Effect of Food Chemical Compositions on the Dielectric and Thermal Properties of Instant Noodles with Chicken Meat, Egg Yolk and Seaweed Enrichment

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***Abstract*—To understand the interaction between enriched protein instant noodles and microwave drying, this study aimed to determine the effect of chemical compositions on the dielectric and thermal properties of instant noodle enrichment with chicken meat (0, 15, 30 g/100 g flour), egg yolk (0, 7.5, 15 g/100 g flour) and seaweed (0, 3, 6 g/100 g flour) according to the factorial design in RCBD. Instant noodle samples had a wide range of the chemical component content (%wet basis): moisture 30.23-42.26, protein 11.81-19.75, ash 1.50-4.45, fat 0.07-6.88, carbohydrate 39.88-46.38 and crude fiber 0.06-0.74. Results revealed that moisture and protein content significantly increased the dielectric constant and loss factor. Moreover, as moisture and ash content increased, the specific heat significantly increased. In addition, fat content significantly decreased the thermal conductivity. In contrast, fat and carbohydrate content did not significantly affect the dielectric properties. In conclusion, the addition of moisture and protein content had a major correlation to increase dielectric properties of instant noodles while fat and carbohydrate content had a negative correlation. Therefore, this knowledge can be applied to the uniformity heating of instant noodles in the microwave processing.**

***Index Terms*—chemical composition, chicken meat, dielectric properties, instant noodle, microwave drying, thermal properties**

I. Introduction

Nowadays, industrial microwave oven becomes an essential appliance in food industries due to faster cooking time, energy saving, food nutritional preserving, and better quality over conventional cooking [1]. Because of the conversion of electromagnetic energy into heat by dipolar rotation and ionic conduction mechanism of microwave heating, it reduces heating time than the conventional heating, which relies on conduction and convection of heat transfer [2].

In microwave processing, the interaction between microwave radiation and the food material depends on the dielectric properties which consist of dielectric constant and loss factor. The dielectric constant is the ability of a material to store energy in electric field and the dielectric loss factor is the ability of a material to dissipate energy into heat [3]. Ref [4] emphasized that to design, optimize and control of the drying process of microwave, dielectric properties' knowledge is essential to know.

In general, the dielectric properties are influenced by frequency, temperature, moisture content, structure of the food material and also determined by their chemical compositions. [5]. The effect of starch, lipid and protein on dielectric behavior is interested because it can explain the interaction between the food matrix and electromagnetic fields [6], [7], which can be useful for formulating functional food. In present, the most popular method for measuring the dielectric properties of foods is open-ended coaxial probe [8], which is non-destructive method. It is easy to use by contact the probe with the material being tested. After that, the dielectric properties are calculated from the phase and amplitude of the reflected signal [9].

Moreover, chemical composition affects the thermal properties of food such as thermal conductivity (k) and specific heat capacity (C_p). The dielectric and thermal properties can be used to predict heating rates, which can describe the behavior of food materials when subjected to the microwave processing. There have been several attempts to develop relationships between thermal conductivity and chemical composition [10], [11]. However, the effect of food chemical compositions on the dielectric properties of food is not well defined. This research aimed to produce non-fried and quick-boiling enriched protein instant noodle by adding chicken meat, egg yolk and seaweed into the basic ingredients of instant noodles in order to increase the nutritional values and

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drying by a continuous industrial microwave oven instead of deep frying process. To understand the interaction of microwave energy and food product, the dielectric properties of instant noodles must be known.

Hence, the objective of this study was to examine the effect of chicken meat, egg yolk and seaweed enrichment on food chemical compositions of the instant noodles. The dielectric properties were measured at frequency 2,450 MHz and 22 ℃ using an open-ended coaxial probe connected to a network analyzer. After that, the influence of food chemical composition on the dielectric and thermal properties was studied. This obtained information can be applied to design the food heating behavior for industrial microwave processing.

