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Effect of some process variables on mass transfer kinetics during osmotic dehydration of bamboo slices

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Abstract

Study was conducted to find out the optimum osmotic concentration, temperature, slice thickness and Fruit to Syrup (F:S) ratio for better osmo-dehydration of bamboo slices. Response Surface Methodology (RSM was used with four factors on five levels. The slices of various thickness (2, 4, 6, 8 and 10 mm) were dipped into various sucrose concentration viz., 20°B, 30°B, 40°B, 50°B and 60°B with the temperature viz., 30°C, 40°C, 50°C, 60°C and 70°C for six hours in various Fruit to Syrup ratio viz.,. 1:1, 1:2, 1:3, 1:4 and 1:5. Water loss (WL) and Solid gain (SG) increased linearly with the increase in sucrose concentrations and temperatures of the solution during osmosis. Slice thickness and F:S ratio recorded comparatively less effect on mass transfer of slices where as high concentration and temperature resulted peak gain in solids with corresponding reduction in weight reduction (WR). The regression analysis and ANOVA showed that the process variables have significant effect on osmosis.

Introduction

Strong health awareness among the human population is creating a genuine need for adopting a nutritionally complete diet, with increasing personalized value of convenience, cost and taste. Bamboo shoots, with their high nutritive value and bioactive compounds, hold great promise for utilization as a health food. Unlike most other agricultural crops, bamboos develop naturally with very little artificial selection, are fairly resistant to disease, insects, and climatic injuries, are free from residual toxicity as they grow well without the use of fertilizers and pesticides, and are protected from the surrounding pollutants by several layers of tightly clasped sheaths. Bamboos are of notable economic and cultural significance in South Asia, Southeast Asia and East Asia (Satya *et al*., 2012). India is the third-largest country in the world, that is, next to China (300 species) and Japan (237 species) as far as diversity of bamboo species is concerned. Other than those countries, 90 bamboo species in Burma, 55 in Philippines, 50 in Thailand, 44 in Malaysia, 33 in Bangladesh, 31 in Indonesia, 30 in Nepal, 30 in Sri Lanka (Sharma, 1980) are found. North East India, especially in Arunachal Pradesh, Bamboo plays essential part in people lives for their variety of uses in day-to-day life viz., shelter, food, furniture, handicrafts, medicine and various ethno-religious purposes. Bamboos are basically tropical plants but in India, out of above 126 species available, nearly half of the variability is available in North Eastern Region alone (Suresh Kumar *et al*., 2009). However, there are very few people who know the importance of bamboo products in world market and convert bamboo shoots into processed produces (Anon, 2008). Drying is one of the most common methods of food preservation for a long time. Innovation of novel technologies and developments are constantly taking place in the existing methods of drying (Marcotte and Le Maguer, 1992; Roult-Wack *et al*., 1992). Among drying and dehydration, osmotic dehydration gained attention recently due to its potential application in the food processing industry (Suresh Kumar *et al*., 2008). Osmotic dehydration is widely used for the partial removal of water from plant tissues by immersion in a hypertonic solution. The diffusion of water is accompanied by the simultaneous counter diffusion of solutes from the osmotic solution into the tissue. Since the membrane responsible for osmotic transport is not preferably selective, other solutes present in the cells can also be leached into the osmotic solution (Marcotte and Le Maguer, 1992; Roult-Wack *et al*., 1992; Le Maguer, 1998). The rate of diffusion of water from any material made up of such tissues depends upon factors such as temperature and concentration of the osmotic solution (Marcotte and Le Maguer, 1992), temperature (Roult-Wack *et al.*, 1992), the size and geometry of material (Le Maguer, 1998) the solution to material ratio (Suresh Kumar and Sagar, 2009), mass of the material and the level of agitation of the solution. Water is diffused through

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the membrane from the dilute to the concentrated solution until equilibrium is reached (Suresh Kumar *et al.*, 2006). The solute is unable to diffuse through the membrane in the reverse direction or can do so only very slowly so that the net result of this process is a transfer of water to a concentrated solution (Lenart, 1996). With the correct choice of process variables, water removal and impregnation, it is possible to enhance natural flavour and colour retention in fruit products (Roult-Wack *et al*., 1992). Response surface methodology (RSM) is the useful technique for complex process variables. This technique can be used in engineering process, industrial research and biological investigation with emphasis on optimizing the process system (Moyano and Berna, 2002; Myers and Montgomery, 1995). RSM is mainly used to reduce the number of experimental runs needed to provide statistically significant information. In recognition of the above needs and in order to explore the possibility of preparation of osmo-dehydrated product from bamboo, the present investigation was carried out to standardize the relation between different process variables (slice thickness, sucrose concentration, temperature and Fruit to Syrup ratio) on osmotic dehydration and to determine a set of optimum processing conditions suitable for better mass transfer kinetics of OD bamboo slices.

