighing less than 0.150 kg are normally not intended for sale (FAO-WHO, 2011).

The increase in profitability in pitaya orchards may be related to the increase in productivity and fruit quality and the reduction of production costs. Regarding costs, producers prefer the cultivation of pitaya species that are self-compatible to reduce labor costs, because, when natural pollinators are present, manual services can be reduced.

The management of manual pollination can be an alternative for markets that want larger fruits, as there is an increase in mass, when fertilization occurs with pollen grains from other plants (DAG, MIZRAHI, 2005; SILVA et al., 2011; LONE et al., 2017). Thus, information related to the profitability of pitaya production with manual cross-pollination and natural pollination makes it possible to assess the viability of this management practice in orchards. Therefore, this work was carried out in order to compare the profitability of a pitaya orchard with the management of manual cross-pollination and natural pollination in self-compatible and self-incompatible species.

Material and methods

The experiment was carried out in an orchard located at 18° 04’ 41” S, 43° 27’ 27” W and 729 m altitude, in the municipality of Couto de Magalhães de Minas, state of Minas Gerais, Brazil. The climate is Aw, with dry winter and rainy summer, according to the Köppen-Geiger classification. The annual average minimum, average and maximum temperatures are 15 °C, 20.8 °C and 26.6 °C, respectively, and the annual precipitation is 1,095 mm, in 2021. The soil in the experimental area is classified as Latossolo Vermelho-Amarelo distrófico (Oxisol order) (SANTOS et al., 2018), with 59 % sand, 24 % clay and 17 % silt and low contents of nutrients and organic matter.

Soil preparation was carried out based on the result of the chemical analysis, proceeding with plowing, harrowing, acidity correction with dolomitic limestone in the total area, digging holes and planting fertilization. Fertilization was calculated from the result of the chemical analysis of the soil, which presented contents of organic matter and nutrients classified as low and very low (VENEGAS et al., 1999); and the amounts of nutrients needed to obtain 90 % of maximum productivity, considered the productivity of maximum economic efficiency (MALAVOLTA, 2006); and in the export of nutrients per ton of pitaya produced, based on studies carried out in the northeast and southeast regions of Brazil (CORRÊA et al., 2014; MOREIRA et al., 2016; FERNANDES et al., 2018; LIMA et al., 2019; SANTANA, 2019; RABELO et al., 2020; ALVES et al., 2021).

The orchard was implanted with the species *S. monacanthus* and *S. undatus*, aiming to ensure natural pollination, carried out naturally by pollinating agents, in the species *S. monacanthus*, which is self-incompatible and depends on cross-pollination (LICHTENZVEIG et al., 2000).

Planting was carried out at a spacing of 3 × 3 m, with one seedling per hole, totaling 48 seedlings already rooted for each species, planted interspersed in the planting rows. The conduction system used was based on the acquisition of 2.5 m concrete poles, installed 1.7 m above the ground, and 1 m beams, for the horizontal structure in the form of a “T”.

The growth and production fertilizations were divided into three applications (RABELO et al., 2020; ALVES et al., 2021) to provide the doses of N, P_2O_5 and K_2O. The sources used were: urea (46 % N), simple superphosphate (19 % P_2O_5, 18 % Ca and 20 % S) and potassium chloride (58 % K_2O). Complementation was carried out with bovine manure, added in the hole (10 kg) and in coverage (5 kg) (SILVA et al., 2022).

The manual cultural practices established for the management of the orchard were formation pruning, to favor the conduction of the plants over the concrete poles; cleaning, carried out annually to distribute the productive cladodes; and the management of weeds in the rainy season, from October to March, starting with manual weeding in the canopy projection and mowing in the rest of the area.

During the flowering period of the plants, from November to March, under the climatic conditions of the place of cultivation, manual cross-pollination was managed. The pollen grains were collected from the flowers of the plants by cutting the anthers with scissors, placing them in a container, and then, with the aid of a brush, they were placed on the stigma of the flowers of the other species (GUIMARÃES et al., 2022). This procedure was carried out in both species, pollinating all the flowers of the plants, in 24 plants for each species. In the other plants corresponding to natural pollination, the flowers of the species *S. monacanthus* and *S. undatus* were naturally pollinated by floral visitors, in 24 plants for each species.

At each harvest, all the fruits were counted and weighed to determine the fruit mass, the number of fruits per plant and the production per plant, calculating the productivity. Productivity was determined considering the commercialization of all harvested fruits.

