International Food Research Journal 24(3): 1110-1116 (June 2017)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effect of pre-frying drying on mass transfer kinetics of taro slices during deep fat frying

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Article history

Received: 12 June 2015
Received in revised form: 15 May 2016
Accepted: 3 June 2016

Keywords

Taro slices
Mass transfer
Kinetics
Frying
Pre-frying drying

Abstract

The effect of pre-frying drying on mass transfer kinetics (moisture loss and oil uptake) of taro slices during frying was investigated. Pre-frying drying time significantly reduced ($P<0.05$) the moisture content and oil uptake of fried taro slices. The exponential models were best fitted to the data for moisture loss and oil uptake during frying process. The moisture and oil transfer coefficient were found in the range of 0.0489 - 0.0395 s^{-1} and 0.0519 - 0.0388 s^{-1} respectively during frying of slices, which were pre-dried in the range of 0-240 min. The textural property, breaking strength of the samples varied from 276 to 438g force for different pre-frying drying time. The pre-frying dried slices initially showed a rapid increase in L^*, a^*, b^* value during the frying process. Sensory data revealed that the pre-frying drying up to 40 min yielded the product with acceptable sensory attributes.

Introduction

Deep fat frying is a process of simultaneous heat and mass transfer in which heat is transferred from the oil to the food that leads to moisture transfer in the form of vapors and the fat is absorbed by the food. The process remains a complex operation because of the two mass transfers in opposite directions within the material being fried. A number of physical and chemical changes occur during frying starting with dehydration to cooking, starch gelatinization, protein denaturation, aromatizing, and coloring via Maillard reactions and finally oil uptake. In recent years, consumers are health conscious and they like to consume low fat products without compromising on the texture (Dar *et al.*, 2014). Therefore, the major challenge for the food industry is to produce low fat fried product with desirable texture, color and flavor.

There are several studies reported that has been concentrated on approaches to reduce oil absorption in fried products. Initial solid content in the product to be fried is a critical factor that influences the oil uptake during frying (Song *et al.*, 2007). Increasing the solid content by Pre-frying drying using hot air in potato chips/French fries (Krokida *et al.*, 2001), chick pea flour based snacks (Debnath *et al.*, 2003) vacuum microwave in potato chips (Song *et al.*, 2007) has been reported for the production of low fat fried products.

Taro *(Colocasia esculenta)* is a tuber crop of high food value in many countries of the tropical area of the world. It is low in fat (0.5-1.2%) and protein, but is a good source of starch 70-80% and minerals (1.6-5.5%) especially magnesium, calcium and potassium. The starch quality is unique with small granules size (1-5 μm) due to which it is highly digestible and useful for the preparation of weaning foods (Kaushal *et al.*, 2012). Tuber is highly perishable primarily due to the presence of high moisture content. Research has been conducted with an aim to minimize their post harvest losses and enhance their utility in many processed foods. The utilization of taro flour has been reported by different researchers (Njintang and Mbofung, 2003; Aboubakar, 2008) in processed foods like biscuits (Himeda *et al.*, 2014), cookies (Nip *et al.*, 1994), bread (Ammar *et al.*, 2009; Emmanuel *et al.*, 2010), noodles (Kaushal and Sharma, 2013) and achu (Njintang *et al.*, 2007). However, the fried product of taro and their behavior during frying is not reported in the literature. The present study was therefore carried out to determine the effect of pre-frying drying on mass transfer kinetics of taro slices during frying.

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Materials and Methods

Materials

Raw taro corms (commercial variety) were procured from local market of Kanpur, Uttar Pradesh, India. They were stored in a refrigerator at 10±0.5^{0}C until used. Sunflower refined oil (Ruchi Soya Industries Ltd., Mumbai, India) was used as a frying medium for different experiments. Food grade NaCl was used for preparing the solution to cook the taro slices. Fresh lemons were purchased from the local market and used to maintain the pH of cooking solution.

Preparations of taro slices

Taro corms were thoroughly washed with clean water and examined to ensure that they were free from disease or any type of injury. After cleaning and peeling, samples were cut into slices of 2 mm thickness. All the slices were immersed into water for 2 hrs and then cooked at 100±0.5^{0}C into acidic salt solution (pH 4.0, NaCl, 0.25%) for 15 min to minimize acridity of taro slices. Cooked slices were blotted with paper towel to eliminate loose surface moisture prior to drying.

