Process modeling and optimization of magnetic field pretreatment of sweet pepper and fluted pumpkin leaf

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Abstract: Modeling and optimization of magnetic field (MF) pretreatment of sweet pepper (SP) and fluted pumpkin leaf (FPL) were done with response surface methodology. Three pretreatment factors combined were: types of MF (static, pulse, and alternating), MF strength (5 - 30 mT), and pretreatment time (5 - 25 min). All the MF pretreated, control (blanched), and fresh samples were dried at 50˚C and analyzed for fibre, vitamin C, potassium, microbial load, and colour; data obtained were used for modeling and optimization of the process. Results showed that the selected 30 developed model equations reliably described the characteristics of the process with adequate precision values of greater than four (4) and significant probability values ($p \leq 0.05$) in all cases. The best optimized process conditions for the MF pretreatment process are Static MF at 14.31 mT magnetic field strength and 16.40 min pretreatment time for SP and Alternating MF at 10.42 mT magnetic field strength and 9.96 min pretreatment time for FPL. Magnetic field (non-thermal) pretreatment was able to achieve all the optimization goals better than blanching (thermal) pretreatment.

Keywords: pretreatment, magnetic field; non-thermal; optimum process conditions; model equations.

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1 Introduction

Sweet pepper (SP) - *Capsicum annuum* and fluted pumpkin leaf (FPL) - *Telfairia occidentalis* are vegetables with excellent health benefits (Wallace et al., 2020). SP and FPL are fruit and leafy vegetables respectively. They are in the group of vegetables that grow above the ground; and are also part of conventional vegetables (Awogbemi and Ogunleye, 2009).

Pretreatment of vegetables before subjecting them to further stages of processing is a common practice. It is done to aid other processing operations and also to ensure overall product quality. Food

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pretreatment can be viewed as taking necessary steps to maintain the desired properties or nature of food for as long as possible and to ensure the consumption of food with high nutritional values (Rahman and Perera, 2007). Depending on how it is done, pretreatment can positively or negatively affect the qualities or properties of foods. Foods can be pretreated conventionally or non-conventionally (Neetoo and Chen, 2014). The use of the conventional method of food pretreatment is popular, and it can either be thermal or non-thermal in nature. Typical thermal examples are: thermal pasteurization, thermal sterilization, and blanching; and some non-thermal examples are: size adjustment and salting. On the other hand, the non-conventional method of food pretreatment is not as popular as the conventional method. It is sometimes referred to as novel or emerging pretreatment technology because it is still evolving. Just like the conventional method of pretreatment, it has thermal and non-thermal sub-classifications. Microwave heating, ohmic heating and *sous vide* are some of the typical examples of the thermal aspect. Pulsed electric field (PEF), irradiation, high hydrostatic pressure (HHP), pulsed light (Neetoo and Chen, 2014), and the use of magnetic field (Ali et al., 2015; Odewole et al., 2020) are some typical examples of its non-thermal aspect. It is very important to note that the non-conventional pretreatment method can still take place at sub-lethal or room temperature (Pereira and Vicente, 2010) that would not cause significant negative effects on product quality.

Magnetism is a phenomenon that leads to the generation of a magnetic field either with permanent magnet or electromagnet (temporary magnet). Permanent magnets are magnets that are made from ferromagnetic materials. They do not require an external source of energy for them to create magnetic field like electromagnet. Examples of permanents are: Neodymium- Iron-Boron (NdFeB or NIB), Samarium-Cobalt (SmCo), and Aluminium-Nickel-Cobalt (AlNiCo). Electromagnetism is the generation of magnetic field due to the flow of current in a conductor. Magnetic technology in food processing has gained increased industrial interest and it is being considered as a substitute to the well-established traditional methods of food processing (Vicente and Castro, 2007). Living cells (some foods inclusively) have ions or free radicals, these free radicals create an internal magnetic field within the food (Dhawi et al., 2009); when the food is placed within an external magnetic field which can be produced by either permanent magnet or electromagnet, interaction in form of attraction or repulsion will occur between the internal magnetic field of the food and the external magnetic field. This interaction will modify the arrangement of structures and constituents of the food depending on the type of magnetic field, strength of the magnetic field, duration of exposure of the food to the magnetic field, type and antecedent conditions of the food before exposure to the magnetic field. In addition to increasing in permeability of food after sufficient exposure to a magnetic field, magnetic field can change the free radicals and ion concentrations of food with no degradation in the chemical profile of the food (Jamil et al., 2012). The use of magnetic field as a non-thermal method of processing food was first proposed in 1985 when a U.S. patent was granted to Hofmann (Barbosa-Canovas et al., 2005). Furthermore, Jamil et al. (2012) explained how magnetic field modified the structures and properties of mushroom spawn before planting. Better growth and yield at low magnetic field strength for a longer duration or high magnetic field strength for a shorter duration were achieved.

