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FEASIBILITY STUDY ON ENVIRONMENTALLY FRIENDLY PROCESS OF PREMIUM CRUDE PALM OIL PRODUCTION

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ABSTRACT: There are more than 149 small palm oil mill factories in Thailand. They mostly produce low-quality crude palm oil (CPO) with high free fatty acid (6-15% of FFA) and low deterioration of bleachability index (≤2.0 of DOBI). This research investigated the application of microwave technology for the production of premium CPO. In this experiment, the CPO quality from two heating processes was compared. The first process was two-timing palm spikelet heating by microwave, and the second one was one-time heating by microwave and hot air drying. The results showed that two processes could produce the premium CPO with less than 1% of FFA, more than 4 of DOBI, about 500 ppm of carotenoid content, and less than 10 meq.kg^{-1} of peroxide value. The operating times of the first and the second processes were 0.28 and 2.23 h, respectively, compared with 10-15 h using the convention process. In summary, microwave technology could reduce operating time and palm spikelet heating has a high potential process for premium CPO production.

Keywords: Premium crude palm oil, Microwave technology, Small palm oil mill, Low free fatty acid.

1. INTRODUCTION

Palm oil is currently the world's largest vegetable oil consumed for food, followed by soybean and rapeseed oil [1,2]. Thailand is the third largest palm oil producer, and it is inferior to Indonesia and Malaysia. There are about 149 mills in Thailand, and they have the capacity to produce 2.8 million tons of CPO per year. About 0.24 million households across the country are involved in this sector, the majority (79%) of which are smallholders [3]. Half of the mills are small palm oil mills. These had limited knowledge and technology and were unable to produce premium CPO. They can only produce low-quality oil [4], which is the main problem of small palm oil mills in Thailand. This research, therefore, focuses on a study of the feasibility of premium CPO production using microwave technology for a small palm oil mill.

In the conventional palm oil milling process in Thailand, there are large- and small- scales. In large-scale mills, fresh fruit bunches are pretreated under the sterilization process, using steam for wet heat treatment. This process is to deactivate the oil-splitting enzyme, softens the palm fruitlets, and encourages the detachment of fruitlets from bunches [5]. Fruits are stripped to separate the sterilized fruits from the sterilized bunch stalks. Then, loose fruits are screw-pressed for CPO products. The sterilization process produced a large amount of palm oil mill effluent (POME) [6]. Most small-scale mills use dry pretreatment of fresh palm fruits (hot air pretreatment) without a POME problem. However, the disadvantage of the dry process is the lower quality of CPO [4].

Microwave heat treatment for improving CPO has been widely accepted and continually developed [7]. Many kinds of research were studied on the sterilization of palm fruit bunch using a microwave. The results found that the microwave consumed a short time when compared with the sterilized process of the large mill. Microwave heating worked only on the outer layer of the fresh fruit bunch due to the limitation on the penetration to the inner layer of the bunch [8-10]. The microwave sterilization of spikelets without a core of fresh fruit bunch would be a much more efficient and effective process.

The sterilization process by one-time microwave heating and hot air consumes time and low temperature which reduces the destruction of antioxidants and produces high-quality CPO [8]. Therefore, two-time microwave heating was a good alternative for less time consumption and was an environmentally friendly process.

2. RESEARCH SIGNIFICANCE

This research is to study the feasibility of premium CPO production using microwave heating and the comparison between two times heating of palm spikelets by microwave and the one-time

