

Jatropha mahafalensis oil from Madagascar: Properties and suitability as liquid biofuel

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ABSTRACT

Access to affordable and renewable sources of energy is crucial to reducing poverty and enhancing rural development in countries of the global South. Straight vegetable oil was recently identified as a possible alternative to conventional biomass for rural energy supply. In this context, the *Jatropha curcas* Linn. species has been extensively investigated with regard to its potential as a biofuel feedstock. In contrast, only little is known about *Jatropha mahafalensis* Jum. & H. Perrier, which is an indigenous and endemic representative of the *Jatropha* genus in Madagascar. This paper explores the potential and suitability of *J. mahafalensis* as a biofuel feedstock. Seed samples were collected in the area of Soalara in south-western Madagascar in February and September 2011. Two agro-ecological zones (coastal area and calcareous plateau) and two plant age groups (below and above 10 years) were considered. These four sample groups were analyzed with regard to oil properties, element contents, and fatty acid profiles. Measured values differed greatly between the two harvests, probably owing to different climatic or storage conditions. No direct relation between age of trees or location and oil quality could be established. The analyses indicate that *J. mahafalensis* oil can be used in oil lamps, cooking stoves and stationary combustion engines for electrification or for biodiesel production. However, modifications in storage and extraction methods, as well as further processing steps are necessary to enable its utilization as a straight vegetable oil and feedstock for biodiesel production. If these technical requirements can be met, and if it turns out that *J. mahafalensis* oil is economically competitive in comparison with firewood, charcoal, paraffin and petroleum, it can be considered as a promising feedstock for rural energy supply.

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Introduction

Access to affordable and renewable energy, especially for the rural poor, is increasingly recognized as a key challenge in poverty reduction and rural development in countries of the global South (Nussbaumer et al., 2012; United Nations, 2012; WBGU, 2011). In Madagascar, traditional biomass (firewood, charcoal, animal dung and agricultural residues) represents nearly 80% of all energy resources consumed and is used mainly for cooking, and heating. In semi-arid south-western Madagascar, the use of firewood and charcoal is exerting great pressure on fragile dry deciduous forests (Raoliarivelo et al., 2010). Moreover, indoor air

pollution from the combustion of traditional biomass fuels is causing respiratory illnesses (Bailis et al., 2005; Bruce et al., 2000). Alternative fuels are needed to insure the access of local communities to clean, non-hazardous, and affordable energy for daily life, while fostering sustainable use of forest resources.

Recently, liquid biofuel were identified as a possible alternative to traditional biomass energy in developing countries (Amigun et al., 2011; Zah et al., 2011). Feedstock that received particular attention in East Africa include sugar cane, maize, sweet sorghum and cassava for bio-ethanol production, as well as *J. curcas*, croton, castor and sunflower for straight vegetable oil (SVO) or biodiesel production (ODI, 2011). SVO has potential for rural energy supply, as rural communities can produce it without sophisticated equipment. However, there are still open questions about possible social, economic, and environmental impacts of SVO production (GTZ, 2009; ODI, 2011; Wahl et al., 2009).

While researchers regularly address these questions with regard to *J. curcas* Linn. (e.g. Ehrensperger et al., 2012; Jongschaap et al., 2007; Messemaker, 2008; Openshaw, 2000), *Jatropha mahafalensis*

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Jum. & H. Perrier, an endemic species representative of the *Jatropha* genus in Madagascar, has so far received very little attention. Recent research on *J. mahafalensis* focused on the alleged ability of this plant to inhibit the malaria pathogen *Plasmodium falciparum* based on the presence of cyclic heptapeptides in its latex (Baraguey et al., 2001; Nayak and Patel, 2009), but only few sources describe the plant from a botanical point of view (e.g. Radcliffe-Smith, 1997), and virtually nothing is known about its potentials and limitations as a biofuel feedstock.

The main goal of this study is to contribute to a better understanding of the potential of *J. mahafalensis* as a feedstock for liquid biofuel. This paper focuses on:

- (1) the assessment of oil content in *J. mahafalensis* seeds
- (2) the analysis of the quality of this oil
- (3) assessing the influence of location, plant age and harvesting season on oil content and quality.