Models are simplified versions of reality. They can be presented in form of equations or as objects. Model equations describe the characteristics of a system or process. They show the mathematical relationships that exist between dependent variable (outputs) and independent variables (inputs) of a system or process. Model equations are useful tools for predicting, estimating, optimizing, and simulating a system or process with a view to having a better understanding of the system or process and to make valid and reliable decisions.

Optimization is the process of determining the best design (Parkinson et al., 2013). The word design is relative; that is, it could mean different things (processes, objects, equations, and others things) to different researchers. In other words, optimization is the process of finding actions that maximize or minimize the value of an objective function. Apart from maximization and minimization as the common goals of optimization within given constraints, outputs of a process or system can be set to a specified range or to a predetermined value as the goal. The execution of optimization process can be done manually or with the use of computer software packages/applications. Differential calculus and linear programming are some of the techniques of optimization. Also, regression analysis is one of the most widely used techniques of optimization. Getting valid and accurate models is the most important step in optimization process; and about 90% of the efforts in optimization are usually spent on developing and validating models (Parkinson et al., 2013). Once a good model is obtained, optimization results can be seamlessly achieved without delay. Optimization of inaccurate models gives misleading (unreliable) results, and also culminates to a waste of time (Parkinson et al., 2013) and other resources that are most times scarce. The optimized process conditions of vacuum dried onion slices were reported to be 58.66˚C drying temperature and 4.95 mm slice thickness (Mitra et al., 2011). Dehkordi (2010) used response surface methodology (RSM) in Design Expert software to optimize the osmotic dehydration and drying of edible button mushroom. Furthermore, the optimum process conditions of PEF pretreated coconut using RSM were 2.3277 kv cm^{-1} and frequency of 2.56 kHz. This was used to obtain 17.57% oil yield and free fatty acid of 0.35% (Dewi et al., 2019). In addition, in the microwave drying of two banana varieties (*luvhele and mabonde*), the optimal process conditions using RSM were 177.67 – 178.76 W for 12 min with desirability values in the range of 0.86 - 0.91 (Omolola et al., 2015). Microwave-alkali assisted pretreatment (MAP) was used for processing cassava rhizome; and the optimal glucose yields were 15.82 g /100 g for 24 h hydrolysis and 16.95 g/100 h for 48 h hydrolysis. The yields of cassava rhizome were obtained at 840 W microwave power, 9 min irradiation time, and 3% (w/v) NaOH concentration with the use of RSM (Sombatpraiwan et al., 2019). Optimization of osmosonication pretreatment of ginger with RSM led to 62.97% ± 0.85% water loss, 9.06% ± 0.04% solid gain, 53.98% ± 0.18% weight reduction and 23.96 ± 0.35 mgGAE/gdw total phenolic content at ultrasonication frequency, sucrose concentration and pretreatment time of 50 kHz, 35% (w/v) and 30 min respectively (Osae et al., 2019).

Food pretreatment with a magnetic field is very scarce, although it is gradually gaining interesting attention in recent times (Lipiec et al., 2004; Ali et al., 2015; Jia et al., 2015; Odewole et al., 2020). In all the aforementioned literatures (and others) on the use of magnetic field for food pretreatment, modeling and optimization of the magnetic field pretreatment process with a view to knowing the best combination of input factors that would give optimum values of outputs are yet to be done. The model equations and optimum values are useful information for the industrial scaling up of the process and expansion of research frontiers in the application of magnetic field for food processing. Hence, the objectives of this study were to model and optimize the magnetic field pretreatment process of SP and FPL.

2 Materials and methods

2.1 Materials

The following equipment, tools, and materials were used for the study: a magnetic field pretreatment device developed in Nigeria and available at the laboratory of the Department of Food Engineering, Faculty of Engineering and Technology, University of Ilorin, Nigeria (longitude $4^{0}35$ E and latitude $8^{0}30$ N). The magnetic field pretreatment device was designed to work on the principle of electromagnetism. The device was used to produce static, pulse, and alternating types of magnetic fields coupled with different magnetic field strengths used for pretreatment operation. Other equipment used were, electronic weighing balance (OHAUS, Model 201, China), laboratory size dryer (Model SM9053, England), colorimeter (CS-260, China), digital microbial colony counter (Model LT-37, India), desiccator; fresh samples of SP and FPL. The RSM software in Design Expert software (version 6.0.6) was used to design the experiment and execute the modeling and optimization process.