Pre-frying drying of taro slices

Cooked taro slices were dried in a laboratory hot air oven at a temperature of 60±1.0ºC. To examine the effect of pre-frying drying time on the mass transfer kinetics during frying, the slices were drawn from the drier at regular interval of time of 20, 40, 60, 90, 130, 180 and 240 min. These slices were cooled at room temperature and used for frying.

Deep fat frying of taro slices

Deep fat frying was carried out in an electric deep fryer (Model no. 3215, Usha International Ltd., Haryana, India) having temperature precision of ±10C. The fryer was filled with two liter of refined sunflower oil. Fresh oil was used for each batch. The temperature of oil was maintained using thermostat and monitored with a digital temperature indicator. The fryer was equipped with a stainless steel mesh basket in which the samples were immersed in the oil and fried. Frying of taro slices, pre-dried for 0, 20, 40, 60, 90, 130, 180 and 240 were carried out at 180ºC for a period of 160, 140, 120, 110, 100, 100, 90 and 80 s respectively. Samples were drawn from the fryer at a regular interval of 10s to study the mass transfer kinetics during frying. Fried taro slices were kept for 2 min on strainer and then 2 min on a blotting paper to remove the surface frying oil.

Moisture and fat content

Moisture content of the samples after frying was estimated using standard method (AOAC, 1990). Fat content of the sample was determined by automatic fat extraction system SOCS PLUS (Model SCS 6 R, Pelican equipments, Chennai, India) by using petroleum ether.

Texture

The hardness of fried taro slices was determined using Texture Analyzer (Model TA-XT PLUS Stable Micro Systems Ltd., Vienna Court, Surrey, UK), equipped with 25 kg load cell. A three-point bending rig (A/3PB), mounted in a Texture Analyzer was used to determine the hardness in terms of breaking strength, which is the force required for breaking the sample. A steel blade of 3 mm thickness with flat edge was used to break the samples at a constant speed rate of 10 mm/s. The maximum force in the plot was considered the breaking strength of the sample. Five replications were performed for each sample.

Color

The color parameters, L^*, a^* and b^* of the fried slices were determined using a Hunter colorflex (Ruston, VA, model 45/0, Ruston, VA, USA). The instrument was standardized each time by using white and black ceramic tiles. The color, L value is a measure of lightness ranging from zero to 100 (zero for black, 100 for white). The color, a value is a measure of greenness/redness ranging from -60 (at the most green end of the scope) and +60 (at the most red end of the scope) and the color, 'b' value is a measure of blueness/yellowness ranging from -60 (blue) to +60 (yellow). Three measurements at different locations on the surfaces of fried slices were conducted for each sample

Sensory quality

The fried samples were evaluated by a semi-trained panel consisting of ten members of faculty and students of the department. The sensory attributes included colour, crispness, taste and overall acceptability were evaluated on a nine-point hedonic scale (Rangana, 1986). Numerical values from 1 to 9 representing 'disliked extremely' and 'liked extremely' respectively were assigned to each attribute on a 9-point scale.

Moisture loss and oil uptake kinetic models

Moisture loss and oil uptake quantities represent the mass transfer taking place during the frying process. The experimental data on moisture content and oil uptake present at any time vs the frying time were fitted to first order exponential models, which were chosen to describe the mass transfer phenomena during frying (Krokida *et al*., 2001).

Moisture kinetic model:

$$(X - X_e)/(X_0 - X_e) = \exp(-K_x * t) \ldots\ldots\ldots\ldots\ldots (1)$$

Oil kinetic model:

$$Y = Y_e\left[1 - \exp\left(-K_y * t\right)\right] \ldots\ldots\ldots\ldots\ldots (2)$$

Where,

X and Y is the moisture and oil content respectively at time t (kg/kg, db)

X_0 and Y_0 is the initial moisture and oil content respectively (kg/kg, db)

X_e and Y_e is the final moisture and oil content respectively (kg/kg, db)

K_x and K_y is the rate constant of moisture loss and oil uptake respectively (s^{-1}).

Mass transfer kinetics during frying process was based on the assumption that taro slices contain uniform moisture content and oil temperature is constant during frying.