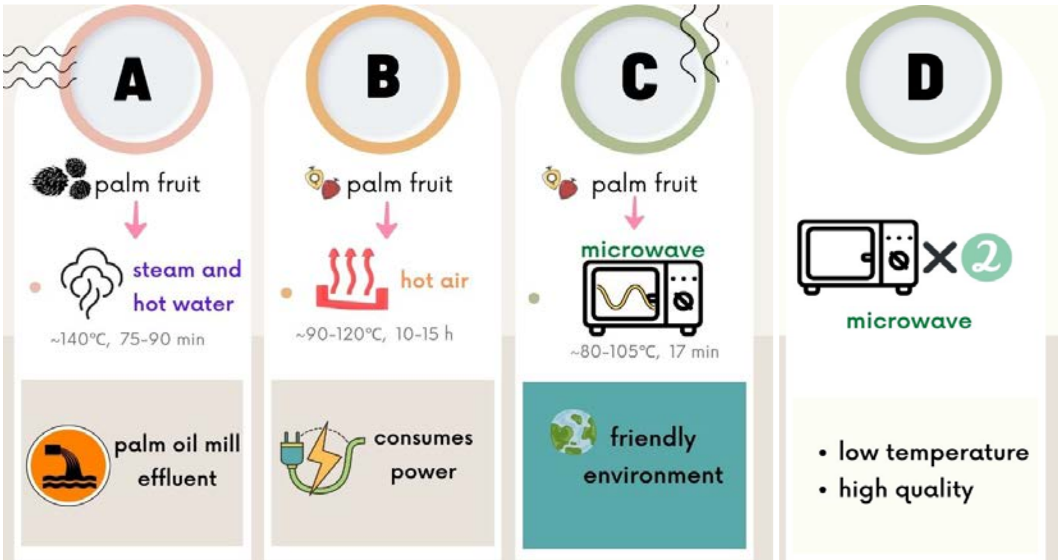

Fig. 1 Typical heat treatment process for crude palm oil production in the large-scale milling process (A), the small-scale milling process (B) and developed process (C and D)

heating by microwave and hot air drying. The optimum conditions were studied, and the quality of premium CPO was measured. This process reduces the problem of the effluent and consumption power conventional processes following in Fig.1. Microwave heating is a friendly environment because it does not require steam or water in the process. The less time and low temperature in the two-time microwave heating process reduced the destruction of anti-oxidants. As a result, premium CPO.

3. MATERIALS AND METHODS

3.1 Materials

Palm fresh bunches were obtained from the Faculty of Agriculture, Kasetsart University, Thailand. Solvents and chemicals were obtained as follows: *n*-hexane (99%), acetic acid, sodium thiosulfate, starch, and hydrochloric acid were purchased from QReC, New Zealand. *n*-hexane (95%) for extraction was purchased from Burdick&Jackson, South Korea. Sodium hydroxide and methanol (95%) were purchased from Merck, Germany. Ethanol (95%) was purchased from the Liquor distillery organization. Potassium hydrogen phthalate, phenolphthalein, potassium iodine, and sodium bicarbonate were purchased from Ajex Finechem, New Zealand. Chloroform was purchased from RCI Labscan Limited, Thailand. Folin-Ciocalteu reagent was purchased from Sisco Research Laboratories, India. Gallic acid was purchased from Sigma-Aldrich.

3.2 Methods

A two-time heating process was carried out as follows: 1) collect palm spikelets from bunches and chop them for the first microwave treatment optimization study, 2) collect fruitlets from spikelets via the first microwave treatment and select the optimum condition with 100% lose fruitless without burning, and 3) divide into 2 groups (one proceeds with the second microwave heating and the other proceeds with hot air drying).

3.2.1 The first microwave pre-heating process for premium CPO production

Palm spikelets were heated by a domestic microwave oven (Samsung, Model MS28H5125BK, 28 liters, 2.4 GH) at medium power intensity (850 W). The duration of heating varied from 2-26 min.

3.2.2 The first and second microwave heating processes for treatment premium CPO production

The fruitlets after the first microwave heating was raw materials for the second microwave heating (two-times microwave heating) and hot air drying processes. In the second process, the fruitlets were heated by microwave at 850 W for 1-5 min. The results were compared by heating the fruitlets in a hot air oven at 90°C for 1-3 hr. The mesocarp was oil extracted by solvent. After that, the CPO has analyzed the physical and chemical properties. After the second microwave heating or hot air drying process, the temperature of the mesocarp was measured five times and CPO was extracted by the solvent extraction. The oil was collected for chemical analysis. The overall experiment is shown in Fig.2.

Then the physical properties of the palm were measured after heat treatment processes as temperature (T), moisture content (MC), oil content (OC), and characteristics of mesocarp and kernel palm fruit.