2.2 Experimental procedures

Fresh samples of SP and FPL were procured and prepared for pretreatment. In preparing the samples after procurement, SP and FPL were sorted to select samples without physical defects, washed in clean water to remove surface foreign materials and manually cut into smaller irregular pieces for proper handling. After these, uniform experimental quantities per run (10 g for FPL and 100 g for SP) were measured with the electronic weighing balance. The measured samples were placed in the magnetic field pretreatment device. Selection of magnetic field types (Static, Pulse or Alternating) with combination of magnetic field strength (5 - 30 mT) and pretreatment time (5 - 25 min) was done on the magnetic field device. The experimental design used in the design expert software was the central composite design under RSM. This design gave 13 different combinations (replicates inclusive) of magnetic field strength and pretreatment time under each of static, pulse and alternating type of magnetic field. The experimental design led to thirty-nine (39) runs for each of SP and FPL to make a total of 78 runs for both SP and FPL for the magnetic field pretreatment. All the 78 samples of SP and FPL were pretreated with magnetic field produced by the magnetic field pretreatment device in combination with different values of magnetic field strength and pretreatment time. Also,12 separate samples for both blanched and fresh samples were also used. All 78 samples pretreated with magnetic field together with 12 samples of blanched and fresh (100 samples all together) were dried at 50˚C in the laboratory dryer; and briefly kept in the desiccator before they were analyzed for the selected quality parameters. AOAC (2005) was used to analyze the nutritional qualities (fibre, vitamin C and potassium-K) and sensory quality (colour: chroma). Also, microbial load (Total Viable Count-TVC) was analyzed according to the procedures in Fawole and Oso (2007) and the use of the digital colony counter.

2.3 Process modeling

All the data obtained from quality analyses were introduced back into the data analysis interface of the Design Expert software for the modeling operation. Modeling of the process preceded the optimization process (Parkinson et al., 2013). This was done to develop thirty (30) equations that validly described the characteristics of the magnetic field pretreatment process.

2.4 Adequacy checking and validation of model equations

Adequacy checking and validation of developed model equations were done to aid the selection of model equations that best described the characteristics of the process. The approach used was the numerical method of model checking and validation. The parameters used for selection were higher values of coefficient of multiple determinations (R^2), closeness of R^2 values to the values of adjusted coefficient of multiple determination R^2_{adj} (Kaye and Freedman, 2011). Also used were, smaller values of coefficient of variation (CV), standard deviation (SD), and standard error (SE). Furthermore, adequate precision

(AP), 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 model equations. AP values of greater than or equal to four (4) indicates good models. Model equations that are significant at probability (P) values of less than or equal to 0.05 were selected as good ones.

2.5 Process optimization

After selecting the model equations that best described the characteristics of the process (via adequacy checking and validation), optimization of the process was done with the use of the selected model equations. This was achieved by following the optimization steps of clicking appropriate buttons of RSM in the design expert software. Optimized values of each output were compared with respective values of control (blanched) and fresh samples of SP and FPL. The selection of the process conditions was done in two stages. The first stage involved choosing one among the three optimized process conditions under SMF, PMF, and AMF for each output (as the most appropriate optimized process conditions); whereas the second involved choosing one overall optimized process condition (as the best optimized process conditions) that encompassed all the outputs. The criteria for selection used for the first stage were either the highest values among the three (SMF, PMF, and AMF) optimized conditions (for maximization)/ lowest (for minimization) or the closest values to the values of fresh samples if all the three optimized conditions are lower than values of fresh samples. However, because of the peculiar nature of microorganisms in food safety, the lowest values of microbial load (TVC) among the three optimized conditions were always selected as the most appropriate, irrespective of whether it was greater than the value of TVC obtained for the fresh sample or not. The selected process conditions were tagged with SMF, PMF, and AMF and place under Overall Performance of optimization (OP) column. The tag with the highest frequency of occurrence under OP was chosen as the best optimized process condition for each vegetable (SP or FPL).