Statistical analysis

Experimental data were subjected to analysis of variance at 5 % significance level ($p<0.05$). The model equations were fitted by using statistical software (Datafit 9.0 trial version, Oakdale Engineering Oakdale, PA 15071 USA). The model fitting was evaluated by determining the correlation coefficient (R^2), χ^2 and RMSE at 5 % significance level ($p<0.05$).

Results and Discussion

Effect of pre-frying drying on moisture loss

The moisture content of fresh taro slices was 400±8.6% (d.b.), which was decreased to 11.1±2.8% (d.b.) in 240 min of drying at 60ºC in hot air oven. The pre-fry drying time significantly reduced ($P<0.05$) the moisture content of the taro slices. In the first hour of pre-fry drying, the moisture content of taro slices decreased rapidly and thereafter it decreased slowly, as was expected.

The effect of pre-frying drying time on moisture content of taro slices during frying is shown in Figure 1. The moisture content experimental data are shown by symbols and the values calculated by proposed models (Eq. 1) are shown by continuous lines. The moisture content decreased significantly with increase in frying time with an initial rapid fall in the first 40 s of frying (Figure 1). This rapid fall was decreased with increasing pre-frying drying time probably due to decrease of free moisture of taro slices. The model gave an excellent fit for all experimental data with coefficient of determination (R^2) greater than 0.9632 and χ^2 and RMSE lower than 5.11×10^{-3} and 7.14×10^{-2} respectively (Table 1). The value of moisture transfer coefficient (Kx) decreased (0.04893 - 0.0395 s^{-1}) with the increase in pre-frying drying time (0-240 min). With increase in pre-frying drying time, moisture transfer becomes more parallel to X axis indicating slower moisture transfer rate of taro slices (Figure 1).

Effect of pre-frying drying on oil content

The variation in oil content during frying of taro slices, dried (pre-frying) for different time, 0-240 minutes is shown in Figure 2. During frying, the oil content increased rapidly up to 40 s and thereafter variation in oil content was marginal. Oil content experimental data were fitted to the model (Eq. 2) and model parameters were calculated (Table 1). The model was best fitted in the entire pre-frying drying time with coefficient of determination, (R^2), (0.9686-0.9890), χ^2, (5.76×10^{-4} - 1.95×10^{-3}) and RMSE (2.4×10^{-2} - 4.41×10^{-2}). The oil transfer coefficient was decreased (0.0519 - 0.0388 s^{-1}) with increase of pre-frying drying time. The oil content during frying was significantly ($P<0.5$) decreased with increase in pre-frying drying time. The maximum oil content, 0.413 kg/kg, db was observed in fresh taro slices (pre-frying drying time, 0) during frying, which was higher than the slices pre-dried for 20 min (0.394 kg/kg, db), 40 min (0.367 kg/kg, db), 60 min (0.338 kg/kg, db), 90 min (0.323 kg/kg, db), 130 min (0.264 kg/kg, db), 180 min (0.242 kg/kg, db) and 240 min (0.206 kg/kg, db). A possible reason for the reduction in oil content during frying due to increase in drying time may be due to compactness of the material matrix or increase in the solid content (Krokida *et al.*, 2000). Krokida *et al.* (2000) reported the similar findings on french fries. Gupta *et al.* (2006) also observed considerable reduction in moisture as well as oil content of fried banana with increase in drying time (pre-frying).

Final oil content and residual moisture content during deep fat frying of pre-dried taro slices at 180ºC is shown in Figure 3. The drying time affected the final moisture and oil content during frying. As the drying time of the slices increased, the moisture and oil content both decreased. Pre-fry dried slices for different time showed the different oil uptake rate. The oil uptake was found to increase from an initial value of 0.0 to 0.413 kg/kg (db) and 0.0 to 0.205 kg/kg, db, whereas the moisture content decreased from 4.0 to 0.025 kg/kg, db and 0.111 to 0.019 kg/kg, db of fresh slices (0 min, non-dried) and pre-frying dried slices, for 240 min during frying. The slices, dried

Table 1. Model parameters for moisture and oil transfer during frying of pre-frying dried taro slices for different period of time