Materials and Methods

Raw material and preparation

Experiment was conducted with Eni bamboo (*Dendrocalamus hamiltonii*), common species used as food. Tender bamboo shoots which were not in proper shape are selected from the Research farm, Gori, Arunachal Pradesh, India. Sheaths of bamboo shoots were removed and cut into circular shape with different sizes viz., 2, 4, 6, 8 and 10 mm (X_1). Then, the shoots were blanched at 80±5°C in water for 25 min to remove the astringency and make the shoots soft to absorb the sucrose. Water was changed twice during the blanching to improve the quality and reduce the bitterness.

Osmotic treatment

The weighed amount of bamboo slices were suspended in sucrose solution containing 0.05% KMS and 0.1% citric acid in the vessel. Osmotic concentration of sucrose was maintained viz., 20°B, 30°B, 40°B, 50°B and 60°B (X_2) with the temperature viz., 30°C, 40°C, 50°C, 60°C and 70°C (X_3). For each treatment, the temperature of the solution was maintained at pre-set value. The ratio of the fruits and osmotic solution was maintained to 1:1, 1:2, 1:3, 1:4 and 1:5 (X_4) in order to ensure proper soaking of the samples without any agitation. Samples were withdrawn after six hours, drained quickly and wiped gently with tissue paper, and analyzed for different process variables like solid gain, water loss, weight reduction and sensory attributes.

Table 1. Coded and uncoded values of different process variables and their values

Process variables	Uncoded symbol	Coded symbol				
		-2	-1	0	1	2
Slice thickness (mm)	X_1	2	4	6	8	10
Sucrose concentration (°B)	X_2	20	30	40	50	60
Temperature (°C)	X_3	30	40	50	60	70
Fruit to Syrup ratio	X_4	1:1	1:2	1:3	1:4	1:5

Response surface methodology (RSM) was adopted in the experimental design and analysis (Dhingra and Paul, 2005; Ravindra and Chattopadhay, 2000). Four factors with five levels central-composite non-factorial design was applied to run RSM with 27 experimental runs. The independent uncoded variables and their coded values are presented in Table 1. The material was weighed before and after the process to calculate the percentage of weight reduction (WR), water loss (WL) and solid gain (SG), as per the following formulae:

$$WR = \frac{Wi - Wf}{Wi} \times 100 \quad ... \ 1$$

$$SG = \frac{WSf - WSi}{Wi} \times 100 \quad ... \ 2$$

$$WL(\%) = SG + WR \quad ... \ 3$$

where W_i= initial weight of the sample (g), W_f= final weight of the sample (g), WS_i= initial total solids content (%), WS_f= final total solids content (%).

Sensory analysis

Descriptive sensory evaluation was carried out to determine the effect of osmosis on the quality attributes of osmosed bamboo slices. Six member sensory panel was used to evaluate the various descriptors for colour, texture and taste of osmotic dehydrated fruits (3). Attributes were scored for degree of liking on 9-point hedonic scale of 1 to 9 (1=dislike extremely, 9=like extremely) and the average value was recorded. Score of 5.5 and above was considered acceptable.

Statistical analysis

The RSM was applied to the experimental data using a commercial statistical package (Statistica Version 6.0, USA). A second order polynomial action was fitted to the data to obtain regression equation.

$$Yk = bk0 + \sum_{i=1}^{4} bkiXi + \sum_{i=1}^{4} bkii\, X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{4} bkijXiXj \quad \ldots\ 4$$

where, Y_k; response dependent variable (Y_1; WL, Y_2; SG, Y_3; WR and Y_4; Sensory score) , Xi; response independent variables and β_{ko}, β_{ki}, β_{kij} are constant regression coefficients (Argaiz *et al.*, 1994). The statistical significance of the terms in the regression equation was examined by analysis of variance (ANOVA). Response surface and contour plots were generated and the optimizations of process variables were carried out by identifying the desirability of process variables. The models generated were used to fit the different processing variables in optimization of mass transfer process of OD bamboo slices.