2.6 Development of user-friendly platform for model equations

All selected model equations were converted to a user-friendly platform with codes written in Microsoft Excel VBA® programming environment. This was done to totally eliminate human errors and ensure faster and easier execution of computation operations in the use of the 30 model equations developed. The application is very portable and can run on any system with Microsoft Office installed. It has an interactive interface where input variables can be entered easily as well as buttons for computing and ending the task being performed. The input variables are, type of product (SP or FPL); type of magnetic field (SMF, PMF, and AMF); values of magnetic field strength (A) and pre-treatment time (B). After selecting and inserting all processing factors, pressing the “compute” button on the platform displayed the results in a readable format in less than five (5) seconds.

3 Results and discussion

3.1 Developed model equations

Equations 1–30 are the developed model equations that described the chracteristics of the magnetic field pretreatment process of SP and FPL. Equations 1 –15 are for SP and Equations 16–30 are for FPL. The qualities of SP and FPL considered under SMF, PMF and AMF are fibre ($Y1$), vitamin C ($Y2$), potassium ($Y3$), chroma ($Y4$), and TVC ($Y5$). Letters A and B in the equations represent the magnetic field strength and pretreatment time respectively. All the equations have different outlooks, in the sense that, they have different powers of A and B, different values of coefficients and constants, as well as enequal number of terms and mathematical signs that formed respective equations in camparison with one another. This is an indication that, the input variables(types of magnetic field - SMF, PMF, and AMF; different values of A and B) did not have the same effect on the qualities (*Y1* - *Y5*) considered as outputs for SP and FPL.

Model equations of qualities of SP

SMF

$$\mathrm{Y1} = 5.87 - 0.12A + 3.75 \times 10^{-3}A^2 \tag{1}$$

$$\mathrm{Y2} = 79.48 - 0.53A + 0.02A^2 \tag{2}$$

$$\mathrm{Y3} = 15.43 + 13.67A - 1.69B - 1.17A^2 + 0.11B^2 + 2.57 \times 10^{-3}AB + 0.04A^3 - 2.17 \times 10^{-3}B^3 - 5.49 \times 10^{-4}A^4 \tag{3}$$

$$\mathrm{Y4} = -89.96 + 35.52A - 8.28B - 2.91A^2 + 0.54B^2 + 0.01AB + 0.09A^3 - 0.01B^3 - 1.23 \times 10^{-3}A^4 \tag{4}$$

$$\mathrm{Y5} = 1.61 \times 10^5 + 1.13 \times 10^5A - 1.16 \times 10^5B - 3031.04A^2 + 3932.44B^2AB \tag{5}$$

PMF

$$\mathrm{Y1} = 3.94 - 0.01\mathrm{A} + 0.17\mathrm{B} + 3.74 \times 10^{-4}A^2 - 4.75 \times 10^{-3}B^2 - 3.41 \times 10^{-4}\mathrm{AB} \tag{6}$$

$$Y2 = 73.85 - 0.07A + 0.50B - 2.27 \times 10^{-3}A^2 - 0.02B^2 + 5.77 \times 10^{-3}AB \tag{7}$$

$$\mathrm{Y3} = 18.15 + 12.72A - 1.00B - 1.13A^2 + 0.03B^2 - 3.79 \times 10^{-3}AB + 0.04A^3 + 1.50 \times 10^{-4}B^3 - 5.95 \times 10^{-4}A^4 \tag{8}$$

$$\mathrm{Y4} = 69.03 - 14.64A + 0.81B + 1.46A^2 - 0.05B^2 - 7.21 \times 10^{-3}AB - 0.06A^3 + 1.15 \times 10^{-3}B^3 + 8.21 \times 10^{-4}A^4 \tag{9}$$

$$\mathrm{Y5} = 1.09 \times 10^7 - 2.83 \times 10^6A + 2.56 \times 10^5B + 2.28 \times 10^5A^2 - 86500B^2 \times -340.90AB - 7845.32A^3 + 10.0B^3 + 98.58A^4 \tag{10}$$

AMF

$$\mathrm{Y1} = 1.54 + 0.78A + 0.23B - 0.04A^2 + 2.64 \times 10^{-4}B^2 - 0.05AB + 3.31 \times 10^{-3}A^2B - 5.00 \times 10^{-4}AB^2 \tag{11}$$

$$Y2 = 59.73 + 2.91A + 1.89B - 0.13A^2 - 0.04B^2 - 0.30AB + 9.88 \times 10^{-3}A^2B + 4.48 \times 10^{-3}AB^2 \tag{12}$$

$$\mathrm{Y3} = 66.28 - 0.27A - 0.26B + 9.41 \times 10^{-3}A^2 + 9.86 \times 10^{-3}B^2 + 3.89 \times 10^{-4}AB \tag{13}$$

$$\mathrm{Y4} = 25.45 - 0.24A \tag{14}$$

$$\mathrm{Y5} = 2.41 \times 10^5 + 46055.88A - 9083.86B - 2605.60A^2 + 445.39B^2 - 1611.11AB + 185.23A^2B - 2.47A^2B^2 \tag{15}$$