II. Materials and Methods

A. Instant Noodle Preparation

Instant noodles were formulated from 100 g all purpose wheat flour, 2 g salt, 47 g liquid (including water and egg yolk), chicken meat and seaweed. Wheat flour and seaweed were mixed in the mixing bowl prior to the addition of chicken meat, egg yolk and water containing dissolved salts. All ingredients were mixed using a mixing machine for 5 min to get crumbly dough and rested in a plastic bag for 30 min at 22 ℃. To make instant noodle, after resting, the dough was flattened with a rolling pin to smooth and firm it and fed into the rollers until number 8 settings of noodle making machine (Altas 150, Marcato, Italy) to obtain 1 mm dough sheet thickness. Then, the sheet was weighted for 120 g, fold and roll to obtain the dough with 2 cm thickness for the dielectric properties' measurement.

B. Dielectric Properties Measurement

The open–ended coaxial probe technique and network analyzer (Hewllet-Packard, Santa Rosa, CA) were used to measure the dielectric properties of 2 cm thickness noodle dough of 120 g. Each sample was measured in 5 replications at room temperature (22 ℃). Calibration was performed using an air, short, and water before every test. The dielectric constant and loss factor were calculated from the phase shift and the magnitude of the reflected signal by the software.

C. Thermal Properties Measurement

The thermal properties were measured using a KD2 Pro Thermal Properties Analyzer (Decagon Devices Inc. Pullman, WA), The 30 mm long, 1.28 mm diameter, and 6 mm spacing dual needle SH-1 sensor measured the thermal conductivity at room temperature (22 ±1 ℃).

The specific heat of instant noodle was determined by differential scanning calorimeter (DSC, Q2000, TA Instruments, New Castle, DE) from the energy required to establish a zero temperature difference between the substance and a reference material. The sample of 40 mg was placed in aluminum pans. Measurements were conducted within a temperature interval between 15 ℃ and 90 ℃. All DSC measurements were performed at a scanning rate of 5 ℃/min.

D. Proximate Analysis

1 mm dough sheet thickness was cut into noodle strands with noodle cutting machine (Altas 150, Marcato, Italy). Sample was broken into small fragments and ground until material sample could pass sieve no.20 and kept the sample in sealed packaging. Moisture content was determined in triplicates by the oven method according to AOAC (2012) method 925.10. Ash was measured by dry combustion (AOAC 2012, 923.03). Protein content was measured by AACC (2000) method 46.30 using LEGO CHN analysis with a protein factor of 6.25. Crude fat was determined by the soxhlet apparatus following AOAC 2012 method 920.39. Crude fiber was determined by AOAC 2012 method 978.10 and total carbohydrate was determined by difference.

E. Experimental Design and Statistical Analysis

Factorial in a randomized complete block design (Factorial in RCBD) was used in this study with three independent variables, chicken meat content (0, 15, 30 g/100 g flour), egg yolk content (0, 7.5, 15 g/100 g flour) and seaweed content (0, 3, 6 g/ 100 g flour) on moisture content, protein content, fat, ash, carbohydrate, and the dielectric and thermal properties (Table I) that was leading to 27 sets of experiments. All experiments were performed in triplicate. Statistical analyses were performed by using SPSS Version 16 (SPSS Inc., Chicago, IL, U.S.A.) and a Duncan's multiple range test in the statistical analysis at a probability level of 0.05.

TABLE I. Variables, Levels in Factorial in Rcbd

Experiment	Chicken meat(g) (X1)	Egg yolk (g) (X2)	Seaweed (g) (X3)
1	0	0	0
2	0	0	3
3	0	0	6
4	0	7.5	0
5	0	7.5	3
6	0	7.5	6
7	0	15	0
8	0	15	3
9	0	15	6
10	15	0	0
11	15	0	3
12	15	0	6
13	15	7.5	0
14	15	7.5	3
15	15	7.5	6
16	15	15	0
17	15	15	3
18	15	15	6
19	30	0	0
20	30	0	3
21	30	0	6
22	30	7.5	0
23	30	7.5	3
24	30	7.5	6
25	30	15	0
26	30	15	3
27	30	15	6