The technical coefficients of the costs of implantation and maintenance of 1.0 ha for the production of pitaya were obtained from the price quotation in the region where this work was carried out, in 2021, considering the technical management information experimentally established in the orchard (FERNANDES et al., 2018; RABELO et al., 2020; ALVES et al., 2021), in order to estimate the profitability on investment in the orchard.

The methodology used to calculate the cost of production was adapted from Matsunaga et al. (1976) and Conab (2020). The production costs surveyed were based on the effective operating cost (EOC), on the expenses demanded with inputs, on the mechanized and manual operations used for the implantation and maintenance of the orchard during the productive cycles and on the total operating cost (TOC), on the expenses related to the acquisition of seedlings, in the conduction system, in addition to tools and packaging, among other necessary items. An attempt was made to contemplate all expenditure items, explicit or not, that must be assumed by the producer, from the initial phases until the pitaya harvest.

The values considered in the gross revenue calculations were based on surveys carried out at the Central de Abastecimento de Minas Gerais, Grande BH (CEASAMINAS, 2020-2021). Gross revenue was estimated based on productivity, multiplied by the sale price, in each evaluated production cycle, since transportation expenses are borne by the buyer.

The calculations referring to the cost of labor considered the payment of half a monthly minimum wage (gross salary), referring to the hiring of a fixed employee on a part-time basis, for manual operations such as area demarcation and alignment, fertilization, weeding, pruning, mowing and pest monitoring, and daily fees for carrying out sporadic activities, such as manual pollination and harvesting. The cost of labor was expressed by the daily rate paid to rural workers, and that of mechanized operations, by the amount paid per machine-hour of an average tractor (75 cv), practiced in the region where this work was carried out. Machinery depreciation was not considered as it uses the allocation price, a practice adopted in the region.

The own land factor (CONAB, 2020) was calculated based on the municipality of Couto de Magalhães de Minas, state of Minas Gerais, for regular aptitude orchards (EMATER, 2020). The value of seedlings plus shipping was calculated in a nursery registered in the Sistema Nacional de Sementes e Mudas (Renasem).

The analysis of crop profitability consists of the difference between gross revenue and total operating cost per hectare and measures the profitability of the activity in the short term, for each production cycle. In this work, the profitability analysis was carried out in a simplified way, considering the production costs of the orchard to be implanted until the third production cycle. Thus, data were evaluated from a descriptive analysis of all variables to compare management with manual cross-pollination and natural pollination, in both species.

Results

According to the technical coefficients for the maintenance of a pitaya orchard of 1.0 ha, if adopting the practice of manual cross-pollination, the total operating cost was on average 40 % higher in the three production cycles, in relation to the natural pollination (Table 1).

The productivity results were similar for the two species and therefore average data are presented, that is, regardless of whether or not the species is self-compatible, the response to manual cross-pollination management was satisfactory (Table 2). The management of manual cross-pollination contributed to increase the productivity of the orchard from the first production cycle of the species *S. monacanthus* and *S. undatus*, reaching 6.3 Mg ha^{-1}, while with natural pollination the productivity was 2.43 Mg ha^{-1} (Table 2). In the second and third production cycles, the average productivity were 18.3 and 28.1 Mg ha^{-1} with manual cross-pollination, and 6.29 and 10.6 Mg ha^{-1} with natural pollination, respectively.

The increase in productivity of manual cross-pollination in relation to natural pollination was 159 %, 191 % and 165 %, in the three production cycles evaluated (Table 2). This increase in productivity may be attributed to the increase in fruit mass and the number of fruits produced per plant. The average mass in the three production cycles was 0.471 kg and the number of fruits produced per plant increased with manual cross-pollination, while with natural pollination the average production of fruits per plant was lower in the three production cycles, reaching an average mass of 0.190 kg.

The difference in productivity as a function of manual cross-pollination and natural pollination reflects the percentage of fruiting; in manual cross-pollination, fertilization occurred in 97 % of the pollinated flowers, resulting in larger fruit mass (Table 2). With natural pollination, the average fruiting percentage was 87 %, resulting in fruits of lower mass. Therefore, in addition to fertilization, the amount of pollen grains deposited on the flower stigma is important for gains in productivity.

