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Development of Accelerated Soaking Method for Mustard using Microwave-Assisted Heating

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ABSTRACT

Mustard seeds are generally undergone the soaking process before use in any food application. But soaking mustard in water takes lots of time and energy. Therefore, the present investigation was carried out to study the soaking characteristics of mustard seed in different soaking conditions. The mustard seed was soaking in ambient water, hot water, and microwave heating applications. The initial moisture content of the mustard seed was found to be 12.64 % db. The moisture gain was found to be 55.46 % db in ambient water soaking after 360 min. In the hot water soaking, the moisture gain was estimated to be 68.33 % db, 80.40 % db, and 86.18 % db at 40°C, 50°C, and 60°C, respectively. The moisture gains in microwave-assisted soaking at 0.2, 0.4, 0.6, 0.8 and 1.0 W/g power densities level were found to be 67.77 % db, 67.80 % db, 103.28 % db, 115.08 % db, 131.51 % db, respectively after 10 min. The Peleg model was found to be suitable for describing the soaking characteristics of mustard seed at all soaking conditions with higher R^2 values. Among all the soaking methods, microwave-assisted soaking showed the best soaking characteristics of mustard with less time consumption and with more amount of moisture gain. Therefore, microwave-assisted soaking of mustard seed may be recommended for soaking of mustard which is less time-consuming and energy-saving process.

Keywords: Microwave-assisted soaking, Peleg model, Capacity constant, Moisture gain.

INTRODUCTION

Mustard also known by the name of Indian mustard, belongs to the plant family *Brassiceae (Cruciferae)* of the mustard family. The seeds are generally 1-2 mm in diameter and the color may be black, yellowish, or white depending on the varieties. Mustards are the most important source of vegetable oil in the last decades [1]. Mustard is also used in the form of condiments and spices in India, Nepal, Sri Lanka, and Bangladesh [2, 3]. Mustard seed contains more than 46% of oil and 4.63% of the protein in the cake. Therefore, after de-oiling, its cake is used as an animal feed due to its high protein content [4, 5]. Mustard is also a good source of phosphorous, iron, calcium, and minerals. Mustard seeds and oil have been traditionally used to relieve muscle pain, rheumatism, and arthritic pain [6].

Mustard seed processing may go through different post-harvest stages like drying, size reduction, and soaking. It is generally spherical in shape and the starchy endosperm contains the highly impermeable layers known as the epidermis [4, 7]. Due to the presence of a highly impermeable membrane, the absorption of moisture into the mustard seed is very difficult. Sometimes, the manufacturer reduced the size of mustard seed using a stone mill for better liquid absorption. The cracked or the broken seed used to be soaked in vinegar or in water and grounded to a fine paste before being used. And some manufacturers soaked the mustard seed for the whole night before grinding it to a paste. All the soaking and the size reduction method takes a lot more of energy before it can be used as a final product.

Now a day's microwave heating is being used in lot many industries. The electromagnetic waves in microwave heating are in the range of 300-3000 megahertz. Microwave causes volumetric heating whereas the traditional heating process does heating from the surface to the center [8]. The use of microwave in food processing has a lot of advantages like shorter heating time, retains better color, texture when compared with conventional heating methods [9, 10]. The research on soaking mustard is very much limited. Also, considering the energy and time consumption of traditional soaking and the benefits of microwave heating, the current research was carried out to study the water absorption characteristics of mustard seed using microwave heating and to compare the soaking characteristics with ambient water, hot water soaking.

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MATERIALS AND METHODS

Materials

The mustard seed was brought from the local market of Paralakhemundi, Gajapati. It was washed properly using clean water. The surface moisture was removed by a hand towel and it was kept under shade for 1 hr. The initial moisture content was determined by keeping the sample in a hot air oven at 105 ± 2°C for 24 h [11]. The initial moisture content of mustard seed was measured using the following equation:

$$\text{Moisture content (\% wb)} = \frac{W_2 - W_1}{W_1} \times 100 \quad \dots (1)$$

Where, W_1 is the initial weight of the sample (gm) and W_2 is the final weight of the sample after oven drying (gm).

Methods

Ambient water soaking

In the ambient water soaking method, the experiment was performed at room temperature in a glass beaker. The room temperature was taken by a thermometer and found to be 29°C at the time of experiments. The sample to water ratio was maintained constant at 1: 4 and the experiment were conducted up to 6 h. Approximately one-two grams of sample was withdrawn from the glass beaker, wiped with tissue paper for surface moisture removal, and kept inside the hot air oven for estimation of moisture content. The samples were drawn at 10 min intervals up to 6 h.