III. RESULT AND DISCUSSION

A. *Effect of Chicken Meat, Egg Yolk and Seaweed on Chemical Composition*

Instant noodle samples had a wide range of the chemical compositions: moisture content 30.23-42.26%wet basis, protein content 11.81-19.75 %wet basis, ash content 1.50-4.45%wet basis, fat content 0.07-6.88%wet basis, carbohydrate content 39.88-46.38 %wet basis and crude fiber 0.06-0.74 %wet basis. The addition of chicken meat significantly ($P \leq 0.05$) increased moisture and protein content and decreased carbohydrate (Table II). Ref [3] reported that the range of moisture content of chicken breast muscle was from 75.7 to 76.2% wet basis that increased moisture content of instant noodle. Moreover, chicken meat contained high protein content approximately 82.05-87.56 g per 100 g dry matter [12]. The addition of egg yolk significantly increased fat content because egg contained 34% fat in the yolk [13]. The ash and crude fiber contents were increased with the addition of seaweed. This finding was in agreement with [14] who reported that seaweed contained higher amounts of macro minerals such as Na, K, Ca and Mg so ash content was approximately between 1.1–39.3 %wet basis and contained large amounts of fiber. Regarding to chemical composition, the addition of chicken meat, egg yolk and seaweed could enhance the nutritional qualities such as protein, fat, fiber and essential minerals of instant noodle product when compare to the control.

TABLE II. EFFECT OF CHICKEN MEAT, EGG YOLK AND SEAWEED ON CHEMICAL COMPOSITION

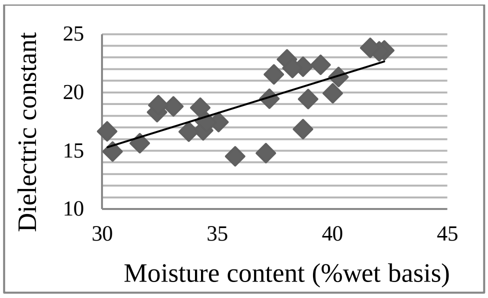
CK	EY	SW	Chemical composition (%wet basis)					
			Moisture	Protein	Ash	Fat	Carbo hydrate	Crude fiber
0	0	0	35.06±0.	11.81±	2.53±	0.16±	50.43±	0.14±
			11d	1.81a	0.09a	0.04a	1.99b	0.02a
			34.27±0.	12.84±			49.35±	
0	0	6	52c	1.47a	3.42±	0.12±	1.37b	0.26±
			30.23±0.	13.47±	0.14c	0.04a	49.76±	0.02c
			37a	1.39ab			1.95b	
0	15	0		13.73±	2.49±	4.05±		0.30±
			31.64±0.	0.92b	0.05a	0.34c	47.71±	0.12d
			63b	16.79±			1.33b	
			42.26±1.	2.58c			37.51±	
0	15	6	08h	17.71±	3.30±	3.63±	4.33a	0.21±
			41.66±0.	1.22c	0.08bc	0.35b	37.51±	0.05bc
			24g	19.75±	3.24±		1.31a	0.14±
30	0	0	38.96±0.	0.36d	0.82bc	0.20±	35.03±	0.02a
			36f	19.64±	3.08±	0.05a	0.22a	
			38.28±0.	0.49d	0.23b		34.82±	0.28±
30	0	6	22e			0.04±	0.96a	0.05d
					2.24±	0.09a		
					0.05a			0.17±
30	15	0				4.01±		0.02ab
					3.01±	0.20c		0.29±
					0.07b			0.03d
30	15	6				4.25±		
						0.28c		

CK: chicken meat; EY: egg yolk; SW: seaweed

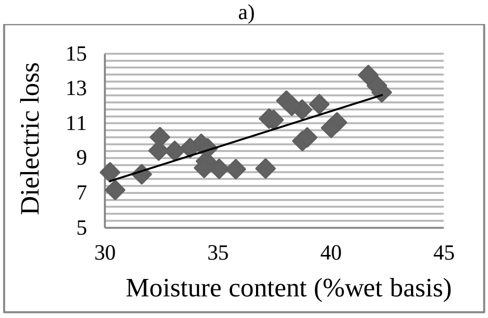
B. *Effect of Moisture Content*

Understanding of the effect of moisture content on the dielectric and thermal properties would be important to analysis of thermal processes. Due to it is the main source for microwave interactions by its dipolar nature [15]. In Fig. 1a and Fig. 1b, higher moisture content significantly ($P \leq 0.05$) resulted in the higher dielectric constant and loss factor of instant noodles. This could be explained by the high dielectric constant and loss factor of water, which was 78 and 23 at 25°C. Ref. [16], [17] described that water was a strong polar molecule and could rotate in the electromagnetic radiation that resulted in the higher dielectric constant. These results were in accordance with previous reports of [18], as the moisture content increased, the dielectric loss factor increased rapidly due to the increasing of ionization of bounds ions in the free water.

