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Original Research Article

Modeling and Optimization of Rehydration Percentage of Magnetic Field Pretreated Sweet Pepper and Fluted Pumpkin Leaf

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ABSTRACT

This study focused on the effect of magnetic field pretreatment on rehydration percentage of sweet pepper (Capsicum annum) and fluted pumpkin leaf (Telfaria occidentalis). Three types of magnetic field (static, alternating and pulsed) of strength range of 5-30 mT was generated using a magnetic field (MF) device. Sweet pepper (SP) and fluted pumpkin leaf (FPL) used for the study was pretreated for a duration of 5-25 minutes. Fresh and blanched SP and FPL samples were used as control and all samples were oven-dried at 50 ℃. Results revealed that sweet pepper pretreated under AMF-6 (14 mT and 5 min) and PMF-6 (19 mT and 10 min) had the highest and lowest rehydration percentages of 80.52% and 62.69% respectively compared to blanched and fresh samples with rehydration percentages of 73.12% and 65.25%. For fluted pumpkin leaf, the highest (77.78%) and lowest (60.00%) rehydration percentages were obtained at PMF-7 (24.5 mT and 15 min) and SMF-6 (19 mT and 10 min) respectively compared to blanched and fresh samples with rehydration percentages of 64.29% and 66.67% respectively. Model equations developed showed that R^2 and R^2_{adj} values are in the range from 86% to 100% for both SP and FPL while the adequate precision (AP) was greater than 4. The best optimized conditions for SP and FPL are AMF (5.56 mT and 25 min) and AMF (10.42 mT and 9.96 min) respectively. MF pretreatment (a non-thermal) method enhances rehydration percentage of SP and FPL than blanching (thermal) method.

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1. INTRODUCTION

Sweet pepper (*Capsicum annum*) is one of the most consumed fruits and vegetables products in the world (Kelley and Boyhan, 2009). It is utilized either as a food or condiment for local dishes (Sharma *et al.*, 2015) and somehow considered the first spice to have been used by man based on archaeological evidence of pepper and other fossil foods dating back to 6000 years (Hill *et al.,* 2013). Sweet pepper is found in high demand by the global food industry due to its inherent characteristics such as flavor, aroma and color (Vega-Gálvez, 2008). Nutritionally, it contains low sodium and calories and also a good source of vitamins A and C (Owusu-Kwarteng *et al.,* 2017). Medicinally, it is used for treatment of various ailments such as arthritis, diabetes and cancer (Nishino *et al.,* 2009; Wahba *et al.,* 2010; Ozgur *et al.,* 2011). However, sweet pepper easily deteriorates due to its high moisture content and the losses are further intensified due to problems in the packaging, distribution and lack of appropriate manufacturing techniques (Sharma *et al.,* 2015).

Fluted pumpkin leaf (*Telfairia occidentalis),* locally referred to as *ugu* in Nigeria rates among many vegetables eaten in Nigeria and has good returns compared to the rest of tropical leafy products (Igbozulike, 2015; Agbugba and Thompson, 2015). Fluted pumpkin leaf is useful in the areas of human fitness, disease prevention and treatment, and supply of essential nutrients to the body (Muhammad and Nwanya, 2017). In developing countries, about 30-40% of harvested vegetables are wasted as a result of poor post-harvest handling (Salami *et al*., 2010; Hailu and Derbew, 2015).