3.3 Analysis of Palm Oil Properties

3.3.1 Determination of free fatty acid content (FFA)

The FFA content of the oil sample was measured by dissolving the oil in 95% ethanol and titrated with 0.1 N sodium hydroxide solution using a phenolphthalein indicator. The FFA content is calculated by following Eq. (1).

$$\text{FFA}\ (\%) = \frac{(S - B) \times N \times 25.6}{W} \qquad (1)$$

Where S is the volume of sodium hydroxide solution for oil titration, B is the volume of sodium hydroxide solution for blank titration, N is the concentration of sodium hydroxide, and W is the weight of oil.

3.3.2 Determination of Deterioration of Bleachability Index (DOBI)

DOBI was determined using the MPOB test method (2004). DOBI is defined as the ratio of the spectrometric absorbance at 446 nm and 269 nm. 0.1 g of oil sample was weighed in 25 mL of volumetric flask and dissolved with hexane. The sample solution was measured at the absorbance of 269 and 446 nm using UV-VIS spectrophotometer. The value of DOBI is calculated by following Eq. (2).

$$\text{DOBI} = \frac{\text{Absorbance at 446 nm}}{\text{Absorbance at 269 nm}} \qquad (2)$$

3.3.3 Determination of carotene content (CC)

Carotene content was carried out using MPOB test method (2004). 0.1 g of oil sample was dissolved with n-hexane in a 25 mL volumetric flask. The absorbance reading of the solution at 446 nm was taken using UV-VIS spectrophotometer. The carotene content is calculated as Eq. (3).

$$\text{Carotene content (mg.kg}^{-1}) = \frac{383\,(A)(V)}{100(W)} \qquad (3)$$

Where A is the absorbance at 446 nm, V is the volume of the oil solution, and W is the weight of the oil sample.