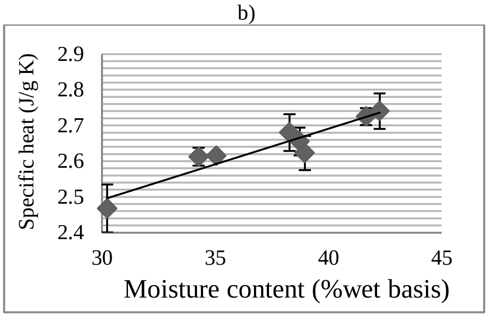
The variation of the specific heat of instant noodles with moisture content is shown in Fig. 1c. It can be seen that the specific heat was significantly ($P \leq 0.05$) increased by moisture content. The results were in agreement with the findings of other researchers [19] that water content would affect the heat capacity more than other components (Table III) and the lower heat capacity values generally occurred with the lower moisture content values.



a)



b)



c)

Figure 1. Increasing of a) dielectric constant and b) dielectric loss factor and c) specific heat due to the effect of moisture content

C. *Relationships between Food Chemical Composition on Dielectric and Thermal Properties*

To understand the relationship between dielectric properties and food chemical compositions, the dielectric properties values of instant noodle dough at various formulations were investigated. The regression equations for the dielectric properties at 2,450 MHz and 22 °C of instant noodles as affected by food chemical compositions are shown in equation 1 and 2. They expressed that the rate of heating was mainly affected by moisture and protein content. Higher coefficients of determination (R^2>0.85) was found in dielectric loss factor predicted equation.

Information on the correlations between food chemical compositions and the dielectric and thermal properties of instant noodles was provided using Pearson correlation analysis (Table III). Moisture content and protein content positively correlated with the dielectric constant and loss factor. As the protein content increased, the dielectric constant and loss factor increased (1 and 2). The increased of the dielectric properties with protein content was also reported for milk and soybean protein [20], [21].

In this case, high protein content came from the addition of chicken meat which was cut and blended by mixer prior supplement into instant noodles. Therefore, the protein became unfold that created protein denaturation and released water and dissolved ions. After that, their mobility increased which increased the dielectric properties. There was a larger increase in the dielectric loss factor than in the dielectric constant. The result corresponded with positively correlated between moisture and protein content (r = 0.687).

TABLE III. CORRELATIONS BETWEEN FOOD CHEMICAL COMPOSITION ON DIELECTRIC AND THERMAL PROPERTIES

	Moisture content	Protein content	Ash content	Fat content	Carbohydrate content
Dielectric constant	0.744**	0.487**	0.08	-0.27	-0.16
Dielectric loss factor	0.824**	0.554**	0.21	-0.31	-0.29
K	0.27	-0.20	0.02	-0.695**	0.15
Specific heat	0.952**	0.681	0.727*	-0.36	-0.11
Moisture content	1.00	0.687**	0.20	-0.359	-0.447*
Protein content	0.687**	1.00	0.07	0.383*	-0.425*

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

$$\text{Dielectric constant} = 51.594 - 91.077ASH - 42.973CB + 635.207MC^{3*} + 4950.459PT^{3*} - 1118.444\,MC{*}PT^{*} + 1373.362\,MC{*}FI \quad (1)$$
(R^2 = 0.74)

$$\text{Dielectric loss factor} = 35.654 - 445.013ASH - 37.890CB^{*} + 320.222MC^{3*} + 1340.838PT^{3} - 514.896\,MC{*}PT^{*} + 1125.513\,MC{*}FI^{*} + 2430.731\,PT{*}ASH \quad (2)$$
(R^2 = 0.85)

* Significant at the 0.05 level
MC: moisture content; PT: protein content; CB: carbohydrate content, and FI: fiber content in fraction

The dielectric constant and loss factor did not have a significant effect from the addition of ash, carbohydrate and fat content. However, dielectric properties had a positive correlation with ash content, especially the dielectric loss factor. This indicated that increased ash adds conductive charge carriers that increase the loss of the system as a result of charge migration. This positive influence of ash on dielectric properties was in agreement with previous observations [22]. Ref [18] found that the increasing of salt concentration largely affected the dielectric properties of the vegetable samples. It increased the ionic conductivity and produced a positive correlation between salt concentration and dielectric loss.

