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Effect of microwave drying on physical and sensory properties of instant mung bean vermicelli

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Abstract

Mung bean vermicelli is manufactured from mung bean starch by mixing, extruding, boiling, cooling, freezing, defrosting and sun drying. However, the end product requires a long rehydration time. Hence, this study investigated microwave drying technology to reduce the rehydration time. Instant mung bean vermicelli was dried in a continuous microwave dryer at 50 Hz, 60 Hz, and 70 Hz with different numbers of rounds. The dried mung bean vermicelli was analyzed for its physical and sensory properties. The experimental design involved 3 treatments (50 Hz, 60 Hz, 70 Hz) with 3 replications of each treatment (3x3). The results indicated that drying at 70 Hz for 16 rounds produced instant vermicelli that had a very good porous structure and good cooking quality. The vermicelli dried at 70 Hz, 60 Hz, and 50 Hz rehydrated within 2.79, 2.81 and 3.05 min, respectively. Compared to a commercial product, the color of the microwaved vermicelli was greater in lightness (L^*), greenness (a^*), and blueness (b^*). There were no significant differences in tensile strength among the 60Hz and 70Hz treatments and the commercial product; however, the elasticity of the microwaved vermicelli samples was lower than for the commercial product. Notably, the overall acceptability scores for the microwaved dried vermicelli at 70 Hz and for the commercial product were the same (7.03 score based on a 9-point hedonic scale). In conclusion, continuous microwave drying technology at 70 Hz was recommended for instant mung bean vermicelli production due to its short drying (18.88 min) and rehydration (2.76 min) times and its good quality with a high level of acceptability.

Keywords: Microwave continuous, Drying, Mung bean vermicelli, Physical, Sensory.
Abbreviations: N_newton (unit of force); Hz_hertz (unit of frequency).

Introduction

Mung bean (*Vigna radiata* L.) has been a traditional food globally for more than 3,500 years (Ganesan et al., 2018) and a functional food consisting of flavonoids, phenolics, and protein (Yao et al., 2019). In addition, mung bean has desirable antitumor, antioxidant, anti-diabetic, and anti-melanocyte as types of physiological functionality (Shi et al., 2016). Starch is a major component of mung bean (> 60%), with a suspected role in thickening, gelling, and retrogradation in the food system due to the starch structure and physicochemical properties (Yao et al., 2019). Mung bean is a common plant and widely cultivated in many countries in Asia, southern Europe, and some warmer parts of Canada and the United States (Yi-Shen et al., 2018). Mung bean starch has excellent characteristics with a very high amylose content and a very strong and viscous gel; thus, it is suitable for making vermicelli.

Mung bean vermicelli is one of the common styles of noodles in Asian countries (Li et al., 2011). It has health benefits for diabetic patients due to its resistant starch that is fermented by probiotic bacteria, which could improve the environment in the human gut system. Furthermore, diabetic patients may not suffer from a high increase in blood sugar after consuming mung bean vermicelli (Chen et al., 2002; Cummings et al., 1996). However, commercial mung bean vermicelli requires a long time for rehydration (8 min) in hot water (90 ^{o}C). This is incompatible with the busy, modern lifestyle of modern consumers, who prefer a short cooking time in hot water for instant products, such as noodles. Thus, research is needed on instant mung bean vermicelli production to produce a high-quality product with a short rehydration time.

Microwave drying is operated mainly by dipolar rotation and ionic polarization in the presence of water and ions. When an electric field oscillates around food, the dipole water molecules in the food rotate and ion molecules move in the direction of the electric field. The high movement of the electric field causes the rearrangement of molecules millions of times per second, which, in turn, creates internal friction in the molecules, resulting in volumetric heating of the food (Datta and Davidson, 2000). In a microwave drying system, the water becomes steam and migrates out of the noodles and then evaporates to the air, leading to many porous structures in the noodles so they can readily rehydrate (Pongpichaiudom and Songsermpong, 2018a). In a hot-air drying system, the heat is transferred by convection and then conduction, so water diffuses from inside to the surface and then evaporates, leading to dense-structured dried vermicelli that is hard to rehydrate.

Generally, microwave drying technology has contributed to rapid and uniform heating due to the heat generated throughout the food volume, with the energy transition not dependent on the diffusion of heat from the surfaces. In addition, microwave processing has a low energy cost and very favorable results from sensory evaluation and its nutrient and functional properties, especially with instant noodles that can be rehydrated in a short time due to the porosity created inside the noodle strands (Pongpichaiudom and Songsermpong, 2018a). Therefore, the objective of the current study was to optimize the drying conditions for microwave continuous drying, especially the speed of conveyor belt and the drying rounds, to produce instant mung bean vermicelli with a good quality and a short rehydration process.