Hot water soaking

The hot water soaking of mustard seed was done at 40°C, 50°C and 60°C temperature in a water bath (Hytek, India) fitted with heating coils. The temperature of the water bath was maintained at 3 different temperatures for 3 different experiments. The sample to water ratio was maintained constant at 1: 4. The sample with water was kept inside the water bath in a glass beaker and the experiment was conducted up to 6 h for all the 3 temperature ranges. The same procedure of sample drawing was followed as ambient water soaking for moisture content analysis at an interval of 10 min up to 6 h.

Microwave-assisted soaking of mustard

A domestic microwave oven (Morphy Richards, 20MBG) available in the laboratory having a maximum power rating of 1000W was used throughout the experiments (Fig. 1). The height, width, and depth of the microwave oven were 280 mm, 300 mm, and 210 mm, respectively. Different parts like a 28 cm diameter of glass turntable, fan, grill arrangements, a control panel for controlling the power level, treatment time, etc are attached in the microwave oven within the microwave. The experiments were planned by taking 5 different power densities levels from 0.2, 0.4, 0.6, 0.8, and 1 W/g. The power density level was calculated by taking the microwave power level and weight of the sample and water. The power level was set first in the microwave control panel. The pre-measured weight of the sample with water was taken in a glass beaker and was kept inside the microwave oven to start the experiment. The microwave oven was paused after 1 min to draw approximately one gm of sample; the sample was kept in the hot air oven for measurement of moisture content [11]. The same process was continued up to 10 min (600 sec) and the same procedure was followed for all the microwave power density levels.

Figure 1: Microwave oven

Modeling of soaking data

A two-parameter sorption equation proposed by Peleg [12] was used in the study to predict the moisture gain during ambient water, hot water, and microwave-assisted soaking. The two-parameter equation is given below:

$$\frac{t}{M_t - M_0} = k_1 + k_2 t \quad \dots (2)$$

Where M_t is the moisture content at soaking time t (% db), M_0 is initial moisture content (% db), k_1 is a capacity constant dependent on the initial water absorption rate (min.%$^{-1}$) and k_2 is rate constant dependent on the equilibrium moisture content (%$^{-1}$).

Calculation of moisture gain

The moisture gain was calculated by taking initial dry basis moisture content using the following formula:

$$MG_t = MC_t - M_0 \quad \dots (3)$$

Where, MG_t is the moisture gain at any time in % db, MC_t is the moisture content at any time % db, and M_0 is the initial moisture content in % db.

RESULT AND DISCUSSION

Effect of ambient water soaking on moisture gain

The ambient water soaking was performed at room temperature for the mustard seed. The moisture gain experimental data is given in Table 1. The initial moisture content was found to be 11.22 % wb for all the experimental samples. The soaking was done for 360 min and the dry basis moisture content was found to be 68.10 % db after 6 h. The moisture gain experimental was calculated and was found to be 55.46 % db after 360 min. The Peleg model was applied to the moisture gain experimental data and found to be the best in describing the soaking characteristics with an R^2 of 0.94 (Table 2). The Peleg rate constant and the capacity constant was found to be 2.7316 min. %$^{-1}$ and 0.0106 %$^{-1}$, respectively (Table 2). The moisture gain predicted was calculated from the values of k1 and k2 and the graph was plotted between moisture gain experimental and moisture gain predicted and is shown in Fig. 2.

Table 1: Moisture gains experimental data during ambient water soaking

Time (min)	MC % db	MG Experimental, % db	MG predicted, % db
0	12.64	0	0
15	17.18	4.54	5.18
30	24.16	11.52	9.83
60	29.94	17.30	17.81
120	41.33	28.70	29.97
180	56.10	43.45	38.80
240	57.47	44.83	45.50
300	61.31	48.67	50.74
360	68.10	55.46	54.98

Table 2: Peleg Model constants and R^2 values of all the soaking conditions

Soaking conditions	Peleg rate constant (k1, min.$\%^{-1}$)	Peleg capacity constant (k2, $\%^{-1}$	R^2
Ambient water soaking	2.7316	0.0106	0.94
Hot water soaking			
40°C	0.5986	0.0129	0.97
50°C	0.5526	0.0111	0.99
60°C	1.8515	0.0078	0.83
Microwave-assisted soaking			
0.2 W/g	3.5597	0.0884	0.94
0.4 W/g	7.4024	0.0028	0.91
0.6 W/g	7.558	0.0035	0.90
0.8 W/g	6.4076	0.002	0.93
1.0 W/g	5.6774	0.0019	0.96