Findings from this study help answer the question whether *J. mahafalensis* oil, similar to *J. curcas* oil, can be envisaged as a liquid biofuel from a technical point of view. The study does not venture into development and implementation questions. These will be addressed in a separate paper focusing on the economic feasibility, in the same study area, of a rural energy supply strategy based on the substitution of firewood, paraffin and kerosene with *J. mahafalensis* oil and press-cake.

Material and methods

Study area

The study was conducted on seed material collected in the village area of Soalara, in Toliara II district (Fig. 1). This area is semi-arid and receives around 420 mm of annual rainfall, two thirds of which fall during one rainy season from December to February (Raoliarivelo et al., 2010). The landscape in the Soalara area is characterized by a sandy coastal area in the west and a calcareous plateau in the east; a steep escarpment separates the two areas. The inhabitants of Soalara base their livelihoods mainly on fishing, breeding small ruminants, some farming, and charcoal production. Livestock herders commonly use agave and cactus fences to corral animals (Fig. 1) or,

conversely, to keep them off the fields. Replacing part of these fences with *J. mahafalensis* fences was identified as an option to produce liquid biofuel for local consumption without increasing pressure on land resources.

Sampling

Samples of *J. mahafalensis* seeds were collected in Soalara in February and September of 2011, during the plant's fructification period. The seeds were packed in paper and stored for about one month in a dry and well-aerated room. Samples were divided into 4 groups according to Table 1, in order to take into account the possible effects of plant age and location on oil content and quality.

As no record of the exact age of plants was available, a more precise differentiation was not possible and field researchers had to rely on estimates.

Oil extraction

The oil was extracted from the seeds at the University of Antananarivo using solvents according to the AFNOR NF V 03-905 norm. This method allows extracting close to 99% of the total oil content of crushed seeds. The extracted oil was shipped to Austria for further analysis. Oil samples were categorized into the above-mentioned groups (I, II, III, IV; see Table 1). Each sample consisted of a mixture from several trees belonging to the same category.

Oil quality analyses

A number of oil quality parameters were analyzed according to the respective standards. Laboratory testing included determination of parameters using the methods listed in Table 2.

Data analysis

Kruskal–Wallis and Mann–Whitney nonparametric tests (Xlstat 2008; Addinsoft) were used to analyze variations in mean oil content between sample groups (combination of plant location and age) and