Results and discussion

Drying curve

In the microwave continuous drying process, liquid nitrogen was applied to form numerous small ice crystals, which is a recommended method to create greater porosity. This agreed with the research by Harnkarnsujerit et al. (2016) on freeze-dried soybean curd that showed that applying liquid nitrogen to pre-freeze prior to freeze-drying could result in a very fine pore size in the product. After the first round, the frozen noodle strands were thawed and separated, with a subsequent round to dry the noodles quickly and generate porosity inside the noodles. Compared to conventional drying technology, microwave drying technology would have a higher energy efficiency and be considered as a new method with the advantage over hot-air drying of quick rehydration. Yoora and Songsermpong (2022) reported that instant fermented rice noodle could reduce the rehydration time to 3 min using microwave continuous drying compared to a hot-air drying time of 3.94 min.

Figure 2 shows the moisture content of vermicelli after each drying round in the microwave heating system. The fresh vermicelli had a moisture content of 71.2% (wb), after one round of defrosting; then, the moisture content of the sample increased slightly and then decreased gradually during the drying process for each condition. The liquid nitrogen caused water condensation from the air in the first period which then evaporated as steam during microwave drying. Thai Industrial Standard Institute (2005) requires the final moisture content of dried instant noodles to be less than 12% (wb). As can be seen from the drying curve in Figure 2 the moisture content of instant mung bean vermicelli decreased gradually during the drying process. The moisture of each treatment was below 12% after 12, 14, and 16 rounds of drying at 50 Hz (11.15%, wb), 60 Hz (11.19%, wb), and 70 Hz (11.08%, wb), respectively, and decreased slowly afterward. Notably, there was a decrease in the rate of drying of the instant mung bean vermicelli during microwave drying.

Microstructure

In general, several small pores could be created inside the vermicelli during the freezing and thawing period. The number of pores increased in the microwave heating process because the ice melted to water in the first round and then became steam removed from the vermicelli strand in the second round until dry. The images produced using scanning electron microscopy (SEM) on the microwaveable vermicelli and commercial vermicelli are shown in Figure 3. It was apparent that the size and number of pores in microwaved, dried vermicelli increased when the speed of the conveyor belt increased. The vermicelli dried at 50 Hz had less pores with small voids and a denser structure, while almost of the structure of the vermicelli dried at 70 Hz had larger pores. Notably, the shorter drying time, the greater the number of pores inside the vermicelli strands, which could be explained by the porosity inside the vermicelli strand being caused by the rearrangement and gelatinization of starch granules. It was in the agreement with Shen et al. (2021) who used a home microwave with a frequency of 2,450 MHz and a power density of 5 W/g for drying the germinated brown rice (GBR) for 1, 2, 3, 4, and 5 min. The structure inside the GBR changed with an increased drying time, resulting in the dense structure of the fresh GBR being rearranged after drying for 1 min, with even more pores after 2 min; however, starch gelatinization occurred at 3 min and was completed by 5 min, due to the rising temperature inside the GBR grains causing gelatinization of the starch granules.

Compared to the microwave dried vermicelli, there were smaller pores in the commercial vermicelli with less uniformity because of the convection and conduction of heat in the hot air-drying system resulting in a long rehydration time for the noodles. Pongpichaiudom and Songsermpong (2018a) demonstrated using SEM that the instant noodles dried using the hot-air method had a more compact surface and smaller voids, compared to the larger, uniform pores following drying using microwave and infrared methods.

Cooking qualities

Cooking qualities are one of the important properties of instant mung bean vermicelli that include water absorption, cooking loss, and volume increase, as presented in Table 3. The results showed that the water absorption of microwaveable vermicelli increased when the speed of the conveyor belt increased due to the porous structure. An increase in porosity leading to the contact surface area between the vermicelli strand and the cooking water resulted in high water absorption (Phukasmas et al., 2021). The water absorption of vermicelli dried at 50 Hz was lowest (372.44%; $p \leq 0.05$), while there was no significant difference between that of 60 Hz and 70 Hz ($p \geq 0.05$; 386.56 and 390.04%, respectively). In comparison, the commercial vermicelli had a lower percentage of water absorption (347.34%) than the microwaved vermicelli, due to the pore characteristics.