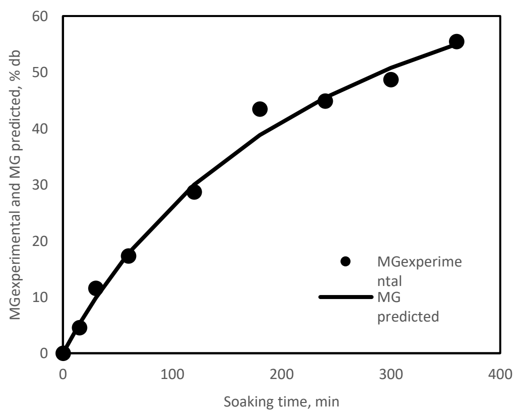

Figure 2: MG experimental vs MG Predicted in ambient water soaking

Effect of hot water soaking on moisture gain

The hot water soaking was performed at 40°, 50°, and 60°C. The moisture content (% db) and moisture gain experimental and predicted data at different time interval is given in Table 3. The dry basis moisture content was found to be 80.98, 93.03, and 98.82 % db for 40°, 50°, and 60°C, respectively at the end of 360 min. The moisture gain experimental was 68.33, 80.40, and 86.18 % db for 40°, 50°, and 60°C, respectively at the end of 360 min. It can be observed from the above data that both the moisture content and moisture gain increased with an increase in temperature from 40 to 60°C. This may be due to an increase in temperature increases the driving force for moisture migration. Similar results were also reported by Thakur and Gupta [13] for paddy. The Peleg model was applied to the moisture gain experimental data and found to be the best in describing the soaking characteristics with R^2 in the range of 0.83 to 0.99 for different temperature range (Table 2). The Peleg rate constant (k1) didn't show any particular trend and was found to be in the range of 0.5526 to 1.8515 min.$\%^{-1}$. The Peleg rate constant (k2) was found in decreasing trend from 0.0129 $\%^{-1}$ to 0.0078 $\%^{-1}$ with an increase in temperature from 40 to 60°C (Table 2). The moisture gain predicted was calculated from the values of k1 and k2 and the graph was plotted between moisture gain experimental and moisture gain predicted for all the temperatures and is shown in Fig. 3.

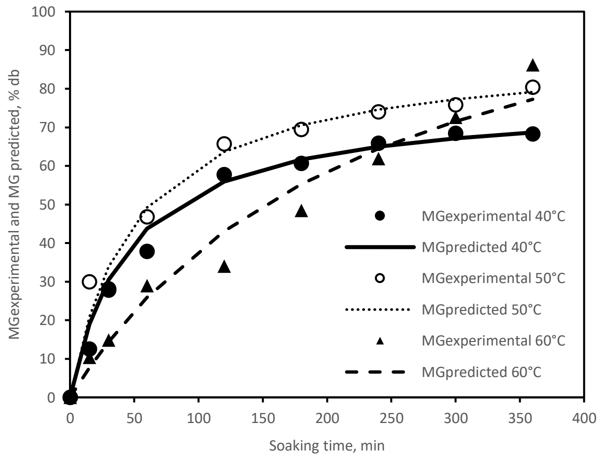

Fig. 3. MG experimental vs MG Predicted for hot water soaking at different temperature

Table 3: Moisture gains experimental data during hot water soaking at different temperatures

	Soaking temperatures								
	40°C			50°C			60°C		
Soaking Time (min)	MC db	% MG % db	Experimental, MG % db	predicted, MC db	% MG % db	Experimental, MG % db	predicted, MC db	% MG % db	Experimental, MG predicted, % db
0	12.64	0	0	12.64	0	0	12.64	0	0
15	25.22	12.58	18.93	42.61	29.97	20.85	23.01	10.37	7.62
30	40.48	27.84	30.43	40.76	28.12	33.87	27.53	14.90	14.38
60	50.51	37.87	43.71	59.45	46.81	49.23	41.64	29.00	25.86
120	70.38	57.74	55.90	78.35	65.71	63.67	46.64	34.00	43.04
180	73.28	60.64	61.63	82.12	69.48	70.57	61.07	48.43	55.30
240	78.51	65.87	64.95	86.67	74.03	74.61	74.53	61.90	64.45
300	81.10	68.45	67.13	88.45	75.81	77.26	85.24	72.60	71.57
360	80.98	68.33	68.66	93.03	80.40	79.14	98.82	86.18	77.26