Model equations of Qualities of FPL

SMF

$$Y1 = 0.81 + 2.28A + 0.28B - 0.19A^2 - 0.02B^2 + 1.25 \times 10^{-3}AB + 6.65 \times 10^{-3}A^3 - 5.43 \times 10^{-4}B^3 - 8.21 \times 10^{-5}A^4 \tag{16}$$

$$Y2 = 9.15 + 12.97A - 0.70B - 1.14A^2 + 0.03B^2 + 1.18 \times 10^{-3}AB + 0.04A^3 - 1.60 \times 10^{-4}B^3 - 5.57 \times 10^{-4}A^4 \tag{17}$$

$$Y3 = 699.65 - 3.48A + 2.99B - 0.08A^2 - 0.19B^2 + 0.08AB \tag{18}$$

$$\mathrm{Y4} = 20.00 + 0.02A + 0.09B \tag{19}$$

$$\mathrm{Y5} = -2.32 \times 10^5 + 39598.23A + 1.30 \times 10^5B - 1044.72A^2 - 13814.11B^2 + 363.33B \tag{20}$$

PMF

$$\mathrm{Y1} = 10.13 + 0.10A + 0.01B - 2.31 \times 10^{-3}A^2 - 3.93 \times 10^{-4}B^2 - 9.77 \times 10^{-4}AB \tag{21}$$

$$Y2 = 58.36 - 0.02A - 0.19B + 4.39 \times 10^{-3}AB \tag{22}$$

$$Y3 = 791.34 - 29.50A + 11.48B + 1.47A^2 - 0.39B^2 - 0.02A^3 \tag{23}$$

$$\mathrm{Y4} = 27.86 - 0.38A + 0.84B + 0.01A^2 - 0.03B^2 - 5.46 \times 10^{-4}AB \tag{24}$$

$$Y5 = -1.31 \times 10^6 + 2.99 \times 10^5A + 82051.30B - 19791.05A^2 - 4928.98B^2 + 727.27AB + 365.64A^3 + 80B^3 \tag{25}$$

AMF

$$Y1 = 9.40 + 0.45A + 0.41B - 0.03A^2 - 0.02B^2 - 0.11AB + 6.17 \times 10^{-3}A^2B + 4.01 \times 10^{-3}AB^2 - 2.19 \times 10^{-4}A^2B^2 \tag{26}$$

$$\mathrm{Y2} = 56.97 + 0.39A - 0.14B - 0.02A^2 + 0.01B^2 - 0.03AB - 2.91 \times 10^{-3}A^2B - 7.78 \times 10^{-4}AB^2 \tag{27}$$

$$Y3 = 650.12 + 8.98A + 3.30B - 0.56A^2 - 0.10B^2 - 0.09A \tag{28}$$

$$\mathrm{Y4} = 2.68 + 3.75A + 1.71B - 0.17A^2 - 0.05B^2 - 0.22AB + 6.01 \times 10^{-3}A^2B + 3.86 \times 10^{-3}AB^2 \tag{29}$$

$$\mathrm{Y5} = 3.18 \times 10^5 - 52310.56A + 2755.75B + 4580.67A^2 + 777.59B^2 - 2166.67AB \tag{30}$$

Tables 1 – 6 show the parameters used to select the model equations that best described the characteristics of the process. Thirty (30) empirical model equations were developed in all for SMF, PMF and AMF. Macal (2005) stated that the main goal of model validation is to ensure that the model provide adequate information about the system under consideration. From the tables, coefficient of multiple determinations (R^2) and adjusted coefficient of multiple determination R_{adj}^2 are relatively close for all outputs; this is what is expected of good models (Kaye and Freedman, 2011). Also, the CV which is the unexplained variances in the data, given by the standard error of model equations are relatively small for all the models developed; this is an indication of goodness of fit (Kaye and Freedman, 2011). The AP, 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. Since the probabilities (P-values) of all models 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.