Considering the technical coefficients raised for the implementation and maintenance of the orchard of the *S. monacanthus* and *S. undatus* species, if adopting manual cross-pollination management, a positive profitability index of 76.42 % was achieved in the second production cycle, paying the total operational cost of implementation and maintenance (Table 2). When establishing natural pollination in the orchard, profitability was negative by 13.94 % in the second production cycle, requiring one more production cycle to achieve a positive profitability on the investment made. Only in the third production cycle it was possible to pay all the costs involved in the implantation and maintenance of 1.0 ha of pitaya with natural pollination, obtaining a positive profitability of 71.93 %; with manual cross-pollination management, profitability reaches 88.08 % in that same cycle.

The initial investment for implantation pitaya orchard tends to be high because, in the survey of technical coefficients, at a density of 1,111 plants per hectare, expenses with the acquisition of agricultural inputs represent 6.5 %, manual and mechanized operations 17.9 % and other necessary expenses, 75.5 %, in relation to the total operating cost (Table 3). The acquisition of the conduction system and seedlings represents 53.6 % of the total operating cost.

Discussion

The difference observed in the total operating cost is due to the demand for labor for handling manual cross-pollination and harvesting. In addition, the acquisition of packaging for the transport and sale of fruits harvested from manual cross-pollination also increases costs in relation to natural pollination, in view of the greater productivity of the orchard in relation to natural pollination. The management adopted in the orchard influences production costs, which can vary. In an orchard that adopted natural pollination and fertilization with organic sources, around 70 % of the costs went to the acquisition of organic fertilizers and labor (MARQUES et al., 2012). However, the demand for labor in pollination and harvesting practices is important for the development of pitaya producing regions, from the generation of employment and income, considering that pitaya orchards are perennial, with a useful life of 20 to 30 years, these activities being an alternative for extra income (EVANS, HUNTLEY, 2011). Even so, it was observed a relevant aspect for the decision-making of producers in relation to the adoption of manual cross-pollination management, even for the cultivation of species that are self-compatible, since it is possible to increase profitability and reduce the time to payback your initial investment.

As for productivity, with natural pollination, the amount of pollen grains deposited on the stigma of flowers tends to be smaller, resulting in smaller-sized fruits in all evaluated cycles (Table 2), which is due to the self-incompatibility of the clones of the same species and poor pollination (LE BELLEC et al., 2006). The efficiency of manual cross-pollination becomes greater due to the greater amount of pollen grains deposited in the flowers (DAG, MIZRAHI, 2005; SENA, 2022; SENA et al., 2025) and, consequently, greater productivity. In self-compatible species, natural pollination decreases with the incidence of rain at flower opening, as this factor reduces the visitation of pollinating insects and the supply of pollen grains, reducing the fruiting and fruit size (SILVA et al., 2011; GUIMARÃES et al., 2022). In addition, the occurrence of precipitation on the day of anthesis has been identified as an element responsible for reducing the viability of pollen grains (MENEZES et al., 2015b).

In self-incompatible species, the absence of fruiting has been observed in *S. undatus* pollinated with its own pollen grains (SILVA et al., 2011) and, when pollination is done manually, using pollen grains from *S. monacanthus* and *S. costaricensis*, the production of fruits with greater mass occurs (LONE et al., 2017). In addition,

Table 1. Technical coefficients for the maintenance of 1.0 ha of *Selenicereus monacanthus* and *S. undatus*, with manual cross-pollination and natural pollination, from the first to the third production cycle, density of 1,111 plants per hectare. Couto de Magalhães de Minas, Minas Gerais, 2021.