Effect of microwave power density on product temperature

The microwave-assisted soaking was performed at five microwave power density levels. i.e. 0.2 to 1.0 W/g. The maximum temperature was found to be 45°C at 0.2 W/g, 46°C at 0.4 W/g, 71°C at 0.6 W/g, 81°C at 0.8 W/g, and 94°C at 1.0 W/g microwave power density level (Fig. 4).

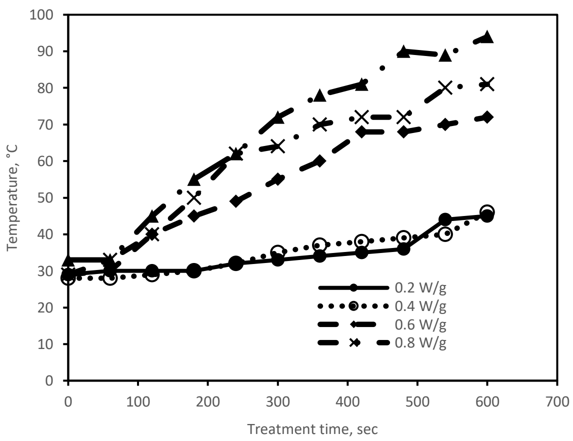

Figure 4: Effect of microwave power density on product temperature

The product temperature was increasing with an increase in the power density level. This may be due to the volumetric heating of the microwave with an increase in power density level. Similar results were also reported by Behera and Sutar [14] for microwave drying of steam gelatinized paddy.

Effect of microwave-assisted water soaking on moisture gain

The microwave-assisted water soaking was performed at 5 different microwave power densities for 600 secs (10 min). The moisture gains experimental and predicted data at different time interval is given in Table 4. The dry basis moisture content was found to be 80.41, 80.44, 115.93, 127.72, 144.23 % db at 0.2, 0.4, 0.6, 0.8 and 1.0 W/g, respectively after 10 min of soaking. Similarly, the moisture gain experimental was 67.77, 67.80, 103.28, 115.08, 131.51 % db at 0.2, 0.4, 0.6, 0.8 and 1.0 W/g, respectively after 10 min of soaking. It can be seen that the moisture gain was increased from 67.77 % db to 131.51% db with an increase in the microwave power density from 0.2 W/g to 1.0 W/g. This may be due to the increase in microwave power density increases the product temperature and the increase in the product temperature ultimately increases the moisture gain. The increase in product temperature with an increase in power density can be also seen in Figure 4. The results were in accordance with the result reported by Behera and Sutar [15] for microwave-assisted absorption of paddy grain. The Peleg model was applied to the moisture gain experimental data and found to be the best in describing the soaking characteristics with R^2 in the range of 0.90 to 0.96 for different microwave power density levels (Table 2). The Peleg rate constant (k1) didn't show any particular trend like other methods of soaking (ambient and hot water soaking) and was found to be in the range of 3.5597 to 6.4076 min.%$^{-1}$. The Peleg rate constant (k2) was found in decreasing trend from 0.0019 %$^{-1}$ to 0.0884 %$^{-1}$ with an increase in power density from 0.2 W/g to 1.0 W/g (Table 2). The moisture gain predicted was calculated from the values of k1 and k2 and the graph was plotted between moisture gain experimental and moisture gain predicted for all the microwave power density levels and is shown in Fig. 5.

Table 4: Moisture gains experimental data during microwave-assisted water soaking at different microwave power density levels