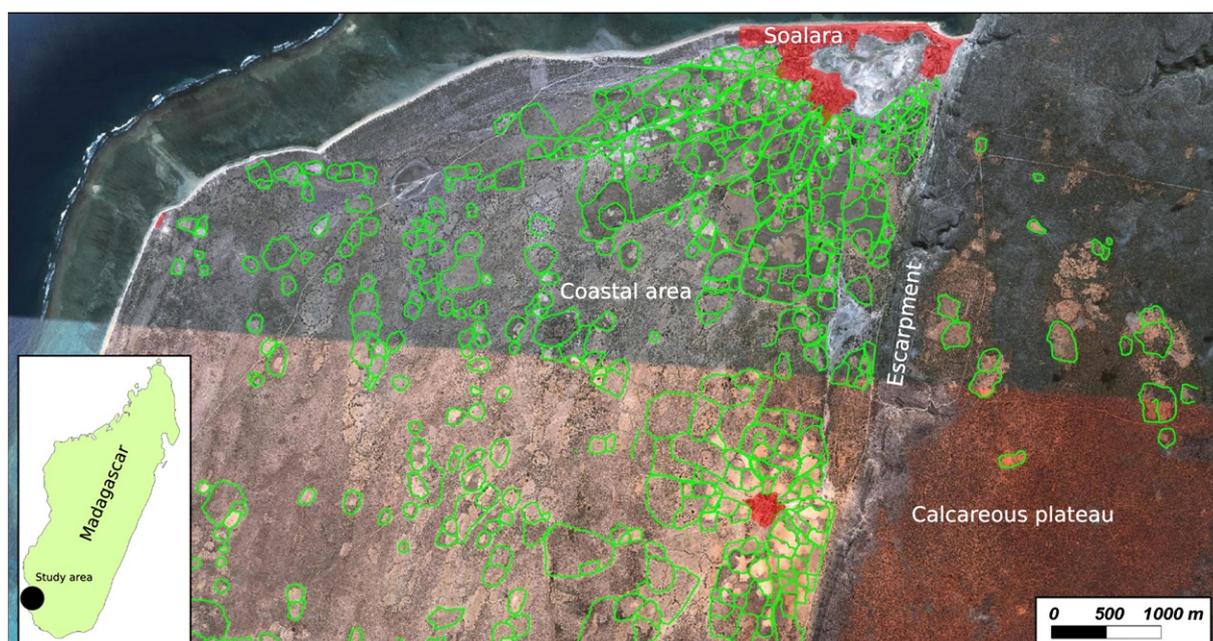


Fig. 1. Study area in Madagascar. Overview of the study area, with Soalara village in the north, the coastal area in the west and the calcareous plateau in the east. The green lines designate existing fences, consisting mainly of agave and cactus, which were digitized in the context of this study.

Table 1
Sample origin and characterization.

Group	Location	Plant age	February 2011	September 2011
I	Coastal area	<10 years	14 plants	15 plants
II	Coastal area	≥10 years	11 plants	7 plants
III	Calcareous plateau	<10 years	19 plants	3 plants
IV	Calcareous plateau	≥10 years	10 plants	5 plants
Total			54 plants	30 plants

between seasons, respectively. Only results with $p < 0.01$ were considered statistically significant.

Results

J. mahafalensis oil content

Oil content results (Table 3) were grouped according to plant location (coastal area [I, II] or calcareous plateau [III, IV]); age group of the plants (younger than 10 years [I, III], or 10 years and older [II, IV]); and harvesting season (February 2011 or September 2011). Oil was extracted from a total of 84 seed samples (54 in February and 30 in September). Mean oil contents in the various seed sample groups ranged from around 36% in February up to 55% in September. They did not vary significantly between groups and harvest seasons ($p > 0.01$; Table 3). Oil content is expressed as [weight percent] of the air-dried seeds.

J. mahafalensis oil quality

Results of the *J. mahafalensis* oil analyses are shown in Tables 4–6 for the four sample groups (as described in Table 1) and for both harvests (February and September 2011). The averages of density [kg/m^3], viscosity [mm^2/s], water content [mg/kg], acid value [$\text{mg KOH}/\text{g}$], and oxidation stability [h] are shown in Table 4. Average oil densities and viscosities were slightly higher for the February than for the September samples. February sample IV had an unrealistically high water content, probably due to water absorption during storage. Mean water content for the February samples was 680 mg/kg, or 557 mg/kg without that outlier, and for the September samples it was 410 mg/kg. For the February samples, acid values ranged from 7.6 to 36.4 mg KOH/g, whereas the range for the September samples was 0.7 to 3.9 mg KOH/g. Mean oxidation stability was 9.3 h for the February samples and 16.9 h for the September samples.

Table 5 shows the oil samples' element contents. At an average of 85.8 mg/kg, potassium content was higher in the February samples than in the September samples (26.7 mg/kg). A definite value could not be determined for February sample IV, as its potassium content was higher than 190 mg/kg. Mean sodium content for the February samples was 7.3 mg/kg, compared to 2.2 mg/kg for the September samples. Sulfur content was below the limit of detection for the February samples, while the average for the September samples was

Table 2
Oil quality parameters determined and respective methods used.

Parameter	Unit	Method
Density	[kg/m^3]	EN 12185
Kinematic viscosity	[mm^2/s]	ASTM D 7042
Water content	[mg/kg]	ISO 12937
Acid value	[$\text{mg KOH}/\text{g}$]	EN 14104
Oxidation stability	[h]	EN 14112
Element contents	[mg/kg]	EN 14107 (P) EN 14538 (K, Na, Ca, Mg) Internal method (S)
Fatty acid distribution	[%]	EN 14103
Iodine value	[$\text{g I}_2/100 \text{ g}$]	Annex B of EN 14214

Table 3
Mean oil content [weight %] of air dried seed samples.

Group	Feb 2011 Mean oil content [weight %]	Sep 2011 Mean oil content [weight %]	p between seasons
I	36.55	45.26	>0.01
II	35.45	51.96	>0.01
III	36.36	55.27	>0.01
IV	36.44	39.19	>0.01
p	>0.01	>0.01	

1.5 mg/kg. A definite phosphorus content value could not be determined for any of the samples; it was above 300 mg/kg for the February samples and above 100 mg/kg for the September samples. Mean magnesium content for the February and September samples was 72.8 and 12.7 mg/kg, respectively. Calcium content in the February samples exceeded 128 mg/kg, and mean calcium content in the September samples was 26.4 mg/kg.