In order to obtain dried fruits and vegetables products with the best organoleptic and nutritional qualities, pretreatment may be applied prior to drying (Onwuka *et al.,* 2002; Isaac *et al*., 2011; Ukegbu and Okereke, 2013; Maisnam *et al.,* 2017; Raponi *et al.,* 2017). Food pretreatment methods are widely applied in food processing so as to prevent the food from borne pathogen and preserve food qualities (Bintsis, 2017). Magnetic field (MF) pretreatment is one of the novel areas applicable to food processing. This method is used to adjust the free radicals and ion concentration without degrading the chemical profile of seeds and electrical charges present in food components (Minatel *et al*., 2017; Žuntar *et al.,* 2019) Furthermore, it improves membrane permeability, improves biochemical and physiological feedback and allows the free movement of ions (Jamil *et al*., 2012). Application of electromagnetic technology in food processing has gained industrial interest and can at least replace well-established conventional processes for conservation of foodstuffs which could promote better food processing (Rahman, 2007; Pereira and Vicente, 2010). More so, MF may be considered environmentally friendly, as they do not utilize chemical agents (Efthimiadou *et al.,* 2014). Static, pulse and alternating types of MF can be generated with electromagnet (Ahmed and Ramaswamy, 2007) and permanent magnets can be used to produce static type of MF only (Laakso *et al*., 2009; Ito *et al*., 2018). Several studies reported the electromagnetic pretreatment of plant materials using pulse electric fields (Toepfl and Knorr, 2006; Chauhan *et al*., 2018; Gomez *et al*., 2019), alternating magnetic field (Jia *et al.,* 2015) and static magnetic field (Kohno *et al.,* 2000). All these studies revealed that quality of plant and food materials were influenced by magnetic field strength and exposure time. Hayder *et al.* (2015) investigated the effect of MF pretreatment on Iraqi cheese and the result showed that MF had influence on the chemical qualities of milk, especially moisture content that significantly increased with increasing magnetic field exposure time and a similar trend was observed in titrated acidity but significant decrease in total bacteria count and increase in quantity of cheese produced from magnetize milk.

Rehydration is the process of moistening a dry material and it is adjudged as one of the quality characteristics of drying process (Wang and Xi, 2005; Akonor *et al.,* 2016). Assessment of rehydration properties is highly essential because it is considered as a remedy to the injury to the material caused by drying (Krokida and Philippopoulos, 2005; Figiel, 2007; Kowalska *et al.,* 2018). The behaviour of products during rehydration is a measure of the damage induced in the material during its drying thereby affecting its integrity and hydrophilic properties (Marques *et al.,* 2009). In general, absorption of water is rapid at the beginning; a consequence of rapid moisture uptake due to surface and capillary suction. Since drying process is characterized by many factors, likewise rehydration process which is a product of drying is said to be dependent on some functional factors such as porosity, temperature, trapped air bubbles, capillaries and surface cavity, soluble solids, dryness of the materials, anions, and the pH level of the soaking water which therefore affects rehydration capacity (Lewicki, 1998; Rahman and Perera, 1999). Also, many studies assessed the impact of rehydration properties of pretreated fruit and vegetables. In the study of Pervin *et al.* (2008), mechanical and solar drying the rehydration rate constant was higher for bean seeds without coat than those with coat. Both rehydration ratio and rehydration rate indicated that mechanically and solar dried bean seeds samples without coat showed better reconstitution properties than those with coat. During the rehydration of the pre-dehydrated dried fruit, a slower hydration could be observed that freeze-dried strawberries absorbed 2-3 times more water than those dried by the ‘puffing’ effect (Kowalska *et al.*, 2018). Others literatures related to rehydration properties related to pretreated dried products are: apple cubes (Winiczenko *et al.*, 2018), apricot and apple (Contreras *et al.,* 2011), and dried lablab bean (Pervin *et al.*, 2008). These studies revealed the importance of rehydration and pretreatment methods in their reports.

Gaware *et al.* (2010) studied the rehydration kinetics of tomato slices at two temperatures (25 and 100 ^oC) using different methods of drying. The authors observed that tomato slices obtained by freeze drying showed the highest rehydration ratio, followed by heat pump drying and microwave drying but reported a lower rehydration ratio in solar cabinet drying and concluded that values of coefficients of determination ($R^2 > 0.98$) indicated that the model proposed by Peleg is adequate to describe rehydration kinetics of tomato slices. Similar observation of coefficients of determination (R^2) was recorded in report of Goula and Adamopoulos (2009) in the rehydration process for dried tomato. Other studies have modeled the rehydration process for fruits and vegetables such as dried pumpkin slices (Benseddik *et al.*, 2019), basil (Demirhan and Özbek, 2010), cassava chips (Ajala *et al.*, 2015) and aloe vera (Vega-Gálvez *et al.*, 2009). These studies confirmed the characteristics of rehydrated products in using different drying models and reported that model fitting is a characteristic of predicting behaviour of rehydrated products.