Time (sec)	Microwave power density levels									
	0.2 W/g		0.4 W/g		0.6 W/g		0.8 W/g		1.0 W/g	
	MG Experimental, % db	MG predicted, % db	MG Experimental, % db	MG predicted, % db	MG Experimental, % db	MG predicted, % db	MG Experimental, % db	MG predicted, % db	MG Experimental, % db	MG predicted, % db
0	0	0	0	0	0	0	0	0	0	0
60	12.35	14.76	8.04	7.92	8.32	7.72	9.40	9.19	10.70	10.36
120	26.73	26.27	15.48	15.50	16.22	15.04	19.94	18.05	21.84	20.32
180	40.51	35.50	22.77	22.76	25.34	21.98	29.45	26.60	33.51	29.90
240	45.58	43.04	29.43	29.72	36.32	28.57	40.11	34.84	46.73	39.13
300	49.35	49.34	37.36	36.40	47.20	34.85	53.04	42.81	60.53	48.01
360	55.90	54.68	42.39	42.80	55.67	40.82	62.46	50.50	72.36	56.60
420	57.57	59.25	47.51	48.96	71.60	46.52	77.47	57.95	87.36	64.86
480	63.25	63.22	54.02	54.87	84.04	51.96	87.93	65.15	99.86	72.84
540	66.70	66.70	61.27	60.57	97.00	57.15	101.15	72.11	116.52	80.55
600	67.77	69.76	67.80	66.06	103.28	62.12	115.08	78.86	131.51	88.01

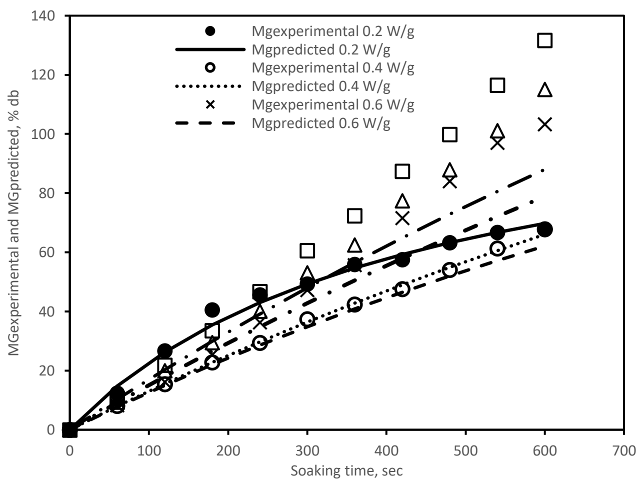

Figure 5: MG experimental vs MG predicted for microwave-assisted soaking at different microwave power density levels

Comparison between all the soaking methods

The moisture content gain in the ambient water soaking method was found to be 55.46 % db after 360 min (6 h). In the hot water soaking, the gain in moisture was estimated to be 68.33, 80.40, and 86.18 % db at 40°C, 50°C, and 60°C, respectively in the same soaking period (6 h). But The moisture content gain has an increasing trend with an increase in temperature. Similarly, the moisture gains in microwave-assisted soaking at 0.2, 0.4, 0.6, 0.8 and 1.0 W/g power densities level were 67.77 % db, 67.80 % db, 103.28 % db, 115.08 % db, 131.51 % db, respectively after 10 min only. The increase in power density level showed an increasing trend of moisture gain from 67.77 % db to 131.51 % db. From all the soaking methods, if we compare the moisture gain data of microwave-assisted soaking with all other methods i.e ambient and hot water soaking (at 3 temperatures), the moisture content gain is very high in microwave-assisted soaking in 10 min only. This may be due to the volumetric heating of microwaves compared to the conventional heating process [8]. The time consumption in ambient water soaking was 6 h whereas, in microwave heating, the higher level of moisture gain was achieved in just 10 min.

CONCLUSION

The initial moisture content of the mustard seed was found to be 12.64 % db throughout the experiments. The moisture gain experimental was calculated and was found to be increasing from 55.46 % db in ambient water soaking. In ambient water soaking, the Peleg rate constant and the capacity constant was found to be 2.7316 h$\%^{-1}$ and 0.0106 $\%^{-1}$. In the hot water soaking, the moisture gain was estimated to be 68.33 % db, 80.40 % db, and 86.18 % db at 40°C, 50°C, and 60°C, respectively after 360 min (6h) of soaking period. The moisture gains in microwave-assisted soaking at 0.2, 0.4, 0.6, 0.8 and 1.0 W/g power densities level were found to be 67.77 % db, 67.80 % db, 103.28 % db, 115.08 % db, 131.51 % db, respectively after 10 min. The Peleg model was found to be suitable for describing the soaking characteristics of Mustard seed at all soaking conditions with higher R^2 values. The Peleg capacity constant and rate constant didn't show any particular trend in all the soaking methods. Among all the soaking methods, microwave-assisted soaking showed the best soaking characteristics of mustard with less time consumption and with more amount of moisture gain. Therefore, microwave-assisted soaking of mustard seed may be recommended for soaking of mustard which is less time-consuming and energy-saving process.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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