Results and Discussion

The second order polynomial equation to the different responses at different processing conditions was shown in Table 2. The regression coefficients obtained thereof are presented in Table 3. ANOVA was conducted to assess the significant effect of variables on the responses (Table 4). It was observed from Table 3 and 4 that the models developed for all the parameters other than sensory score to be very adequate, possessing no significant lack of fit. However the process variables did not have much influence on sensory attributes of bamboo slices. Nonetheless, results revealed that all the four process variables had a significant effect on overall effect on the three responses. Concentration, temperature had the most significant effect while the slice thickness and Fruit to Syrup ratio had the least significant effect. Computer generated response surfaces and contour plots were obtained using predictive models. Such three dimensional surfaces give accurate geometrical representation and provide useful information about the behaviour of the system within the experimental region (Argaiz *et al.*, 1994). The regression values shows that the model is fit for process parameters besides showed the intrinsic properties of the fruits on structure, compactness of the tissue, the size of the contact surface between the fruit, water loss and sugar exchange.

Changes in water loss

Amount of WL increased with the increase in concentration of sucrose and temperature (Table 2). Maximum WL was 40.8% while the minimum was 25.3%. The regression co-efficient was 0.88 in case of water loss. Table 3 clearly indicates that the lack of fit was not significant confirming the significance of the model at both 1 and 5%. i.e. the process variables in the model have significant effect on the response. It was further observed that the cross product was also significant for water loss (Table 4). The effect of process variables on WL is showed in figure 1 in RSM and contour plots. It was lucid that they had profound effect on process parameters. The osmosis effect increased linearly with the increase in sucrose concentration up to 55°B (Figure 1). Further increase of sucrose concentration reduced the water loss that might have led to the solid gain by the fruits which was not desirable. This was attributed to the diffusion of water from dilute medium to concentrated solution

Table 2. Central Composite factorial design matrix and observed values of process variables*

Treatment	X_1	X_2	X_3	X_4	Y_1	Y_2	Y_3	Y_4
1	4	30	60	2	27.2	9.4	15.4	6.2
2	4	30	40	2	25.3	8.1	15.8	5.6
3	8	50	40	4	31.8	11.8	18.7	7.1
4	4	30	60	4	27.6	9.5	18.8	6.2
5	6	60	50	3	37.0	13.1	26.6	8.0
6	8	30	40	4	26.1	8.8	16.8	5.6
7	4	50	40	2	29.4	10.4	17.7	6.7
8	6	20	50	3	27.0	9.3	15.0	6.0
9	8	50	40	2	31.3	11.7	19.8	7.0
10 (C)	6	40	50	3	33.2	12.0	23.3	7.4
11	8	30	60	4	30.5	11.5	17.0	6.9
12	2	40	50	3	28.1	9.9	14.2	6.3
13	8	50	60	2	38.9	13.5	28.6	8.2
14	8	50	60	4	40.8	13.9	30.2	8.7
15	6	40	50	5	29.2	10.3	16.8	6.7
16	4	50	60	2	30.0	10.6	17.4	6.6
17	4	50	40	4	35.0	12.4	23.7	7.8
18	6	40	70	3	35.7	12.6	26.6	8.0
19	8	30	60	2	30.2	11.3	18.3	6.8
20	6	40	30	3	26.6	9.1	18.0	5.9
21 (C)	6	40	50	3	32.8	11.9	22.8	7.5
22	8	30	40	2	26.1	8.6	13.1	5.8
23	6	40	50	1	28.2	10.0	17.7	7.9
24	4	50	60	4	36.5	13.0	28.2	8.0
25	10	40	50	3	29.8	10.5	29.8	6.4
26	4	30	40	4	25.7	8.3	25.7	5.6
27	4	30	60	2	27.2	9.4	15.4	6.2

*The experimental runs were performed in random order
Y1: WL, Y2; SG, Y3; WR and Y4; Sensory score