Cooking loss is the amount of starch and other soluble components in the vermicelli that are leached into the water, resulting in cloudy, thickening cooking water during the cooking time (Fu, 2008), Thus, cooking loss was used to evaluate the quality of the noodle product, where a lower amount of cooking loss indicated better quality (Photinam et al., 2016), with the maximum loss level being 10% (Tan et al., 2009). The cooking loss values of the instant mung bean vermicelli are presented in Table 2. The highest value (0.70% cooking loss) was for the commercial vermicelli, followed by the vermicelli dried at 70 Hz (0.38% cooking loss) and the lowest loss (0.26%) was in the vermicelli dried at 50 Hz. In fact, instant noodles prepared using the microwave drying method had a lower percentage of cooking loss than the infrared drying and hot air-drying method (Pongpichaiudom and Songsermpong, 2018a).

The volume increase in the microwaved vermicelli was in the range 20.75–24.22%, while that of commercial vermicelli was 15.19% (Table 2). The volume increase in the vermicelli was correlated highly with water absorption—the more water absorption, the greater the volume increase in the vermicelli. This was very consistent with the study of Kang et al. (2017), who reported that the volume increase in wheat flour noodles was highest due to it having the highest water absorption.

The rehydration time of instant mung bean vermicelli is the time taken for the absorption of hot water (90 ^{o}C) to inside the noodle strands. An increase in the water absorption rate produces a short rehydration time (Table 2). The vermicelli dried at 50 Hz rehydrated in 3.05 min, while there was no significant difference ($p \geq 0.05$) between drying at 60 Hz and 70 Hz with rehydration times of 2.81 and 2.79 min, respectively. These results agreed with the research of Phukasmas and Songsermpong (2019), who reported that the rehydration time of instant rice decreased from 8 min to 7 min to 4 min, when the controller frequency increased from 20 Hz to 30 Hz to 40 Hz, respectively. Notably, the rehydration of the microwaved vermicelli was shorter than for the commercial vermicelli which rehydrated within 8 min. Thus, it was generally proved that microwave drying generated a porous structure inside the vermicelli, resulting in a short rehydration period. Similarly, Pongpichaiudom and Songsermpong (2018a) compared infrared and hot-air drying technology and reported that instant noodles supplemented with protein dried using microwave technology was rehydrated in the shortest period (within 3 min) using hot water at 90 ^{o}C.

Color

Color has been become an important factor in the evaluation of the quality of cooking materials or the age of the products due to the visual impact for the customer. Therefore, a dark, or gray color would be a negative attribute (Piwińska et al., 2015). In Asia, consumers prefer transparent mung bean vermicelli and a white color, while dark colors are rejected. The final vermicelli products dried in a continuous microwave oven at different inverter power levels are shown in Figure 4.

The color parameters (L^*, a^*, b^*, and ΔE^*) of the dried instant mung bean vermicelli are shown in Table 3. Compared to the color of the commercial vermicelli (Lion brand), the microwaved vermicelli had higher values for lightness (L^*), greenness (a^*), and yellowness (b^*). There was good removal of protein during the starch extraction process and the short drying process at high temperature in the microwave treatments. In these microwave treatments, the L^* value of samples dried at 50 Hz was highest (74.56), followed by that at 60 Hz (73.36) and lowest for at 70 Hz (72.37). The a^* value of samples dried at 50 Hz (0.42) was higher than that at 60 Hz (-0.82) and at 70 Hz (-0.77). The highest b^* value was in samples dried at 50 Hz (7.82), while the results at 60 Hz (6,85) and 70 Hz (6.89) were not significantly different. These results were due to the longer drying times under high temperature influencing nonenzymatic browning (Song et al., 2007) which were necessary for the 50 Hz treatment. Phukasmas and Songsermpong (2019) studied the whiteness of instant rice using microwave drying at 20 Hz, 30 Hz, and 40 Hz and reported that the whiteness index decreased when as the speed of the conveyor belt of the dried instant mung bean vermicelli, values of 71.21, 74.22, and 76.78, respectively. The total color difference (ΔE^*) of microwave-dried vermicelli was not significantly different compared to commercial vermicelli with values of 7.54, 6.14, and 6.96 at 50 Hz, 60 Hz, and 70 Hz, respectively.

After cooking, the color of the instant mung bean vermicelli had higher values for lightness, greenness, and blueness compared to commercial vermicelli and uncooked vermicelli (Table 3). Notably, the color of the cooked vermicelli dried at 70 Hz was the most different based on L^*, a^*, and b^* values compared to the others. The total color difference of cooked vermicelli was lower that of uncooked vermicelli, while the values for the vermicelli samples dried at 60 Hz and 70 Hz were not significantly different from the commercial vermicelli. These results revealed that protein affected the color of the vermicelli during processing, with the more protein in the noodle, the darker the noodle. Ozkan et al. (2007) observed that microwave drying minimized the change in color and preserved the color without causing any surface overheating.