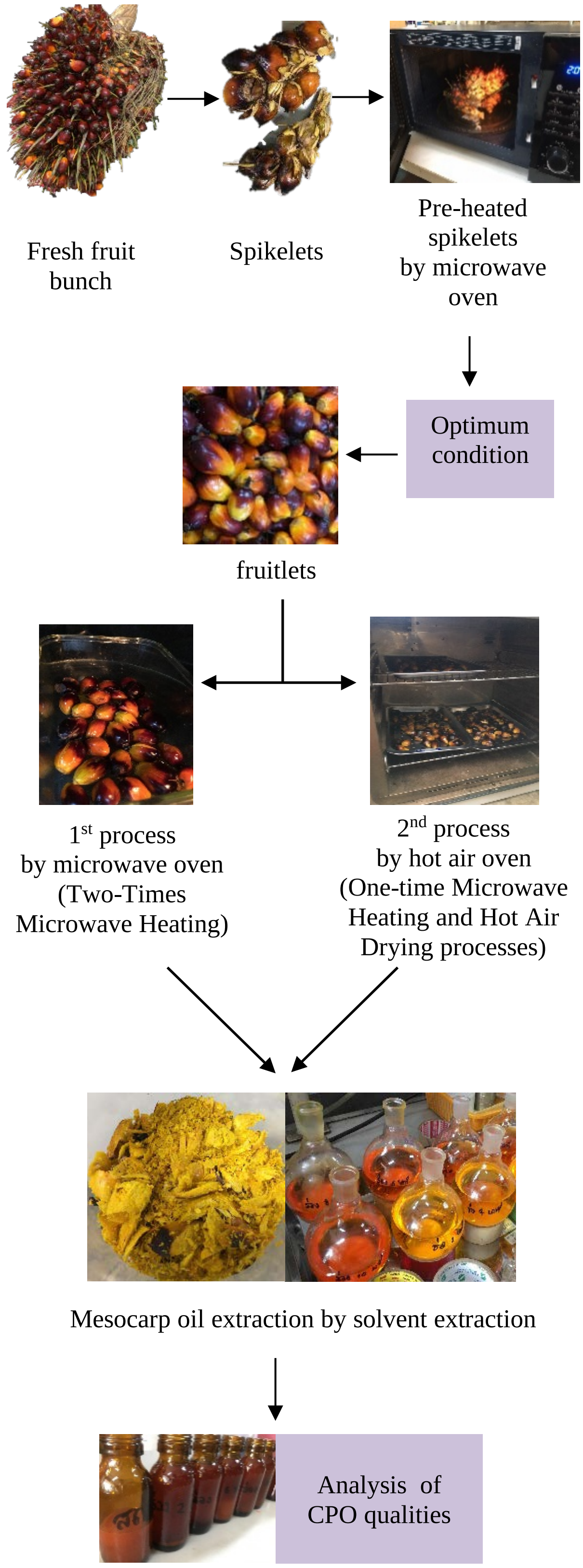

Fig. 2 The experimental diagram for premium CPO production

3.3.4 Determination of peroxide value (PV)

5 g of oil sample was dissolved in a 30 mL mixture of acetic acid and chloroform, then 0.5 mL of saturated potassium iodide solution was added and the solution was shaken. After that, 30 mL of water was added and shaken vigorously to liberate iodine from the organic layer to the aqueous layer. Iodine was titrated with a 0.1 N sodium thiosulphate solution using a starch indicator. A blank determination was made using the same procedure without the oil sample. PV was calculated using Eq. (4).

$$PV = \frac{(X-Y)\times C \times 1000}{g} \quad (4)$$

Where X is the volume of sodium thiosulphate used to titrate with the oil sample, Y is the volume of sodium thiosulphate used to titrate with blank, C is the concentration of sodium thiosulphate, and g is the weight of oil.

3.3.5 Determination of total phenolic content (TPC)

Total phenolic content was determined using the Folin-Ciocalteau colorimetric method by Wolf [11]. Gallic acid (GA) was the standard for the standard curve constructed by a range of concentrations dissolved with the solvent. The equation was obtained, total phenolic content of the CPO as GA equivalent per gram of oil extract (mg GAE/ 100 g oil).

3.3.6 Determination of 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity

DPPH analysis is the method for evaluating antioxidant activity in oil. DPPH scavenging activity was determined using a modified method of Yingngam and Chooklin [12,13]. Different concentrations of sample dilution (0.3 mL) were mixed with 1.5 mL of 0.1 mM ethanolic DPPH solution. The resulting mixture was kept in the dark for 30 min and measured absorbance by UV-Vis spectrophotometer at 517 nm. The percentage of free radical inhibition of the palm oil was calculated according to the following Eq. (5).

Fig. 3 The characteristic of palm fruit after 14 min of microwave pre-heating

$$\text{Inhibition (\%)} = \left[\frac{A_0-(A_1-A_2)}{A_0}\right] \times 100 \quad (5)$$

Where, A_0 is the absorbance of ethanol and DPPH mixed, A_1 is the absorbance of standard and DPPH mixed and A_2 is the absorbance of standard and ethanol mixed. Inhibition (%) was used to plot the standard curve. The equation was obtained DPPH antioxidant activity on µg Trolox/g CPO.

4. RESULTS AND DISCUSSIONS

4.1 Spikelets pre-heating by microwave heat treatment

Table 1 shows the physical properties of palm spikelet after microwave heating. The criteria for optimum condition of the first microwave heating was completely losing palm fruit and having CPO high quality (FFA<4%, PV<10). The results found that 14 min of heating showed 100% fruitless. The characteristic of palm fruit was good physical.

Table 1 Physical properties of palm after microwave pre-heating

Heating duration (min)	T (°C)	MC (%)	OC (%)	fruitlets (%)	Condition	
					Mesocarp	Kernel
2	51.74	38.20	72.47	0.02	no changes	white
8	84.06	27.80	75.37	58.41	no changes	white
14	89.14	17.32	76.17	100.00	slightly soft	white
20	100.76	13.04	76.76	100.00	slightly soft	white
26	108.34	6.68	78.55	100.00	oily and soft	white

Mesocarp was slightly soft and the kernel was white following in Fig.3, which whole palm fruit could produce crude palm oil and crude palm kernel oil. The temperature of palm fruit at 14 min was 89.14°C, which the temperature was more than 90°C affecting carotenoids degradation [14]. So, the optimum condition for the first microwave heating was 14 min of heating duration. The cause of loosing fruitlets by the microwave heating could replace the steam heating and dielectric properties of the materials. Water in materials was a major absorber of microwave energy. The generated microwave is distributed and absorbed by the component leading to the temperature rise. Consequently, palm spikelets received fast heating in the kernel and mesocarp [8]. Although 26 min of heating duration gave 6.68% of the moisture content (MC) and complete fruitlet which the MC was optimum condition for oil production by screw press. The temperature was 108.34°C affecting antioxidant degradation which this condition gave lower TPC (Table 2). The MC of the mesocarp was decreased rapidly with higher heating time because the water was rapidly evaporated from inside to outside of palm fruits. Moreover, overheating of microwaves has an effect on the destruction of the physical structure, especially oil cell rupture, as well as the effect on oil content (OC) [14,15].