Table 6 shows the fatty acid distribution and the calculated iodine value for the oil samples in detail. The following fatty acids are represented: C 16:0 (palmitic acid), C 16:1 (palmitoleic acid), C 18:0 (stearic acid), C 18:1 (oleic acid), C 18:2 (linoleic acid), C 18:3 (α -linolenic acid) and C 20:0 (arachidic acid). The fatty acid distributions in the February and September samples were quite similar; for both seasons, the main fatty acids were C 18:1 (total average 28.9%) and C 18:2 (total average 47.3%). C 16:0 was represented with 13.8% and C 18:0 with 9.4%. C 16:1, C 18:3, and C 20:0 each accounted for less than 0.5% of the overall fatty acid content. The calculated iodine value ranged between 105 and 110 g $\text{I}_2/100 \text{ g}$ oil as a result of the high C 18:2 content.

Discussion

J. mahafalensis oil content

Location and age do not significantly influence oil content ($p > 0.01$). Mean oil content was higher in September than in February; this might be explained by the aridity prevailing during that time of the year. Oil content in the seeds of the more popular *J. curcas* is reported to range roughly between 25% and 40%, depending on genetic expression (Henning, 2000; Jongschaap et al., 2007; Pant et al., 2006; Rathbauer et al., 2012). With values ranging from roughly 35% to 55% and mean values between 36% and 52%, the sampled seeds are comparable to high-oil content *J. curcas* accessions. However, no literature sources were found

Table 4
Properties of *Jatropha mahafalensis* oil samples.

Sample	Density [kg/m^3]	Viscosity [mm^2/s]	Water content [mg/kg]	Acid value [$\text{mg KOH}/\text{g}$]	Oxidation stability [h]
<i>Feb 2011</i>					
I	916.3	28.88	520	7.57	10.7
II	916.3	28.79	590	10.84	10.5
III	913.9	26.71	560	20.88	8.7
IV	910.4	23.93	1050 ^a	36.40	7.1
Mean, Feb 2011	914.2	27.1	680 (557 ^b)	n.a. ^c	9.3
SD [%]	0.2%	6.7%	28.3% (4.5% ^b)	n.a.	14.2%
<i>Sep 2011</i>					
I	904.1	20.80	370	0.90	17.1
II	902.5	20.02	390	0.98	16.6
III	887.6	13.83	540	3.94	17.3
IV	888.4	13.75	340	0.72	16.6
Mean, Sep 2011	895.7	17.1	410	n.a.	16.9
SD ^d [%]	0.8%	17.4%	16.8%	n.a.	1.6%

^a Unrealistic value, probably caused by water absorption during storage.

^b Average value including only samples I to III.

^c Not applicable.

^d Standard deviation.

Table 5
Element contents in *Jatropha mahafalensis* oil samples.

Sample	K [mg/kg]	Na [mg/kg]	S [mg/kg]	P [mg/kg]	Mg [mg/kg]	Ca [mg/kg]
<i>Feb 2011</i>						
I	75.1	4.7	<LOD ^a	>300	67.6	>131
II	69.3	5.8	<LOD	>300	70.2	>128
III	112.9	7.7	<LOD	>300	71.5	>138
IV	>190	10.9	<LOD	>300	81.4	>150
Mean, Feb 2011	85.8	7.3			72.8	
<i>Sep 2011</i>						
I	21.2	1.8	1.5	>100	11.2	21.0
II	22.7	1.8	1.7	>100	12.5	24.7
III	41.1	3.8	1.3	>100	15.9	39.8
IV	21.6	1.4	1.5	>100	11.0	19.9
Mean, Sep 2011	26.7	2.2	1.5		12.7	26.4

^a Less than limit of detection.

that could have confirmed or contradicted these oil content values for *J. mahafalensis*, hence additional analyses might be needed to strengthen the database.