Textural properties

Textural characteristics of the noodles affect the final acceptability to consumers (Pongpichaiudom and Songsermpong, 2018b). During the soaking in hot water, the noodles absorbed water from the surface toward the center of the noodle strands, resulting in a soft texture (Jang et al., 2016). The tensile strength and the elasticity of the instant mung bean vermicelli are shown in Table 4, which revealed the extensibility and prolongation of the vermicelli. The tensile strength of the microwaved samples was in the range 0.0100–0.0116 N compared to commercial vermicelli with a value of 0.1148 N. However, the elasticity of the microwave-dried vermicelli was significantly lower than that of commercial vermicelli. The elasticity values of the instant mung bean vermicelli dried using microwaves at 50 Hz, 60 Hz, and 70 Hz were 19.89, 15.14, and 12.95 mm, respectively, while that of commercial vermicelli was 25.82 mm. The lower elasticity of the microwaved vermicelli might have been due to their weak structure (Nura et al., 2011) cause by the porosity inside the vermicelli strands, with greater porosity resulting in poorer elasticity. Furthermore, differences between factory and hand-made production techniques might have affected the texture of the vermicelli.

Sensory evaluation

The instant mung bean vermicelli was evaluated by serving with and without soup and the results are presented in Table 5. As can be seen, without adding soup, the appearance and clarity attributes of the microwave-dried vermicelli were not significantly different ($p \geq 0.05$) from the commercial vermicelli. The appearance score of the microwaved vermicelli

Table 1. Operation properties of microwave continuous dryer.

Inverter (Hz)	Mass load (g)	Conveyor belt speed (cm/min)	Microwave heating time per round (min)	Number of rounds on conveyor belt	Total drying time (min)
50	80	128/1.50(= 85.33)	1.50	12	18.00
60	80	128/1.33 (= 96.24)	1.33	14	18.62
70	80	128/1.18 (= 108.47)	1.18	16	18.88

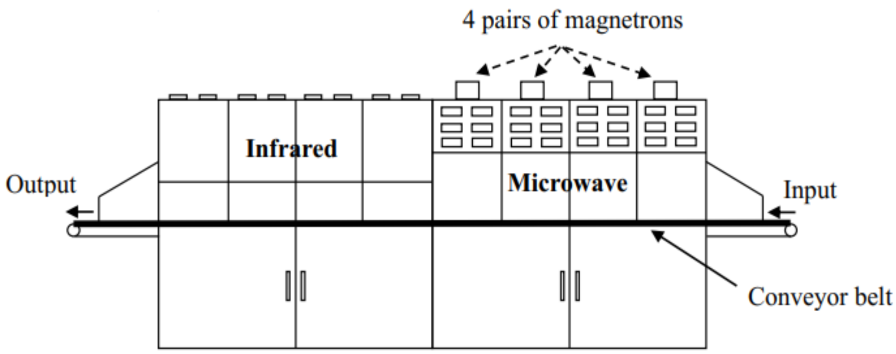

Figure 1. Illustration of microwave continuous dryer (J&W Engineering Co. Ltd.; Thailand)

Table 2. Cooking characteristics of instant mung bean vermicelli.

Inverter (Hz)	Water absorption (%)	Cooking loss (%)	Volume increase (%)	Rehydration time (min)
50	372.44 ± 4.01^{b}	0.26 ± 0.01^{d}	20.75 ± 0.03^{c}	3.05 ± 0.05^{b}
60	386.56 ± 3.77^{a}	0.32 ± 0.04^{c}	23.03 ± 0.55^{b}	2.81 ± 0.09^{c}
70	390.04 ± 1.39^{a}	0.38 ± 0.06^{b}	24.22 ± 0.45^{a}	2.79 ± 0.03^{c}
0 (Commercial)	347.34 ± 0.66^{c}	0.70 ± 0.02^{a}	15.19 ± 0.00^{d}	8.00 ± 0.02^{a}

Mean ± SD values with different, lowercase superscripts in the same column are significantly different at $p \leq 0.05$, according to Duncan's multiple range test.