Pre-fry drying time (min)	Moisture transfer model parameters				Oil transfer model parameters			
	K_x (s^{-1})	R^2	χ^2	RMSE	K_Y (s^{-1})	R^2	χ^2	RMSE
0	0.0489	0.9935	4.57×10^{-4}	2.14×10^{-2}	0.0519	0.9686	1.95×10^{-3}	4.41×10^{-2}
20	0.0470	0.9981	1.56×10^{-4}	1.25×10^{-2}	0.0493	0.9825	1.24×10^{-3}	3.52×10^{-2}
40	0.0469	0.9997	2.76×10^{-5}	5.30×10^{-3}	0.0452	0.9849	1.21×10^{-3}	3.48×10^{-2}
60	0.0458	0.9989	1.01×10^{-4}	1.01×10^{-2}	0.0448	0.9847	1.29×10^{-3}	3.59×10^{-2}
90	0.0446	0.9962	4.12×10^{-4}	2.03×10^{-2}	0.0442	0.9938	5.76×10^{-4}	2.40×10^{-2}
130	0.0427	0.9902	1.11×10^{-3}	3.33×10^{-2}	0.0438	0.9862	1.29×10^{-3}	3.59×10^{-2}
180	0.0407	0.9878	1.47×10^{-3}	3.84×10^{-2}	0.0401	0.9890	1.08×10^{-3}	3.29×10^{-2}
240	0.0395	0.9632	5.11×10^{-3}	7.14×10^{-2}	0.0388	0.9890	1.14×10^{-3}	3.38×10^{-2}

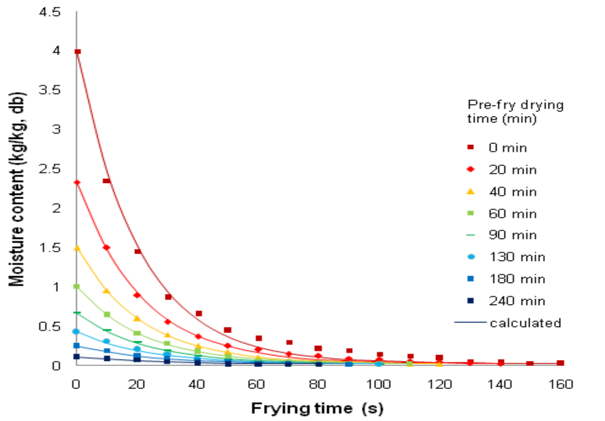

Figure 1. Effect of pre-frying drying time on moisture content during frying of taro slices

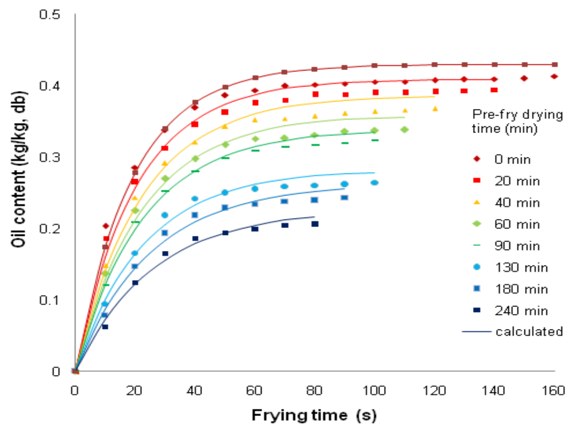

Figure 2. Effect of pre-frying drying time on oil content during frying of taro slices

for longer period of time (>180 min), had slower rate of moisture removal as compared to oil uptake rate during frying. This may be due to lesser amount of moisture available in the slices after drying. Thus, the ratio of oil absorption to moisture loss, for the samples dried for longer time (>180 min), during frying was higher than unity (Figure 3). These results are in agreement with those reported by Debnath *et al*. (2003) for chickpea flour based snacks.

Effect of pre-frying drying on texture

The textural property of fried taro slices was measured in terms of breaking strength. The breaking strength of the samples varied from 276 to 438 g force for different pre-frying drying time. Breaking force of the fried taro slices increased with increase of pre-frying drying time but the rate was slower in the beginning and then was higher after one hour of drying. The difference in breaking strength was observed probably due to the difference in moisture and oil content of the product that may bring changes in the textural attributes. The statistical analysis showed that there was a significant difference ($p<0.05$) in breaking strength with pre-frying drying time. Similar effect of pre-frying drying was reported by Debnath *et al.* (2003) in chickpea flour based snack foods. Franco and Pedro (2005) found that the drying significantly increased the hardness of blanched fried potato as compared to the non-fried potato.