J. mahafalensis oil quality

No causal relation could be established between the location (coastal area or calcareous plateau) or age (<10 years or ≥10 years) of *J. mahafalensis* plants and the quality of their oil – as was the case for oil content, as well. In contrast, the time of harvesting seems to have a significant influence on oil quality, as the values for February 2011 differ markedly from those for September 2011. In particular, the February samples have higher element contents and acid values (7.5 to 36 mg KOH/g, compared to 0.7 to 3.9 mg KOH/g for September). These differences are either caused by climatic conditions during the growing period or by storage conditions. Prolonged storage at high temperatures can reduce oil quality; moreover, the high contents of unsaturated fatty acids such as linoleic and oleic acids accelerate rancidity.

Fatty acid distribution is very similar in all samples. Like in *J. curcas*, the highest proportions of fatty acids in *J. mahafalensis* oil are those of C 18:1 and C 18:2. But unlike *J. curcas*, *J. mahafalensis* contains more C 18:2 (47.3%) than C 18:1 (28.9%). Rathbauer et al. (2012) analyzed *J. curcas* oil from Mali; in their samples, the fatty acid shares of C 18:1 and C 18:2 were both 35%. In *J. curcas* oil samples from Malaysia, Thailand, and Indonesia, Emil et al. (2010) found fatty acid shares of 45% for C 18:1 and 32% for C 18:2. Of all vegetable oils considered for energy supply, rapeseed oil has the highest proportion of C 18:1 (60%), with a C 18:2 value of 20% (Dubois et al., 2007)

Table 6
Fatty acid distribution and iodine value in *Jatropha mahafalensis* oil samples.

Sample	C 16:0 ^a [%]	C 16:1 [%]	C 18:0 [%]	C 18:1 [%]	C 18:2 [%]	C 18:3 [%]	C 20:0 [%]	Iodine val _{cal} [g I ₂ /100 g]
<i>Feb 2011</i>								
I	13.70	<LOD ^b	9.08	28.72	48.00	<LOD	0.50	108
II	13.98	<LOD	9.35	28.32	47.85	<LOD	0.49	108
III	14.00	<LOD	9.04	27.99	48.47	<LOD	0.49	108
IV	13.54	<LOD	8.76	28.15	49.10	<LOD	0.45	110
<i>Sep 2011</i>								
I	14.13	0.25	9.98	29.75	45.04	0.33	0.51	105
II	13.59	0.25	9.71	30.42	45.23	0.31	0.49	106
III	14.06	0.00	9.36	29.35	46.47	0.33	0.45	107
IV	13.86	0.26	9.56	28.18	47.38	0.30	0.45	107

^a Calibration of the gas chromatograph included the following fatty acids: C 8:0, C 10:0, C 12:0; C 14:0, C 16:0, C 16:1, C 18:0, C 18:1, C 18:2, C 18:3, C 20:0, C 22:0, C 22:1, C 24:0.

^b Less than limit of detection.

High contents of elements such as P, Mg, and Ca as seen in Table 5 might have been caused by the extraction method (solvent extraction); oils that are extracted mechanically have lower contents of these elements. In particular the high phosphorus content poses a problem for further processing to straight vegetable oil or biodiesel. The contained phospholipids could hinder phase separation in the production process. Therefore, mechanically extracted oil should be analyzed as well in order to further assess the suitability of *J. mahafalensis* oil as a fuel.

Table 7 compares the results of this study with *J. curcas* oil and a standard for rapeseed oil. The density of *J. mahafalensis* samples collected in February 2011 is within the common range for vegetable oils. The samples collected in September 2011 have lower densities, averaging 896 kg/m³. Viscosity values are lower than for rapeseed or sunflower oil. Lower viscosity can be an advantage for some applications; for example, it improves oil flow in a combustion engine and also makes the oil easier to use in lamps. Compared to *J. curcas* oil and the rapeseed oil standard, the average water content in *J. mahafalensis* oil is very low (545 mg/kg, or 473 mg/kg after removing the outlier value – see Table 4). The acid value and element contents in *J. mahafalensis* oil are much higher than those in the rapeseed oil standard or *J. curcas* oil. Hence, further processing before utilization as fuel in a combustion engine is recommended – in particular filtration or degumming to reduce element contents before use. Oxidation stability and the iodine value are within the standard values for rapeseed oil. Oxidation stability is lower than in *J. curcas* oil, and the iodine value is higher.