Heat penetration is the key factor in palm sterilization via microwave heating. Notably, the qualities of palm spikelet oil after microwave heating are shown in Table 2. At the optimum pre-heating, DOBI, peroxide value, and FFA were 3.89, 3.28 $mg.kg^{-1}$, and 0.60% respectively. The result showed that the CPO met the premium palm oil standard. FFA was reduced by microwave heating because the lipase enzyme induced the hydrolysis reaction of triglyceride to generate the FFA with inactivated by microwave [4, 6]. The result of carotene content, peroxide value and total phenolic contents were slightly reduced due to the deterioration of palm oil from high heating [8].

Table 2 The qualities of palm spikelet oil after microwave pre-heating

Heating duration (min)	DOBI	PV ($mg.kg^{-1}$)	FFA (%)	TPC (mg.GAE/100 g)
2	2.97	1.97	10.97	20.21
8	3.72	2.63	1.44	18.45
14	3.89	3.28	0.60	16.45
20	3.58	3.60	0.51	16.19
26	3.88	4.35	0.43	14.91

The advantage of spikelet pre-treating by microwave was reducing 1% of FFA without chemicals when compared with the conventional process. The main problem of community palm oil mills is high FFA content. In CPO production, FFA reduction was performed by neutralizing with alkaline chemicals. Using microwave heating, the activity of the lipase enzyme was stopped, and reversed reaction of hydrolysis to produce oil content was interrupted, leading to the low FFA [14].

4.2 The Two-times Microwave Heating Processes compared with the One-time Microwave Heating and Hot Air Drying processes

Table 3 shows the conditions of palm fruitlets after two-times heating by microwave and the one-

Table 3 The condition of palm fruitlets after Two-times heating by microwave for treatment premium CPO production

Microwave Heating					
Heating duration (min)	T (°C)	MC (%)	OC (%)	Condition of the heated fruitlets	
				Mesocarp	Kernel
1	69.82	16.74	76.46	slightly soft	white
2	98.76	11.94	77.20	slightly soft	white
3	105.58	7.43	78.29	slightly soft	white
4	109.04	4.53	78.19	partially dry	slightly brown
5	120.50	1.43	78.83	dry and stiff	completely brown

Table 4 The condition of palm fruitlets after One-time Microwave Heating and hot air drying for treatment premium CPO production

Hot Air Heating					
Heating duration (h)	T (°C)	MC (%)	OC (%)	Condition of the heated fruitlets	
				Mesocarp	Kernel
1.00	57.08	13.77	75.60	slightly soft	white
1.50	66.34	9.88	76.38	slightly soft	white
2.00	70.52	7.69	76.66	slightly soft	white
2.50	72.84	7.29	77.76	slightly soft	white
3.00	78.14	5.53	78.74	slightly soft	white

time microwave heating and hot air drying processes shown in Table 4.

When comparing both processes, the temperature increase was proportional to the heating duration of microwave and hot air. The optimum microwave heating duration of palm fruitlets was determined to be 3 min of microwave heating, compared with 2.0 h of hot air heating. The physical characteristic of the fruitlet was slightly soft of mesocarp and white of kernel, and not burning [6]. In the first process, temperature sharply increased, leading to low MC and high OC, which is a positive effect on the quality of the oil.