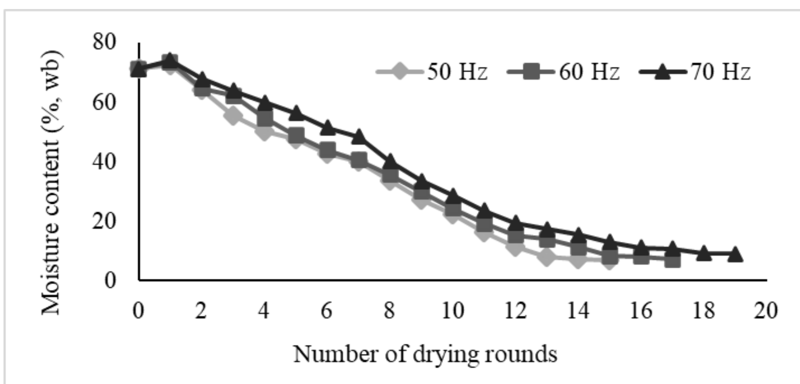

Figure 2. Drying curves of instant mung bean vermicelli during microwave heating.

Table 3. Color of instant mung bean vermicelli before and after cooking.

Inverter (Hz)	Color parameter							
	L^*		a^*		b^*		ΔE^*	
	Uncooked	Cooked	Uncooked	Cooked	Uncooked	Cooked	Uncooked	Cooked
50	74.68 ± 0.87^{Aa}	70.44 ± 0.43^{Bb}	-0.88 ± 0.07^{Ac}	-3.00 ± 0.04^{Bb}	7.82 ± 0.55^{Aa}	-4.53 ± 0.23^{Bc}	7.38 ± 0.82^{Aa}	2.43 ± 0.18^{Bb}
60	73.36 ± 0.79^{Aab}	73.29 ± 0.54^{Aa}	-0.82 ± 0.06^{Abc}	-2.34 ± 0.03^{Ba}	6.85 ± 0.75^{Ab}	-2.81 ± 0.28^{Bb}	5.76 ± 0.91^{Aa}	3.16 ± 0.49^{Bb}
70	72.62 ± 0.45^{Aab}	73.09 ± 0.79^{Aa}	-0.77 ± 0.10^{Ab}	-2.33 ± 0.08^{Ba}	6.89 ± 0.77^{Ab}	-2.91 ± 0.21^{Bb}	6.96 ± 0.43^{Aa}	2.97 ± 0.77^{Bab}
0 (Commercial)	69.43 ± 0.99^{Bb}	70.20 ± 0.17^{Ab}	-0.42 ± 0.03^{Aa}	-2.28 ± 0.05^{Ba}	2.69 ± 0.21^{Ab}	-2.26 ± 0.16^{Ba}	-	-

Mean ± SD values with different, lowercase superscripts in the same column and uppercase superscripts in the same row of each parameter are significantly different at $p \leq 0.05$, according to Duncan's multiple range test.

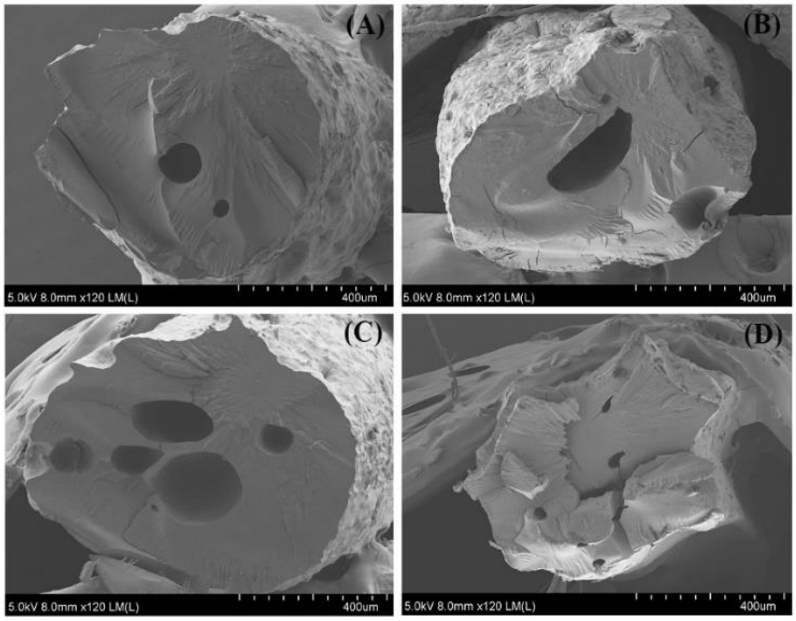

Figure 3. Images of microstructure of instant mung bean vermicelli after drying at different inverter power levels: (A) 50 Hz, (B) 60 Hz, and (C) 70 Hz. (D) 0 (commercial vermicelli).

Table 4. Texture parameters of instant mung bean vermicelli.