Technical suitability of *J. mahafalensis* oil for rural energy supply

In rural areas of Madagascar, energy is used mainly for cooking and lighting. In addition, the powering of stationary engines for off-farm income generation is an interesting development opportunity. Currently, people mainly use firewood, farm residues and charcoal for cooking, paraffin for lighting, and fossil diesel to power generators. The findings of this study show that, from a technical point of view, *J. mahafalensis* has the potential to contribute to rural energy supply. There are, however, a number of technical challenges to be considered.

Lighting. *J. mahafalensis* oil has the advantage of burning slower and with fewer emissions than petroleum. However, due to its high viscosity it is not suitable for use in common kerosene lamps for household lighting. Lamps that include a simple pre-heating device, for example a copper tube around the wick, are needed to reduce oil viscosity before combustion. However, the use of oil in such lamps is a very inefficient way of lighting in comparison with electrical lamps. Simple and inexpensive solar lamps or gravitation lamps might prove to be a better alternative.

Table 7
Comparison of oil quality parameters of *Jatropha mahafalensis*, *Jatropha curcas*, and rapeseed oil standard.

	<i>J. mahafalensis</i> Average	<i>J. curcas</i> Average ^a	Rapeseed oil standard ^b
Density [kg/m ³]	905	n.a. ^c	910.0–925.0
Viscosity [mm ² /s]	22.1	n.a. ^c	≤36.0
Water content [mg/kg]	545	712–730	≤750
Acid value [mg KOH/g]	10.3	6.0–7.6	≤2.0
Oxidation stability [h]	13.1	18.1–19.8	≥6.0
Iodine value [g I ₂ /100 g oil]	107	92.8–94.0	≤125
S [mg/kg]	1.5	1.5–4.0	≤1.0
P [mg/kg]	>100	74.6–86.5	≤3.0
Ca [mg/kg]	26.4	15.6–22.0	≤1.0
Mg [mg/kg]	42.7	16.8–18.9	≤1.0

^a Rathbauer et al. (2012).

^b DIN 51605.

^c Not analyzed.

Cooking. Replacing traditional biomass with straight vegetable oil (SVO) as a cooking fuel has several advantages, the main ones being reduced smoke emissions and reduced pressure on forests. *Jatropha* oil can be used for cooking but requires specially adapted stoves, again due to its high viscosity. Two basic designs are currently available: pressure stoves and wick stoves. Both require frequent cleaning to remove carbon deposits (Brittaine and Lutaladio, 2010). Further research is needed for the development of inexpensive cooking stoves adapted to *Jatropha* oil.

Powering engines. The use of *Jatropha* oil as a feedstock for biodiesel production or as a SVO in combustion engines necessitates further processing, such as filtration or degumming, which can be done at village level, to reduce the element contents. The viscosity of *Jatropha* oil is significantly lower than that of rapeseed or sunflower oil, leading to a better oil flow when used in a combustion engine. Different types of diesel engines (combustion engines, stationary engines) have been successfully powered with purified *J. curcas* oil and diesel blends (e.g. Agarwal and Agarwal, 2007). These existing systems, which can be used for transportation and electrification should be applicable in Madagascar and could be powered with *J. mahafalensis* oil that has undergone the above-mentioned processing steps.

5. Conclusions

The analyses of *J. mahafalensis* oil samples could not establish a direct relation between the location or age of the tree and the oil quality. The time of harvesting seems to have an influence on oil parameters like element contents and acid value — this can be either caused by climatic conditions during the growing period or by storage conditions. Comparing oil quality parameters of *J. mahafalensis* and the standard for rapeseed oil only the element contents and the acid value are not within the range of the standard. Therefore certain modifications or processing steps are required. *J. mahafalensis* oil is suitable for biodiesel production or as a SVO in combustion engines, but filtration or degumming are needed to reduce its element content prior to such use. Provided that these technical challenges can be met, *J. mahafalensis* is a promising feedstock for liquid biofuel production and could therefore contribute to rural energy supply. However, further research is needed to establish whether a rural energy supply system based on *J. mahafalensis* is economically viable and culturally acceptable for poor rural communities. These questions are addressed in a separate study conducted in the same research project (see Acknowledgements below).

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