Effect of pre-frying drying on color

The color of the fried taro slices was measured in terms of color values L^*, a^* and b^* in order to determine color changes due to pre-fry drying time and frying time (Figure 4). The lightness, L^* value of fried taro slices varied from 24.04 to 51.25 for different pre-frying drying conditions. Lightness of taro slices decreased significantly with increase of pre-frying drying time (Figure 4a). Decrease in lightness value may be as a result of non-enzymatic browning reactions during pre-frying drying process. The lightness value of the slices for all pre-frying drying time increased with frying time (Figure 4a). The lightness value increased more rapidly during

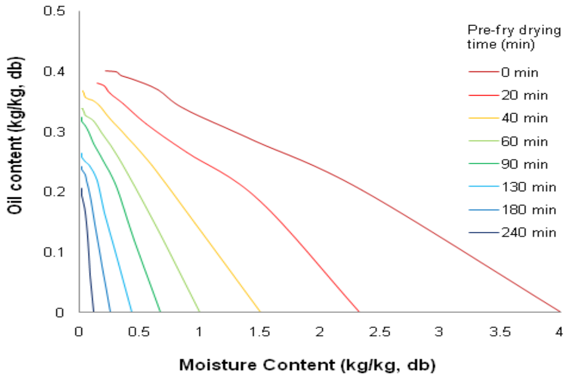

Figure 3. Variation of oil content against moisture content during frying of pre-frying dried taro slices

the early phase of frying and thereafter it was almost constant. Fresh and 20 min pre-dried samples showed more rapid change in L* value up to 40 s of frying. The L* value increased from 38.38 to 51.25 in fresh samples (0 min pre-frying drying). The increase in L value was also evident in all the dried (pre-frying) samples but the increase in L value was lesser as compared to the fresh sample. The increase in L value was the least, when the samples dried (pre-frying) for maximum period of time, 240 minutes. It indicates that pre-fry drying had the negative impact on the lightness value of the fried taro slices. Highest L* value (51.25) was observed in the fried taro slices which was not dried before frying (0 min), this may be due to presence of high moisture level, which causes more porous and shiny structure from the rapid loss of moisture during frying. Similar trend for L* has been found for frying of French fries (Krokida *et al*., 2001).

The effect of pre-frying drying and frying time on color, a* value of taro slices is shown in Figure 4 (b). The color, a* value of fried taro slices increased with increase of pre-frying drying time. As pre-frying drying time increased, the frying time was shortened probably due to lesser moisture available for removal during frying process. It was also noted that the duration of frying time had an influence on the color, a* value. In the initial stage of frying up to 30s, the change was rapid, thereafter the changes were gradual. The redness (increase in a* value) of the sample was more intense with pre-frying drying time and frying time because of moisture loss and browning reaction takes place during pre-frying drying and frying.

The yellowness, b* value of the taro slices was affected by pre-frying drying and frying time (Figure 4c). The color, b* value for taro slices decreased from 10.23 to 4.35 with the increase in pre-frying drying time from 0 to 240 min. However, as the frying time