Table 3. Regression co-efficient of different responses in OD Bamboo slices

Effect	WL	SG	WR	Sensory Score
Intercept β_{k0}	12.90	-14.12	21.8	-1.25
β_{k1}	0.57*	0.90*	-2.99*	0.49*
β_{k2}	-0.11	0.26**	-0.48	0.12*
β_{k3}	0.01*	0.27*	-0.72	0.11
β_{k4}	4.36**	2.23**	16.21**	-0.39*
β_{k11}	-0.23	-0.10	-0.08	-0.07
β_{k22}	-0.01	-.0.03*	-0.02	0.001
β_{k33}	-0.01	-0.002	-0.002	-0.001
β_{k44}	-0.98**	-0.42*	-1.49	-0.05
β_{k12}	0.02	-0.001	0.07	0.01*
β_{k13}	0.06	-0.02	0.09	0.02
β_{k14}	0.01	-0.03	0.02	-0.003
β_{k23}	-0.32*	-0.11	-0.85	-0.06
β_{k24}	0.08	0.03	0.01	0.02
β_{k34}	0.02	0.01	-0.03	0.006

*significant at 5% level **significant at 1% level

Table 4. ANOVA value for the different response variables of OD bamboo slices

Source	Df	Sum of Squares			
		WL	SG	WR	Sensory Score
Model	14	466.55**	81.17**	585.39**	20.88*
Linear	4	369.06**	58.31**	331.42**	15.12*
Quadratic	4	34.17**	7.33*	47.94*	2.18
Cross product	6	42.75*	14.97	169.84*	1.88
Residual					
Lack of fit	10	25.54	3.63	38.94	2.22
Pure error	1	0.08	0.06	0.23	0.005
Total error	11	25.62	3.69	39.17	2.23
r^2		0.88	0.91	0.83	0.86

*significant at 5% level **significant at 1% level

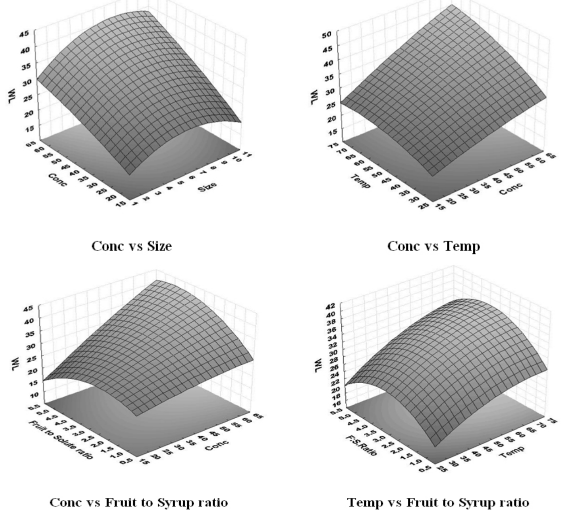

Figure 1. Response surface and contour plots showing the effect of processing variables on WL (Third and fourth factor at the fixed mid level)

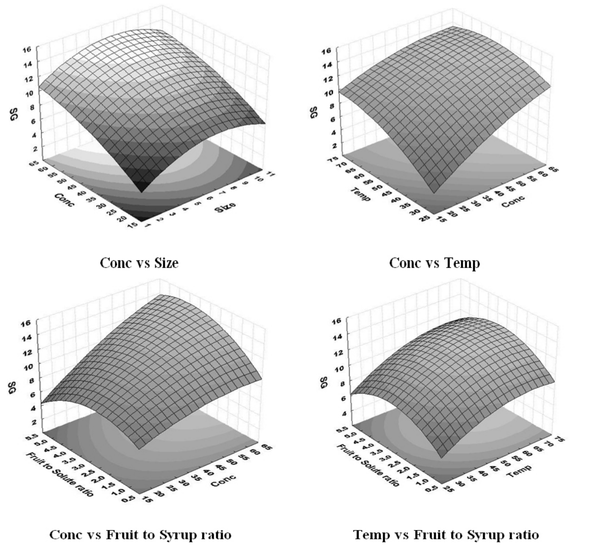

Figure 2. Response surface and contour plots showing the effect of processing variables on SG (Third and fourth factor at the fixed mid level)