However, not only moisture content, but ash content also positively correlated with specific heat (r = 0.727). Ash content came from the addition of seaweed which contained high amounts of minerals such as Na and K. Specific heat of Na and K was 1.26 and 0.54 kJ/kgK, respectively. Therefore, the high specific heat of Na and K increased the specific heat of the instant noodles.

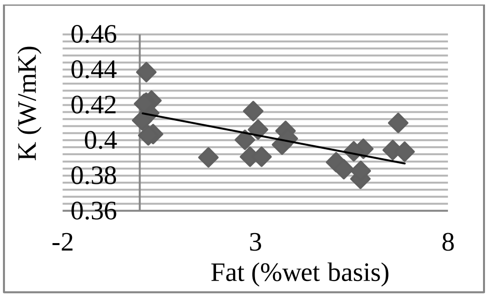


Figure 2. Effect of fat content on thermal conductivity

In contrast, carbohydrate and fat content negatively correlated with the dielectric properties. Carbohydrate has small dielectric properties at microwave frequencies because it does not show dipole polarization at microwave frequencies [3]. For high carbohydrate food such as instant noodles, the effect related to stabilization of hydrogen bonding patterns through hydroxyl–water interaction. After starch bonded with water molecules through hydrogen bonding that decreased water polarization and resulted in decreasing of the dielectric properties [23]. That related to negatively correlated between moisture and carbohydrate content (r = -0.447). However, ref [24] supported that the differences in starch type were not significant affected the dielectric properties, but water content was the most important factor affecting the dielectric properties.

General, fat has very low dielectric properties compared to water. Fat is regarded as inert in microwave field because of its non-polar molecule that has a low interaction with polarizing electromagnetic wave. Ref. [3] indicated that with higher fat content of meat, the result of dielectric properties was lower than lean tissue meat. In addition, the increase of fat content reduced the dielectric constant and loss factor, because the increasing of fat content diluted water ratio in the food system and resulted in the lower dielectric constant and loss factor [20].

Moreover, increasing of fat content not only reduced the interaction between food and electromagnetic wave. It significantly ($P \leqslant 0.05$) decreased the thermal conductivity (Fig. 2). Similar to result of [11] that thermal conductivity was strongly influenced by fat content. All these results provided necessary dielectric properties information to apply to microwave heating technology in the processing of dried instant noodles. In a microwave drying process, the reduction of loss factor resulted in less ability to convert electromagnetic energy into thermal energy. The wet part of the product could convert more microwave energy into thermal energy than the dry part. Therefore, drying time of microwave drying could be reduced significantly when compare to hot air drying processes, where the core of samples had higher moisture content than the surface [8]. Then it took longer time until it reached the final moisture content by hot air drying processes.

IV. Conclusion

To enhance nutritional values of the instant noodles, chicken meat, egg yolk and seaweed were supplemented and dried by a continuous microwave oven instead of deep oil frying. Therefore, the dielectric properties are being needed to understand the behavior of the instant noodles when it is submitted to electromagnetic heating. Food components such as moisture, protein, ash, carbohydrate and fat content are important parameters to design and improve the quality of microwaved food and develop new microwave process. Hence, chemical compositions, and the dielectric properties and thermal conductivity of instant noodles were investigated. The addition of chicken meat significantly increased moisture, protein and decreased carbohydrate content of instant noodles. Furthermore, egg yolks significantly increased fat content and seaweed significantly increased ash and fiber content.

The relationship between chemical compositions and the dielectric properties indicated that moisture and protein content significantly increased the dielectric constant and loss factor due to the increasing of dipole molecules of releasing water from protein muscle after protein denaturation. Moisture and ash content positively correlated with the dielectric properties and specific heat due to higher amount of water from chicken meat and Na and K from seaweed addition. In contrast, carbohydrate negatively correlated with the dielectric properties causing from the decreasing of water polarization when carbohydrate formed hydrogen bonding with water. Higher amount of fat content also decreased the dielectric properties and thermal conductivities. This knowledge will be useful for developing new food products and processes based on electromagnetic energy application that could improve the food qualities.

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