The qualities of CPO after microwave and hot air processes are shown in Table 5. The results from the first process presented the premium CPO at 3 min of heating duration. This condition gave 4.80 of DOBI, 544.22 mg.kg^{-1} of CC, 9.24 meq.kg^{-1} of PV, and 0.29% of FFA which the results were supported high potential of microwave technology for premium CPO production. After 3 min of heating, the temperature of palm fruit was more than 100°C, indicating the destruction of the physical structure, and oil cell rupture of the mesocarp [14,15]. The antioxidants of CPO had reported that the hexane extraction mechanism gave high concentrations of vitamin E and carotene from mesocarp fiber [6]

Table 5 The qualities of crude palm oil after two times heating by microwave (first process) and hot air (second process) at various of heating duration

Two-times Microwave Heating Processes					One-time Microwave Heating and Hot Air Drying processes				
Heating duration (min)	DOBI	CC (mg.kg^{-1})	PV (meq.kg^{-1})	FFA (%)	Heating Duration (h)	DOBI	CC (mg.kg^{-1})	PV (meq.kg^{-1})	FFA (%)
1	4.15	444.90	15.21	0.47	1.00	3.66	487.04	5.58	0.48
2	4.14	458.58	15.11	0.36	1.50	3.71	457.36	5.80	0.48
3	4.80	544.22	9.24	0.29	2.00	4.42	521.17	5.86	0.51
4	3.96	521.36	8.37	0.27	2.50	5.09	509.06	7.35	0.60
5	3.73	531.89	6.50	0.26	3.00	4.49	521.35	7.05	0.87
Limit	>4.00	500-700	<10.00	<1.00	Limit	>4.00	500-700	<10.00	<1.00

Note: Limit – the trending specifications limit of crude palm oil (CPO) which is an antioxidant to encourage protection of the oil from oxidation reaction [8]. Correspondingly, total phenolic contents indicated that the oil has antioxidants. From experiment found that the value of TPC and DPPH has similar trending.

The result indicated the qualities of crude palm oil after two times heating by microwave (first process). This is within the limit of crude palm oil. Especially the very low FFA value allows the oil to be stored for a long time. Although premium grade palm oil should have a very high carotene value. But the oil produced is not high value. It also depends on the raw material.

Table 6 shows the result of TPC and antioxidative activity by the DPPH method for two-times microwave heating process. Decreased TPC and DPPH when heating duration was increased. The optimum condition at 3 min of microwave heating duration is 12.23 mg.GAE/100 g of TPC and 20.0 μg Trolox/g CPO of DPPH.

The result of TPC and antioxidative activity by DPPH method for one-time microwave heating and hot air drying processes is show in Table 7. The optimum condition at 2.00 h of Hot Air Heating duration is 13.05 mg.GAE/100 g of TPC and 20.8 μg Trolox/g CPO of DPPH. This process was higher antioxidant more than the microwave process. Due to the temperature below 80℃ on process is not destroy antioxidants.

Both processes had slightly decreased TPC and DPPH when the heating duration was increased. Oxidation-reduction in the oil could be reducing TPC and DPPH. The two-high temperature and long heating duration could reflect the deterioration in the CPO. Decreasing of antioxidants indicated that the oil was less protected against oxidation which the CPO deteriorated [8]. Although, both processes provided similar antioxidative values but hot air heating consumed a long time for premium CPO production. Thus, the two-time microwave heating process was less time and had better CPO quality compared with the one-time microwave heating and hot-air drying process.

Table 6 Total phenolic content and anti-oxidative activity by DPPH method of the CPO from two-times microwave heating process

Microwave Heating Treatment		
Heating duration (min)	TPC (mg.GAE/100 g)	DPPH (μg Trolox/g CPO)
1	15.17	22.3
2	12.55	21.6
3	12.23	20.0
4	12.40	19.5
5	12.92	18.8

Table 7 Total phenolic content and anti-oxidative activity by DPPH method of the CPO from one-time microwave heating and hot air drying processes

Hot Air Heating Treatment		
Heating duration (h)	TPC (mg.GAE/100 g)	DPPH (μg Trolox/g CPO)
1.00	14.93	22.5
1.50	13.26	21.6
2.00	13.05	20.8
2.50	12.91	17.4
3.00	11.11	16.9

5. CONCLUSION

Microwaves had a high potential for premium CPO production. The optimum conditions were 14 min for the first microwave heating and 3 min for the second microwave heating. The important point of oil palm pretreatment by microwave was short operated time for protection of oil deterioration. All results of the experiment supported that microwave technology was an environmentally friendly process and can improve the oil quality.

6. ACKNOWLEDGMENTS

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