until the equilibrium concentration was reached. The driving force in this process was the water activity gradient caused due to the osmotic pressure (Pan *et al*., 2003; Sagar and Suresh Kumar, 2007). For solute concentrations of above 60% and below 40%, there was impregnation and crystallization of sucrose and poor moisture removal respectively. This strongly suggested that for optimal osmotic dehydration, the sucrose concentrations should be in the range of 55-60%. Increase in temperature up to a certain degree increased the osmosis. Further increase in temperature affects the semi-permeability of the cell walls and reduced the rate of osmosis (Gill *et al.*, 2004). This may be due to reduction in viscosity of hypertonic solution and increase in diffusion coefficient of water at high temperature (Suresh Kumar and Sagar, 2009).

WL was very less in 20^{o}B sucrose concentration and 30^{o}C temperatures. This may be due to the fact that the low concentration of sucrose syrup may get diluted and reached the saturation point quickly which would not help in removing water during the osmosis process. It was concluded that the every 10^{o}C increase in temperature or by increasing in Brix of sucrose, there was an almost equal increase in the final water loss (Kiranoudis *et al.*, 1997). It is also showed that the dehydration rate was better in concentrated syrup due to an increased osmotic pressure in the sucrose syrup at higher concentrations, which increased the driving force available for water transport (Argaiz *et al*., 1994). The contour plots on interactions showed that there was linear increase in water loss with increase in concentration and temperature however same kind of interaction was not found with thickness and concentration or temperature. However the slice thickness above 8 mm did not have any influence on the water removal and the Fruit to Syrup ratio recorded very little influence on water loss from the bamboo slices.

Changes in solid gain

The higher sucrose concentration raised the solid gain of bamboo slices. Maximum SG of 13.9% was recorded after 6 h in 60^{o}B at 50^{o}C while the minimum (8.1%) solid gain was recorded with minimum level (Table 2). Further, Table 3 illustrate that the lack of fit was not significant confirming the significance of the model. In linear terms sucrose concentration, temperature and slice thickness were found to be significant in model terms. The regression coefficient r^2 (0.91) value indicated that the model was most significant for solute intake into the slices. Most of the treatments were performed with optimum solid gain. However it was clear from the Table 4 that the cross product value was not significant for the model. Results obtained on apple cylinders treated with osmotic solutions suggested that volumetric

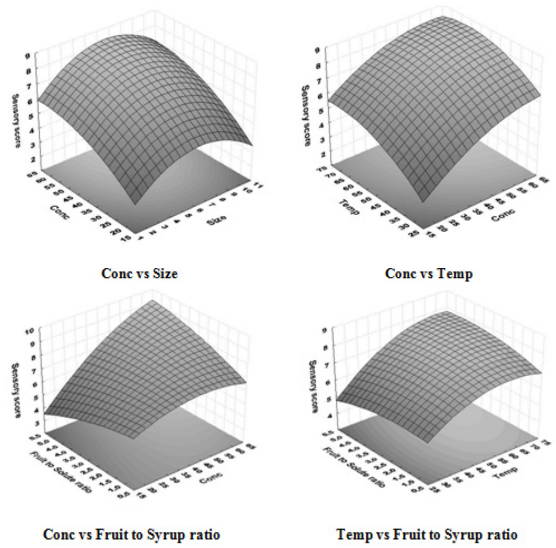

Figure 4. Response surface and contour plots showing the effect of processing variables on Sensory score (Third and fourth factor at the fixed mid level)

shrinkage is essentially due to water removal/solid gain and offer a simple way to predict such changes during industrial processing (Shahabuddin *et al.*, 1990). It was clear on solid gain (Figure 2) that with the increase in sucrose concentration from 20 to 60°Bx the solid gain also increased. But above certain coded value the solid gain got decreased. The minimum solid gain was occurred with minimum concentration and temperature. This was attributed to longer time by osmosis to approach equilibrium between cellular fluids and osmotic solution along with volume and compactness of fruits solution (Suresh Kumar and Sagar, 2009; Yao and Le Maguer, 1996). Tissue damage due to too high temperature causes a dramatic decrease in dehydration efficiency through increased solute and decreased moisture diffusivities.