Modeling can be used for better understanding of the rehydration property of dried foods; this will clearly bring out the functional relationships between the inputs and output variables of the process; and optimization will reveal the most suitable values or type of input variables that will give the values of conditions of all desired outputs. Magnetic field pretreatment of food is not so popular, even though it has many positive prospects due to its non-thermal characteristics. Information on modeling and optimization of rehydration property of magnetic field pretreated food is presently very scarce (most likely not in existence). Therefore, the objectives of this research were to investigate the effect of magnetic pretreatment factors (type of magnetic field, magnetic field strength and pretreatment time) on the rehydration percentage of sweet pepper and fluted pumpkin leaf; and to model and optimize the process.

2. MATERIALS AND METHODS

2.1. Experimental Equipment and Materials

The following major materials and equipment were used: a developed magnetic field pretreatment device; electronic weighing balance (OHAUS, Model 201, China), laboratory oven (Model SM9053, England), desiccator, fresh samples of fluted pumpkin leaf.

2.2. Methods

Fresh samples of fluted pumpkin leaf (FPL) and sweet pepper (SP) of good quality were procured in Ilorin, Kwara State, Nigeria. They were sorted, washed and cut into pieces to ensure better exposure to the magnetic field effect. Experimental quantities (10 g for FPL and SP) were measured with the electronic weighing balance. The measured samples were placed in the pretreatment chambers of MF device and selection of magnetic field types: Static Magnetic Field (SMF), Pulse Magnetic Field (PMF) and Alternating Magnetic Field (AMF) with combination of magnetic field strength (5 – 30 mT) and pretreatment time (5 – 30 min). Blanched (thermally pretreated) and fresh samples were used as controls. The experiment was designed with Design Expert (version 6.0.6) statistical package. After pretreatment, all samples were dried in the laboratory oven at 50 ˚C. The experiment was carried out at the laboratory of the Department of Food Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin, Nigeria.

2.3. Procedure for Rehydration

At the end of drying, all samples were packaged and briefly kept in a desiccator, and were rehydrated following the procedures stated in Taiwo *et al.* (2002) and Etsey *et al.* (2007). The rehydration percentage was calculated for using Equation (1) according to Pervin *et al.* (2008).

$$R_{y\ (\%)} = \frac{W_f - W_i}{W_i} \tag{1}$$

R_y is the rehydration percentage (%)
W_f is the final weight of the sample after soaking in distilled water (g)
W_i is the initial weight of the sample before soaking in distilled water (g)

2.4. Data Analysis

All the data obtained were used to plot bar charts on Excel 2016, and input into the Design Expert data analysis interface for the development empirical model equations and optimization the process.

3. RESULTS AND DISCUSSION

3.1. Effect of Magnetic Field (MF) Pretreatment on the Rehydration Percentage of SP

The effect of MF pretreatment on the rehydration percentage of SP with different combinations of magnetic field strengths and pretreatment time; and in comparison, with untreated (fresh) and blanched samples is shown in Figure 1. Result shows that MF pretreated sweet pepper using AMF-6 (14 mT and 5 min) had the highest rehydration percentage (80.52%) and sweet pepper pretreated with PMF-6 (19 mT and 10 min) had the lowest rehydration percentage (62.69%). The blanched sample of sweet pepper had rehydration percentage of 73.12% compared to that of fresh sample with a rehydration percentage of 65.25%. These values were quite different from the report of Pervin *et al.* (2008) where the rehydration percentages for dried lablab bean ranged from 47.6-56.8% under different drying methods. The reason for different values of rehydration percentage could be attributed to the possibility of leaching of total soluble solids during drying (Sharma *et al.*, 2015); type of drying methods (Tunde-Akintunde *et al.*, 2005); enzymatic browning that may affect drying properties (Take *et al.*, 2012); different characteristics of the wave pattern of the types of magnetic field used (Bird, 2010) and strength of field and pulse characteristics (Knorr and Angersbach, 1998) which could impose different effects on the structures of the pretreated products. Also, the rehydration percentages of some the MF pretreatment combinations are significantly higher than those of control samples (fresh and blanched) as indicated by the 5% error bars on each bar. This implies that MF pretreatment at some combination of factors improved the rehydration percentage of SP better than those of control samples.