Specification	Unit	First production cycle			Second production cycle			Third production cycle		
		Quantity	Unitary value (R$)	Value (R$)	Quantity	Unitary value (R$)	Value (R$)	Quantity	Unitary value (R$)	Value (R$)
Agricultural inputs										
Simple superphosphate 19 % P_2O_5	bag 50 kg	6	109.00	654.00	7	109.00	763.00	8	109.00	872.00
Urea 46 % N	bag 50 kg	6	155.00	930.00	7	155.00	1,085.00	8	155.00	1,240.00
Potassium chloride 58 % K_2O	bag 50 kg	4	154.00	616.00	5	154.00	770.00	6	154.00	924.00
Bovine manure superficially	ton	6	150.00	900.00	6	150.00	900.00	6	150.00	900.00
Subtotal 1				3,100.00			3,518.00			3,936.00
Manual operations										
Mowing (3×) *										
Organic fertilization (1×) *										
Weeding *										
Production fertilization (3×) *										
Plant pruning *										
Pest monitoring *										
Fixed employee	half monthly minimum wage	12	826.84	9,922.08	12	826.84	9,922.08	12	826.84	9,922.08
Pollination (5×) MP	man-day	5	30.00 **	150.00	15	30.00 **	450.00	25	30.00 **	750.00
Harvest (5×) MP	man-day	15	60.00	900.00	35	60.00	2,100.00	60	60.00	3,600.00
Harvest (5×) NP	man-day	5	60.00	300.00	15	60.00	900.00	20	60.00	1,200.00
Subtotal 2 MP				10,972.08			12,472.08			14,272.08
Subtotal 2 NP				10,222.08			10,822.08			11,122.08
Effective operating cost MP				14,072.08			15,990.08			18,208.08
Effective operating cost NP				13,322.08			14,340.08			15,058.08
Other expenses										
Cardboard box 11 kg *** MP	unit	578	5.20	3,005.60	1,680	5.20	8,736.00	2,810	5.20	14,612.00
Cardboard box 11 kg *** NP	unit	223	5.20	1,159.60	578	5.20	3,005.60	1,060	5.20	5,512.00
Subtotal 3 MP				3,005.60			8,736.00			14,612.00
Subtotal 3 NP				1,159.60			3,005.60			5,512.00
Total operating cost MP				17,077.68			24,726.08			32,820.08
Total operating cost NP				14,481.68			17,345.68			20,570.08

MP, manual pollination. NP, natural pollination. Effective operating cost MP = Subtotal 1 + Subtotal 2 MP. Effective operating cost NP = Subtotal 1 + Subtotal 2 NP. Total operating cost MP = Effective operating cost MP + Subtotal 3 MP. Total operating cost NP = Effective operating cost NP + Subtotal 3 NP. * Manual operations performed by the fixed employee. ** Part time job. *** 56.4×37.6×14.4 cm (L×W×H).

Source: authors (2021).

the origin of the pollen grains can influence the characteristics related to the flavor of the fruit. Fruit production using pollen grains from *S. setaceus* resulted in more acidic fruits compared to fruits from pollination with pollen grains from *S. monacanthus* (SILVA et al., 2011).

Table 2. Profitability of 1.0 ha of *Selenicereus monacanthus* and *S. undatus*, with manual cross-pollination and natural pollination, from the first to the third production cycle, density of 1,111 plants per hectare. Couto de Magalhães de Minas, Minas Gerais, 2021.

Specification	Unit	First production cycle		Second production cycle		Third production cycle	
		Natural pollination	Manual pollination	Natural pollination	Manual pollination	Natural pollination	Manual pollination
Average price (P)	R$/kg	9.80	9.80	9.80	9.80	9.80	9.80
Average mass of fruits	kg	0.210	0.502	0.190	0.489	0.170	0.423
Number of fruits per plant	unit	11	13	30	35	50	60
Productivity (PT)	kg/ha	2,430	6,300	6,290	18,300	10,600	28,100
Revenue gross (RG)	R$/ha/cycle	23,814.00	61,740.00	61,642.00	179,340.00	103,880.00	275,380.00
TOC maintenance	R$/ha/cycle	14,481.68	17,077.68	17,345.68	24,726.08	20,570.08	32,820.08
TOC implantation	R$/ha	62,221.03	62,221.03	52,888.71	17,558.71	8,592.39	0.00
Profitability (PF)	R$/ha/cycle	-52,888.71	-17,558.71	-8,592.39	137,055.21	74,717.53	242,559.92
Profitability index (PI)	%	-222.09	-28.44	-13.94	76.42	71.93	88.08

RG = P × PT. PF = RG - (TOC maintenance + TOC implantation). PI = PF/RG × 100. TOC, total operating cost. Productivity (PT) is the average of the two species.

Source: authors (2021).

Floral morphology is another factor that also limits natural pollination in self-compatible species, which can lead to lower productivity compared to manual cross-pollination (Table 2). In the flowers of most pitaya species, the anthers are located below the stigma, making self-pollination difficult, which can be considered an indicator of the need for manual pollination (TRAN et al., 2015). This is because this characteristic increases the dependence on pollinating agents for production on a commercial scale.