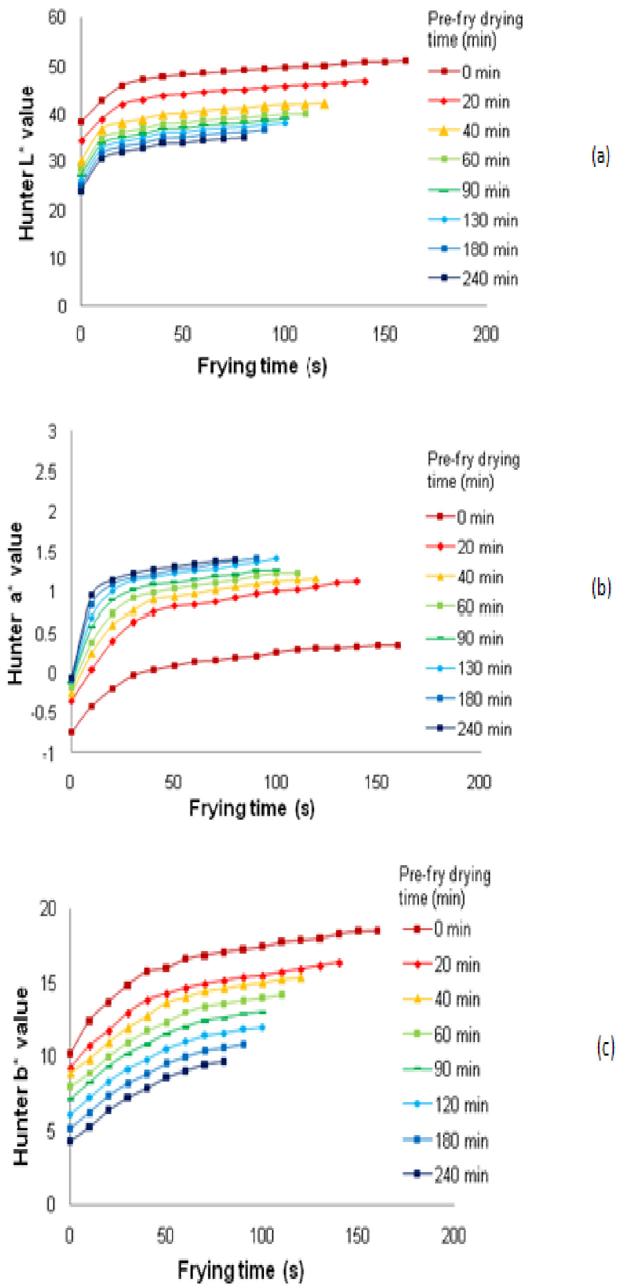

Figure 4. Effect of pre-frying drying time on color (a) L* value (b) a* value (c) b* value during frying of taro slices

increased, the yellowness value increased initially and thereafter it was almost constant till the end of the frying. The color quality of taro slices increased during frying process. Similar effect on b* value was observed by krokida *et al.* (2001) in french fries. Increase in color, b* value with vacuum microwave pre-frying drying time was also reported by Song *et al*. (2007) in potato chips.

Sensory evaluation of fried taro slices

Sensory data of the fried taro slices were collected for the attributes namely color, crispness, taste, and overall acceptability. The attributes were evaluated in all the samples with respect to the control sample (0 min pre-frying dried). The sample pre-frying dried for 20 min significantly rated best (8.1) followed by control sample (7.9), while the sample dried for 240 min had the least rating (5.4).

It was observed that pre-frying drying up to 40 min, did not exhibit any significant difference (P<0.05) in the sensory quality of fried taro slices. Crispiness and color of the sample were drastically deteriorated after one hour of pre-frying drying. Prolonged pre-frying drying reduced the higher amount of moisture content which possibly created shrinkage in the structure of the product that led to decrease in crispiness.

Conclusion

The pre-frying drying affected significantly quality parameters of fried taro slices. Mass transfer kinetics during deep fat frying exhibited that the moisture loss and oil uptake rate was decreased with increase in pre-frying drying time. First order exponential kinetic models of moisture loss and oil uptake during frying were best fitted to the data. The moisture and oil transfer coefficient were found in the range of 0.0489 - 0.0395 s^{-1} and 0.0519 - 0.0388 s^{-1} respectively for the pre-frying drying time, 0-240 min. The breaking strength of the samples was significantly increased ($p<0.05$) with pre-frying drying time. It was increased about 1.8 times in the slices, pre-frying dried for 240 min as compared to without pre-frying dried slices. With increase of pre-frying drying time, lightness and yellowness value decreased whereas redness value increased. Sensory data revealed that the pre-frying drying up to 40 min gave the product with acceptable sensory attributes. Pre-frying drying up to 40 min rendered a product having lesser fat uptake (0.367 kg/kg, db) medium breaking strength (303 g force) and acceptable color (L^*= 42.2, a^*= -0.29, b^*= 15.4) with a sensory score of (7.8).

Acknowledgements

This study was conducted at Biochemical Engineering and Food Technology Department, Harcourt Butler Technological Institute, Kanpur, Utter Pradesh, India. The authors are grateful to BEFT and OPT Department, HBTI, Kanpur for providing facility and excellent support.

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