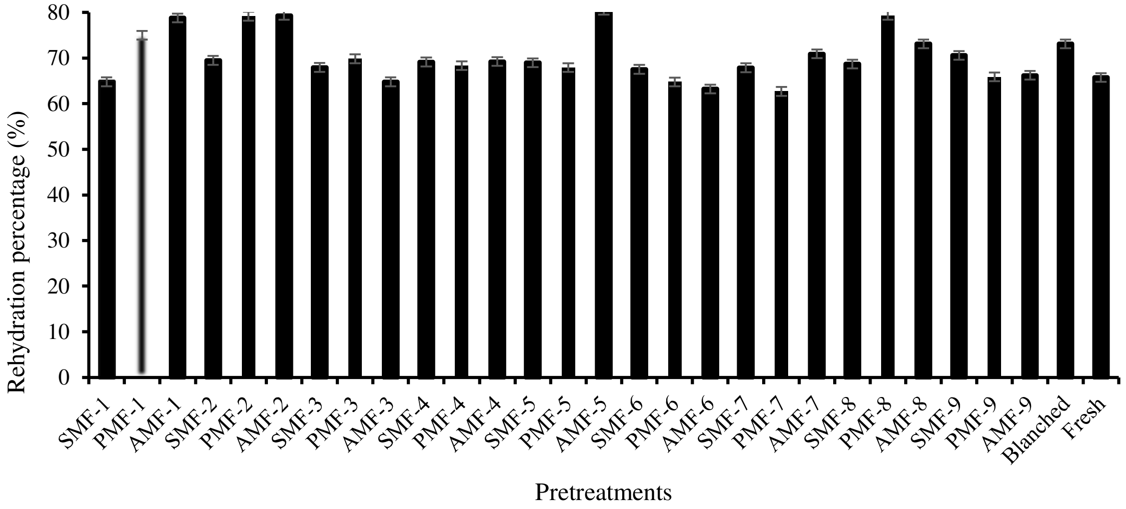

Figure 1: Rehydration percentage for MF pretreated and untreated sweet pepper

3.2. Effect of MF Pretreatment on the Rehydration Percentage of FPL

Figure 2 shows the effect of MF pretreatment on the rehydration percentages of FPL. From the figure, the highest (77.78%) and lowest (60.00%) rehydration percentages of FPL were obtained at PMF-7 (24.5 mT and 15 min) and SMF-6 (19 mT and 10 min) respectively. Also, blanched and fresh samples had rehydration percentages of 64.29% and 66.67% respectively. The rehydration percentages of many of the MF pretreatment combinations are significantly higher than those of control samples (fresh and blanched) as indicated by the 5% error bars on each bar. This is an indication that MF pretreatment at some combination of factors improved the rehydration percentage of FPL better than those of control samples. These values are within the range (52.32-70.07%) of rehydration capacity of osmotically dehydrated pineapple slices in sugar/salt solution, and 40.50% - 54.40% pineapple slices pretreated in sugar solution (Fasogbon *et al.*, 2013). Higher rehydration percentages of MF pretreated FPL might be due to structural changes caused by the pretreatment to cell structures (Rastogi and Niranjan, 1998). In addition, fluted pumpkin leaf contains some functional and antioxidant properties that might have possibly influenced the pretreatment process (Gbadamosi *et al.*, 2018). Furthermore, the constituents of the soil where the plants were grown may have had effect on the composition of the plant; in the sense that, some of the elements in the soil might have found their way into the biomass of the plant, thereby creating some yet to established effects on the structures of plant during pretreatment, drying and rehydration processes. In a previous research, Orubite *et al.* (2015) reported the presence of six heavy metals (arsenic, cadmium, lead, mercury, zinc, chromium) in the soil where fluted pumpkin leaf was grown in an area characterized by oil exploration and gas flaring in Umebulu community, Rivers State, Nigeria.