Another important aspect to be considered when taking the decision to adopt manual cross-pollination management is the classification of fruits for commercialization. Without carrying out management practices that favor quality and increase commercial productivity, producers can lose, on average, 46 % of production, due to the fact that the fruits do not reach a standard for commercialization (SANTOS, 2020). In this present work, the commercialization of all harvested fruits was considered, however, in natural pollination, the fruits have lower mass and may not reach the commercial standard, which is, at least, 0.150 kg (FAO-WHO, 2011; ASEAN STAN 42, 2015), which may lead to lower profitability, since the production of fruits of commercial standards will be lower.

When planning a pitaya orchard, the source of pollen grains and the pollination method are important for production. The management of manual cross-pollination favors the production of fruits of greater mass, increases the productivity of the orchard, anticipates the profitability on the initial investment and maintains the profitability index higher than that of natural pollination (Table 2). Thus, manual cross-pollination is an alternative in regions where natural pollinators are scarce, and should be considered even for self-compatible species, especially for large areas and when climatic conditions are unfavorable. Thus, manual cross-pollination can be recommended to increase fruit set and productivity of pitaya orchards.

Table 3. Technical coefficients for the implantation of 1.0 ha of pitaya, density of 1,111 plants per hectare. Couto de Magalhães de Minas, Minas Gerais, 2021.

Specification	Unit	Implantation		
		Quantity	Unitary value (R$)	Value (R$)
Agricultural inputs				
Simple superphosphate 19 % P_2O_5	bag 50 kg	10	109.00	1,090.00
Urea 46 % N	bag 50 kg	4	155.00	620.00
Potassium chloride 58 % K_2O	bag 50 kg	2	154.00	308.00
Dolomitic limestone PRNT 80 %	ton	2	114.00	228.00
Bovine manure planting	ton	12	150.00	1,800.00
Subtotal 1				4,046.00
Mechanized operations				
Plow (2×)	machine-hour	2.5	80.00	200.00
Harrow (1×)	machine-hour	1.5	80.00	120.00
Liming	machine-hour	1	80.00	80.00
Dig holes	machine-hour	6	80.00	480.00
Subtotal 2				880.00
Manual operations				
Area demarcation *				
Installation of tutors	man-day	3	60.00	180.00
Fertilization planting (holes) *				
Planting and conduction	man-day	3	60.00	180.00
Mowing (3×) *				
Weeding *				
Post-planting fertilization (3×) *				
Formation pruning *				
Pest monitoring *				
Fixed employee	half monthly minimum wage	12	826.84	9,922.08
Subtotal 3				10,282.08
Effective operating cost				15,208.08
Other expenses				
Own land	hectare	1	3,466.75	3,466.75
Tutor in concrete “T”	unit	1,111	25.00	27,775.00
Seedlings + shipping	unit	1,111	5.00	5,555.00
Backpack brushcutter	unit	1	2,348.90	2,348.90
Hoe	unit	2	57.50	115.00
Pruning shears	unit	2	134.00	268.00
Shovel	unit	1	26.00	26.00
Manual post hole digger	unit	1	40.00	40.00
Plastic tape for conduction	kg	6	23.00	138.00
Plastic box 25 kg	unit	12	26.00	312.00
Wheelbarrow	unit	2	200.00	400.00
Soil analysis	unit	2	30.00	60.00
Metal shed 4 × 9 m	m^2	36	180.00	6,480.00
Subtotal 4				46,984.65
Taxes	R$/ha/year	1	28.30	28.30
Total operating cost				62,221.03

Effective operating cost = Subtotal 1 + Subtotal 2 + Subtotal 3. Total operating cost = Effective operating cost + Subtotal 4 + Taxes. * Manual operations performed by the fixed employee.

Source: authors (2021).

The profitability values reported in this work do not include possible losses that may occur in the pitaya production chain, whether due to pests and diseases, management problems, meteorological changes or factors in the relationship between supply and consumer demand, which can alter profitability. The probability is less than 1 % that pitaya cultivation is not a profitable activity for producers (EVANS, HUNTLEY, 2011).

Conclusions

The management of manual cross-pollination in the pitaya orchard increased productivity by more than 150 %, from the first production cycle.

Manual cross-pollination made it possible to profitability the capital invested in 1.0 hectare of pitaya in the second production cycle of the orchard, with a profitability of 76 %. With natural pollination, the profitability on the initial investment occurred in the third production cycle, with a profitability of 72 %.

The profitability of pitaya orchard is higher with manual cross-pollination in self-compatible and self-incompatible species compared to natural pollination.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. We thank Federal University of Jequitinhonha and Mucuri Valleys and the Program in Plant Production, for the infrastructure made available to carry out the research project.

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