Inverter (Hz)	Tensile strength (N)	Elasticity (mm)
50	0.0100 ± 0.002[b]	19.89 ± 1.91[b]
60	0.0113 ± 0.002[a]	15.14 ± 2.19[c]
70	0.0116 ± 0.002[a]	12.95 ± 2.48[d]
0 (commercial)	0.0117 ± 0.001[a]	25.82 ± 5.98[a]

Mean ± SD values with different, lowercase superscripts in the same column are significantly different at $p \leq 0.05$, according to Duncan's multiple range test.

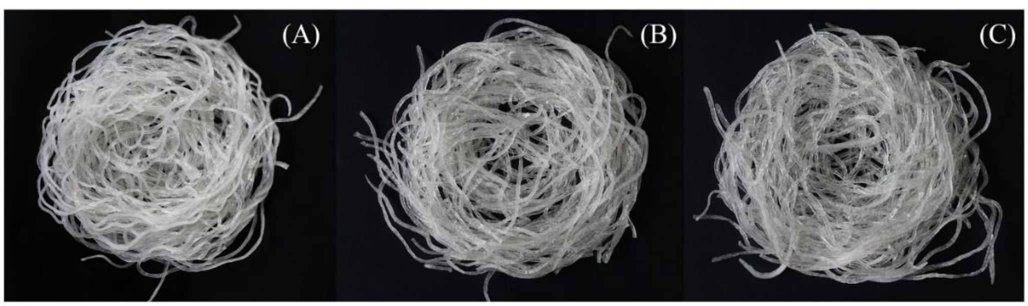

Figure 4. Instant mung bean vermicelli after drying using microwaves at different inverter power levels: (A) 50 Hz, (B) 60 Hz, and (C) 70 Hz.

Table 5. Sensory evaluation score of cooked instant mung bean vermicelli.

Attributes	Inverter (Hz)			
	50	60	70	0 (Commercial)
Without adding soup				
Appearance	6.73 ± 1.17[a]	6.90 ± 1.42[a]	7.00 ± 1.29[a]	6.77 ± 1.41[a]
Clarity	6.17 ± 1.18[a]	6.10 ± 1.65[a]	6.40 ± 1.48[a]	6.70 ± 1.34[a]
Flavor	6.20 ± 1.49[b]	6.63 ± 1.47[ab]	6.33 ± 1.65[ab]	7.10 ± 1.27[a]
Texture	6.00 ± 1.72[b]	6.60 ± 1.54[ab]	6.60 ± 1.69[ab]	7.20 ± 1.45[a]
Overall acceptability	6.13 ± 1.38[b]	6.77 ± 1.33[ab]	7.03 ± 1.35[a]	7.03 ± 1.35[a]
With adding clear soup				
Appearance	6.20 ± 1.56[a]	6.67 ± 1.18[a]	6.83 ± 0.83[a]	6.47 ± 1.46[a]
Clarity	6.07 ± 1.56[a]	6.30 ± 1.29[a]	6.43 ± 6.43[a]	6.30 ± 1.37[a]
Flavor	6.63 ± 1.40[a]	6.67 ± 1.24[a]	6.80 ± 1.13[a]	6.70 ± 1.21[a]
Texture	6.20 ± 1.65[b]	6.83 ± 1.18[ab]	6.63 ± 1.19[ab]	7.10 ± 1.47[a]
Overall acceptability	6.37 ± 1.52[a]	6.77 ± 1.14[a]	6.80± 0.76[a]	6.77 ± 1.17[a]

Mean ± SD values with different, lowercase superscripts in the same row of each attribute are significantly different at $p \leq 0.05$, according to Duncan's multiple range test.

was in the range 6.73–7.00, while that of the commercial vermicelli was 6.77. There were no significant differences ($p \geq 0.05$) in flavor, texture, and overall acceptability among the samples dried at 60 Hz, 70 Hz, and the commercial sample, while the results for the vermicelli dried at 50 Hz were th lowest. Notably, the score of general acceptability of vermicelli dried at 70 Hz (7.03) was the same as for the commercial vermicelli. Adding hot soup to the cooked instant mung bean vermicelli before serving to panelists resulted in no significant differences in the appearance, clarity, flavor, and general acceptability between all microwaved and commercial vermicelli samples. The texture of microwaved vermicelli dried at 50 Hz had the lowest score (6.20), while there were no significant differences ($p \geq 0.05$) among the others that were in the range 6.63–7.10. These results provided strong evidence that the microwave drying technology could produce good quality, instant, mung bean vermicelli.