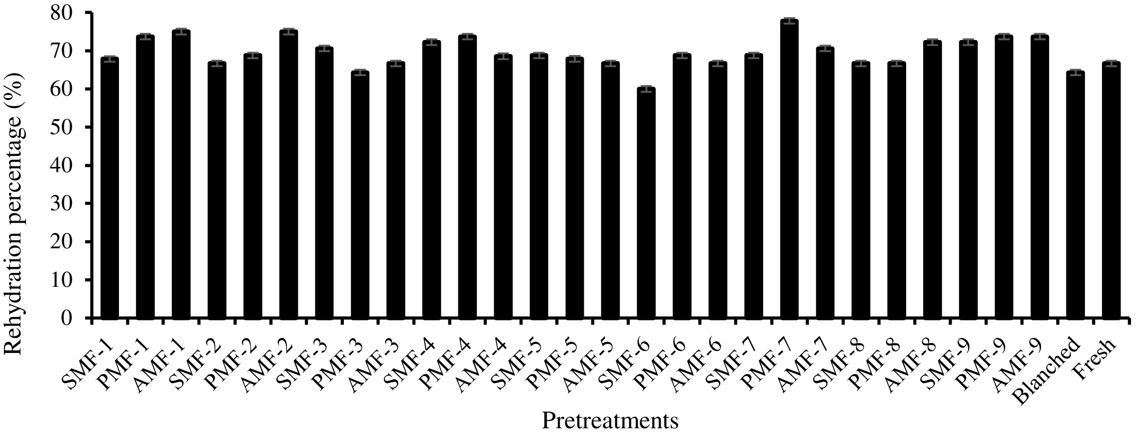

Figure 2: Rehydration percentage for MF pretreated and untreated fluted pumpkin leaf

3.3. Developed Model Equations and Model Adequacy

The developed model equations that gave reliable functional relationship between input variables (type of magnetic field-SMF, PMF and AMF; magnetic field strength-*A* and pretreatment time-*B*) and output variable (rehydration percentages-Ry) are as presented in Equations (2) to (4) for SP and Equations (5) to (7) for FPL. Tables 1 and 2 show the parameters for selecting the model best model equations from pool of developed model equations under each specific condition. This approach is a numerical method of model adequacy checking/validation. Macal (2005) stated that the main goal of model checking is to ensure that the model is useful in addressing the right problem and provide adequate information about the system (or process) under consideration. From the tables, coefficient of multiple determinations R^2- (88 -97% for SP and 96 – 97% for FPL) and adjusted coefficient of multiple determination R^2_{adj}- (86 -95% for SP and 94 – 97 % for FPL) are relatively close for all outputs; this is what is expected of good models (David *et al.*, 1998; Kaye and Freedman, 2011). Also, the coefficient of variation (C.V) (0.50 – 3.16 for SP and 0.43 – 1.42 for FPL) which is the unexplained variances in the data, given by the standard error of regression models was relatively small for all the models developed. This is an indication of goodness of fit (Kaye and Freedman, 2011). The adequate precision-AP (4.76 – 61.25 for SP and 8.56 – 15.34 for FPL), which is the signal-to-noise ratio (it compares the range of predicted values at the design points to the average prediction error) of all models are greater than four (4), hence, they are all good models (Stat-Ease, 2000). Since the probability, P-values (0.001 – 0.030 for SP and 0.001 – 0.004 for FPL) of all model equations are significant at $P \leq 0.05$, the models are good ones. Darvishi *et al.* (2013) and Taheri-Garavand *et al.* (2011) got R^2 of 92.7% and 99.2% respectively for validation of bell pepper drying models. Odewole and Olaniyan (2017) obtained not less than 72% R^2_{adj} values for vitamin C, vitamin A, ash content and drying rate for validated models of sweet pepper processed with osmotic solution of salt and drying. Adequate precision of not less 4 and P values of ≤ 0.05 were obtained for the validation of empirical models of green pepper pre-treated in osmotic solution of salt and dried at 60 °C (Odewole *et al.*, 2016).

Model equations for sweet pepper

SMF:
$$\text{Ry}\ (\%) = 143.89 - 16.88A - 2.55B + 1.44A^2 + 0.19A^2 - 9.27A \times 10^{-3}B - 0.05A^3 - 3.89B^3 + 3.89 \times 10^{-3}A^4 + 6.14\ (R^2 = (98\%) \quad (2)$$

PMF: $$\text{Ry}\ (\%) = 26.91 + 15.54A - 10.39B - 0.87A^2 + 0.71B^2 + 0.03AB + 0.01A^3 - 0.01B^3 (R^2 = 98\%) \tag{3}$$

AMF: $$\text{Ry}\ (\%) = 80.76 - 1.05A (R^2 = (98\%) \tag{4}$$

Model equations for fluted pumpkin leaf

SMF: $$\text{Ry}\ (\%) = 393.03 - 85.67A + 4.73B + 7.06A^2 + 0.04B^2 - 9.91 \times 10^{-3}AB - 0.25A^3 - 7.44B^3 + 3.27 \times 10^{-3}A^4 \ (R^2 = 88\ \%) \tag{5}$$