Changes in weight reduction

Weight reduction was increased with an increase in concentration and temperature of sucrose syrup (Figure 3). The difference in WR attributed to osmosis, might be a cause of variation in WR rate among different concentration of sucroses (Roult-Wack, 1994; Pokharar *et al.*, 1997; Park *et al.*, 2002). Table 4 on ANOVA revealed that the cross product of process variables were highly significant besides the linear and quadratic value which were also significant. The reason was that the viscosity of hypertonic solution was lowered and the diffusion coefficient of water increased at high temperature (Kiranoudis *et al.*, 1997). In addition the non significant value of lack of fit put the model as the perfect for process optimization for bamboo slices. The regression coefficient value was 0.83 which was highly significant for the model. Table 3 indicates that concentration and temperature influenced the weight reduction more than slice thickness and Fruit to Syrup ratio. The negative value indicates that the Fruit to Syrup ratio had no effect on mass transfer kinetics. The concentration above certain coded value recorded the least effect on weight reduction. The Fruit to Syrup ratio above optimum (1:4) did not have any effect on weight reduction (Barat *et al.*, 2001).

Changes in sensory score

Sensory score appear to be useful to select the best osmotic concentration and temperature as chemical constituents were very indistinctness. However it was evident from Table 3 and 4 that sensory attributes are least affected by different process variables. Treatment 14 scored highest value on sensory attributes (Table 2). But the high temperature and concentration negatively affect the colour of the slices (not shown). Best colour was obtained with 50°B with 55°C temperature (Figure 4). This is due to prevention of enzymatic and oxidative browning as the pieces were surrounded by sucrose thus making it possible to retain good colour (Morrera and Sereno, 2001). The contour plot clearly shows that other than F:S ratio all other process variables significantly affected the sensory attributes of bamboo slices. However, increase in high concentration and very high temperature hinders the solid gain and there by resulted poor colour score (Sharma and Kaushal, 1999). Better flavour was also obtained with the same concentration and temperature. Poor texture was observed with very low concentration of sugar. During the osmotic step, furanones, pyranones and to a lesser extent, esters remain in the fruit tissue, while alcohols and carbonyl compounds moves from the fruit to syrup, probably due to the solubility of these compounds in water. Furthermore, the concentration of pineapple slices, through osmotic dehydration, improves the volatile retention during air drying in such a way that previously osmo-dehydrated slices could be dried up to higher drying levels when compared to non treated fruit (Saputra, 2001).

Overall effect of process variables was further statistically performed. This analysis is a joint test on all the parameters involving one particular factor (Table 5). For example test for slice thickness (X_1) tests the hypothesis that for parameters of X_1, X_1^2, X_1X_2, X_1X_3 and X_1X_4. Results revealed that the process variables had a significant effect on the four responses studied. It was lucid that concentration and temperature has the most significant effect for the responses. However, slice thickness and Fruit

Table 5. ANOVA for overall effect of different process variables on OD of bamboo slices

Process variables	Df	Sum of Squares			
		WL	SG	WR	Sensory Score
Slice thickness (mm)	5	66.55*	10.69*	166.80**	4.19
Sucrose concentration (°B)	5	251.06**	38.18**	261.98**	10.27**
Temperature (°C)	5	129.22**	19.94*	163.32**	6.01*
F:S Ratio	5	47.82*	16.65*	126.91**	3.06

*significant at 5% level **significant at 1% level

to Syrup ratio witnessed the little effect on sensory score. Concentration and temperature enhanced mass transfer rates, resulting in faster osmo-drying and improved the physical structure.

Conclusion

It was clear from the Table 2 that treatment 14 followed by treatment 13 performed well among the different response process combinations. Therefore in order to optimize the process condition, the sucrose concentration could be optimized with the range of 55-58°Bx, the temperature with 55°C, slice thickness equal to 8 mm and Fruit to Syrup ratio with 1:4 can be chosen to obtain higher values for different process variables. Osmotic dehydration due to its energy and quality related advantages, is gaining popularity as a complimentary processing step, in the chain of integrated food processing. However, Osmotic treatments have been applied frequently as low cost processing method neglecting process optimization, but the current interest in this technique and the development of industrial applications on a large scale demand controlled processes. It is necessary to develop predictive models through understanding of mechanism of mass transport.

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