Ethical issues

This study was approved by the Kasetsart University Research Ethics Committee on 16 June 2022 (study code KUREC-SSR65/101) and was carried out in compliance with the International Guidelines for Human Research Protection as detailed in the Declaration of Helsinki, Belmont Report, CIOMS Guidelines, International Conference on Harmonization in Good Clinical Practice (ICH-GCP) and 45CFR 46.101(b).

Materials and methods

Materials

The hulled-split mung bean (Khao Thong Brand; Thai Food Industry Co. Ltd.; Thailand) were purchased from a supermarket. The handle extruder (made in Thailand), supermass colloider (Masuko Sangyo Co. Ltd.; Japan), basket centrifuge (Centurion Scientific Ltd.; UK), and microwave continuous dryer (J&W Engineering Co. Ltd; Thailand) were provided by the Food Processing Pilot Plant, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand.

Instant mung bean vermicelli preparation

Mung bean starch was extracted from the hulled-split mung bean following the method reported by Photinam et al. (2016). The mung bean vermicelli was prepared using the method of Tan et al. (2006), with slightly modifications. The mixture starch was made using 95.5 g of uncooked starch and 4.5 g of pre-gelatinized starch. The pre-gelatinized starch was prepared by heating the raw starch and water in the ratio 1:10 (w/w) for 5 min. Then, hot water was added into the starch and mixed for about 10 min until the dough did not stick to the hands of the person doing the mixing. Then, 120 g of hot water was continuously added to reach a dough moisture content of 55%, after which it was extruded into boiling water (98–100 ^{o}C) using a handle extruder with a diameter of 1.5 cm. The extruded dough was cooked for 3 min and after that the vermicelli strands were transferred to cold water. Finally, the vermicelli strands were drained, frozen at -15 ^{o}C for 24 h and then thawed to separate the vermicelli strands.

Drying procedure

Liquid nitrogen of 500 g was used to freeze 4 pieces in each 20 g circular sample in a Teflon tray for 2 min before drying dried at 50, 60, or 70 Hz in a speed-controlled inverter that produced equivalent conveyor belt speeds of 85.33, 96.24, and 108.47 cm/min, respectively. During the processing, the tray containing the vermicelli strands was placed on the conveyor belt and passed through the microwave heating section (length of 128 cm), while the infrared section was not operated in this study. The unit operated as a pulsed system (Figure 1), with the sample taken out after one drying round and then returned to conveyor belt with a lag time between each round of 1 min. Therefore, different speeds had different rounds, with the fast speed having more rounds until dried. The final product was packed in plastic bags and stored at 25 ^{o}C for further analysis. A commercial vermicelli sample (Lion Brand; Thailand) dried using the conventional process was used as a control sample.

The operation parameters for the microwave dryer at 50–70 Hz are presented in Table 1. Notably, the time spent drying decreased as the speed of the conveyor belt increased, resulting in a greater number of rounds in the drying process (the highest speed needed more rounds, resulting in the highest total time. The final moisture content was expected to be below 1% on a wet basis (wb).

Determination of moisture content

The method of AOAC (2000) was used to determine the moisture content of the instant mung bean vermicelli. A sample of 10 g from every round for every condition was collected and dried at 105 ^{o}C for 24 h in a hot-air oven. The sample was weighed to calculate the moisture content, which was presented as a percentage on a wet basis.

Microstructure evaluation

The microstructure of the dried instant mung bean vermicelli strand was observed using scanning electron microscopy (SEM; FEI, Inspect S50; the Netherlands). The vermicelli strands were attached onto the top of an aluminum stub using double-sided tape. The porous structure was detected at 50X magnification.

Determination of cooking quality

Following the protocol of 60 – 55 AACC, 2000 to determine the cooking quality of the mung bean vermicelli. Water absorption was determined using 25 g (on a dry basis) of dried vermicelli immersed in 300 mL hot water at 90 ^{o}C until the white core inside the vermicelli strand disappeared. Th sample was cooled in 50 mL of distilled water for 1 min and then allowed to drain for 5 min. Then, the cooked vermicelli was weighed immediately and water absorption was calculated using for equation (1):

$$\text{Water absorption (\%)} = \frac{\text{Weight of cooked vermicelli (g)} - \text{Weight of uncooked vermicelli (g)}}{\text{Weight of uncooked vermicelli (g)}} \text{ x } 100 \quad (1)$$

Cooking loss was determined by transferring the cooking water above to a moisture can and drying at 105 ^{o}C for 24 h. The loss was calculated using equation (2):

$$\text{Cooking loss (\%)} = \frac{\text{Weight of dry matter in cooking water (g)}}{\text{Weight of dry noodles (g)}} \text{ x } 100 \quad (2)$$