PMF: $$\text{Ry}\ (\%) = -422.06 + 127.18A - 4.79B - 10.48A^2 - 0.12B^2 - 7.29 \times 10^{-3}AB + 0.37A^3 + 0.01B^3 - 4.7 \times 10^{-3}A^4 \ (R^2 = 96\%) \tag{6}$$

AMF: $$\text{Ry}\ (\%) = 55.83 + 7.03A - 0.85B - 0.46A^2 + 0.11B^2 - 0.35AB + 0.03A^2B - 8.17 \times 10^{-3}AB^2 \ (R^2 = 97\%) \tag{7}$$

Table 1: Empirical parameters of optimized mf pretreatment of rehydration percentage for sweet pepper

Magnetic fields	C.V	R^2	R^2_{adj}	A.P	P-value
AMF	3.16	88%	86%	4.76	0.030*
PMF	0.50	96%	94%	61.25	0.001*
SMF	0.78	97%	95%	13.09	0.001*

Table 2: Empirical parameters of optimized MF pretreatment of rehydration percentage for fluted pumpkin leaf

Magnetic fields	C.V	R^2	R^2_{adj}	A.P	P-value
AMF	0.51	96%	94%	8.56	0.002*
PMF	1.42	96%	95%	12.25	0.001*
SMF	0.43	97%	94%	15.34	0.004*

3.4. Optimized Process Conditions

The essence of optimizing the process is to establish the type and values of input parameters that will give the most suitable (maximum) rehydration percentages. Tables 3 and 4 show the summary of the optimized conditions for the rehydration percentages of sweet pepper and fluted pumpkin leaf respectively. For SP the highest and most suitable optimized rehydration percentage of 74.92% was obtained at AMF (5.56 mT and 25 min) whereas, blanched and fresh samples of SP have 64.29 and 66.67 % respectively. Also, PMF (19.56 mT and 10.94 min) were the input parameters that gave the highest optimized rehydration percentage (73.81%) for FPL; but 73.12 and 67.75% were obtained for blanched and fresh samples of FPL respectively.

Table 3: Optimization result for rehydration percentage of MF pretreated sweet pepper

Treatment Methods	*A* (mT)	*B* (min)	Rehydration (%)
AMF	5.56	25	74.92
PMF	19.56	10.94	73.81
SMF	14.83	14.25	67.22
Blanched	-	-	64.29
Fresh	-	-	66.67

Table 4: Optimization result for rehydration percentage of MF pretreated fluted pumpkin leaf

Treatment methods	*A* (mT)	B (min)	Rehydration (%)
AMF	10.42	9.96	71.19
PMF	19.56	10.94	73.81
SMF	14.83	14.25	67.22
Blanched	-	-	73.12
Fresh	-	-	65.75

Maximum rehydration ratio was obtained at 11% salt concentration, 30 °C osmotic solution temperature, osmotic process duration of 120 min for carrot cubes (Singh *et al*., 2006). Faisal *et al*., (2013) obtained optimized rehydration ratio of 4.58% for potato at 80 °C drying temperature, 1 cm thickness with KMS pre-treatment solution. Dehkordi (2010) obtained optimum rehydration ratio of 2.2% for edible mushroom at osmotic solution (14% salt and 53% sucrose concentrations); osmotic solution temperature 39 °C; osmotic process duration of 164 min, 600 mbar pressure and 40 °C drying temperature. The rehydration percentages obtained in this research were far higher than those obtained in previous researches stated. This might be attributed to different method of pretreatments and different food materials used.

4. CONCLUSION

Magnetic field pretreatment generally increased the rehydration percentages of sweet pepper and fluted pumpkin leaf better than blanching. Also, the model equations developed validly revealed the characteristics of the rehydration process. The best optimized conditions are AMF (5.56 mT and 25 min) with 74.92% rehydration percentage and AMF (10.42 mT and 9.96 min) with 73.81% rehydration percentage for SP and FPL respectively. With the positive effect of magnetic field pretreatment (non-thermal) on the rehydration of SP and FPL, the method is a possible pretreatment method that can be used to replace blanching (thermal pretreatment).

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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