The volume increase was calculated by soaking 20 g of instant vermicelli before and after cooking, respectively, in 300 mL of distilled water in a 500 mL cylinder. The volume increase was calculated using equation (3):

$$\text{Volume increase(\%)} = \frac{\text{Volume of cooked vermicelli (mL)} - \text{Volume of uncooked vermicelli(mL)}}{\text{Volume of uncooked vermicelli (mL)}} \times 100 \quad (3)$$

The rehydration time was determined following the method of Pongpichaiudom and Songsermpong (2018a), with a slight modification. A sample (25 g) was contained in a lidded cup of 500 ml, then added with 300ml hot water of 90 ^{o}C, and the lid was sealed, with stirring every 30 s. The rehydration time was recorded as the time until the white core inside the vermicelli strand had disappeared.

Color measurement

A Hunter Lab colorimeter (Hunter Associates Laboratory Inc.; USA) was used to measure the color of the mung bean vermicelli samples. About 20g of ground sample were placed in plastic bags before measuring. A white and black standard was used to calibrate the colorimeters. The color values of L^* (100 for white and 0 for black), a^* (redness-greenness), and b^* (yellowness-blueness) were measured using a D65 illuminant. The total color difference (ΔE^*) values between the commercial vermicelli (control sample) and the different mung bean vermicelli samples were determined using equation (4):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (4)$$

where ΔL^* is $L^*_{sample} - L^*_{control}$, Δa^* is $a^*_{sample} - a^*_{control}$, and Δb^* is $b^*_{sample} - b^*_{control}$.

Texture measurement

The tensile strength (maximum force; N) and elasticity (distance at maximum force, mm) of the mung bean vermicelli samples were measured using a texture analyzer (TA; XT. Plus; Stable Micro Systems Ltd.; Godalming, UK) following the method of (Photinam *et al.*, 2016) with modification. Each sample (25 g dry basis) of dried vermicelli was immersed in 300 mL of hot water (90 ^{o}C) until the white core inside the vermicelli strands had disappeared. Next, the vermicelli strands were cooled in 50 mL distilled water for 1 min and drained for 5 min. The sample was cut into 25–30 cm lengths and placed around a parallel spaghetti rig probe (A/SPR). The instrument settings for each treatment of 20 specimens were: extension mode; trigger type, auto 5.0 g; pre-test speed, 3.0 mm/s; post-test speed, 5.0 mm/s; test speed, 3.0 mm/s; and trigger distance, 70 mm.

Sensory evaluation

Thirty untrained panelists volunteered to do sensory evaluation, they were aged from 22 to 40 years from the Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand. Each panelist was served separate 20 g samples of cooked vermicelli with and without clear soup (500 g of water boiled with 200 g of Clear Chicken Broth Concentrate Soup (CP Brand)) with a ratio of sample-to-soup of 1:1. The attributes of appearance, clarity, flavor, texture, and general acceptability were evaluated by each panelists based on a 9-point hedonic scale, with 9 being 'extremely like' to 1 being 'extremely dislike'.

Ethical issues

The ethical considerations regarding the panelists were based on the three principles of human research ethics (Respect for person, Beneficence/non-maleficence, and Justice). Each panelist was provided with an overview of the study and asked to make an independent informed decision on whether to participated in the research. They were told that the privacy and confidentiality of the panelists would be respected at all times. No personal identifying information was kept with the collected data. There was no perceived beneficence/non-maleficence associated with the study, with only a small risk that the confidentiality of the 30 research subjects would be disclosed. The principle of justice was based on clear inclusion and exclusion criteria, with the benefits and risks being equally distributed without bias.

Statistical analysis

Analysis of variance (ANOVA) was performed using the statistical SPSS software Version 17 (IBM; Chicago, IL, USA). Comparisons between means were examined based on Duncan's multiple range test (DMRT) at the $p \leq 0.05$ significance level. The results from three replications were presented as the mean value ± standard deviation.

Conclusions

The developed microwave continuous drying method reduced the rehydration time of instant mung bean vermicelli to less than 3 min at 60 Hz or 70 Hz. In addition, the sensory properties of the instant mung bean vermicelli dried at 60 Hz or 70 Hz were not significantly different; in particular, the same score for general acceptability (7.03) was given by the panelists for the vermicelli dried at 70 Hz and the commercial vermicelli. Furthermore, the 70 Hz power setting for the inverter and using 16 rounds were recommended to produce good quality instant mung bean vermicelli with a short rehydration time.

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