Table 1 Models adequacy checking and validation for SP for SMF

Response Variables	R^2(%)	R^2adj(%)	CV (%)	AP	SE	SD	P-value
Fibre	78	73	5.67	4.9	0.14	0.29	0.04*
Vitamin C	59	51	0.98	5.46	0.36	0.98	0.00*
Potassium	86	84	0.65	8.29	0.98	1.01	0.00*
TVC	78	76	3.67	7.57	304.25	181.15	0.02*
Chroma	98	95	2.15	18.4	1.32	2.15	0.00*

Note: CV, coefficient of variation; AP, adequate precision; SE, standard error; SD, standard deviation; P, probability

*significant at ≤ 0.05

Table 2 Models adequacy checking and validation for SP for PMF

Response Variables	R^2 (%)	R^2adj (%)	CV(%)	AP	SE	SD	P-value
Fibre	89	81	2.12	8.9	0.1	0.11	0.00*
Vitamin C	94	89	0.57	13.37	0.42	0.43	0.01*
Potassium	93	90	0.21	10.44	0.24	0.37	0.00*
TVC	78	75	1.31	4.89	127.96	134.27	0.01*
Chroma	93	90	1.97	8.37	1.99	2.31	0.00*

Table 3 Models adequacy checking and validation for SP for AMF

Response Variables	R^2 (%)	R^2adj (%)	CV(%)	AP	SE	SD	P-value
Fibre	99	95	0.6	7.56	0.02	0.03	0.00*
Vitamin C	96	89	0.51	13.26	0.25	0.38	0.00*
Potassium	79	74	0.72	6.77	0.22	0.45	0.03*
TVC	88	82	8.49	8.43	602.99	521.79	0.04*
Chroma	83	79	5.11	4.71	0.41	1.18	0.05*

Table 4 Models adequacy checking and validation for FPL for SMF

Response Variables	R^2 (%)	R^2adj (%)	CV(%)	AP	SE	SD	P-value
Fibre	94	90	1.22	12.64	0.04	0.07	0.00*
Vitamin C	88	84	0.96	11.28	0.18	0.25	0.00*
Potassium	92	86	0.62	14.96	4.12	4.24	0.00*
TVC	95	90	11.18	15.42	0.11	31.77	0.00*
Chroma	87	84	2.39	9.01	0.21	0.52	0.01*

Table 5 Models adequacy checking and validation for FPL for PMF

Response Variables	R^2 (%)	R^2adj (%)	CV(%)	AP	SE	SD	P-value
Fibre	93	89	0.62	14.84	0.07	0.06	0.00*
Vitamin C	83	79	0.94	10.56	0.23	0.53	0.01*
Potassium	80	75	1.35	7.55	6.51	9.18	0.02*
TVC	95	89	11.74	14.63	807.58	115.39	0.01*
Chroma	82	79	1.27	9.5	6.96	0.39	0.01*

Table 6 Models adequacy checking and validation for FPL for AMF

Response Variables	R^2 (%)	R^2adj (%)	CV(%)	AP	SE	SD	P-value
Fibre	98	95	0.87	7.65	0.76	0.87	0.00*
Vitamin C	98	93	0.04	8.95	0.01	0.02	0.00*
Potassium	98	97	0.4	26.15	1.36	2.77	0.00*
TVC	98	96	9.42	22.15	689.49	805.81	0.00*
Chroma	92	89	2.11	10.8	0.31	0.47	0.01*

Table 7 Optimized process conditions of magnetic field pretreated sp

	SMF	PMF	AMF				
	*MFS (14.31 mT) and *PT (16.40 min)	*MFS (18.42 mT) and *PT (14.36 min)	*MFS (5.00 mT) and *PT (6.22 min)				
Outputs				OG	Blanched	Fresh	OP
Fibre (%)	4.88	5.18	4.72	Maximized	4.73	5.09	PMF
Vitamin C (mg /100 g)	74.81	76.19	74.09	Maximized	70.28	74.82	PMF
K (mg /100 g)	64.89	63.07	63.96	Maximized	60.16	63.76	SMF
TVC (CFU ml^{-1})	312,039	373,763	349,992	Minimized	300,000	220,000	SMF
Chroma	28.30	24.18	24.24	Maximized	27.50	27.25	SMF

Note: Selected best optimized process condition is SMF: same as SMF at 14.31 mT and 16.40 min

SMF- static magnetic field; PMF, pulse magnetic field; AMF- alternating magnetic field.

MFS - magnetic field strength (A); PT- pretreatment time (B); OP- overall performance of optimization; OG - optimization goal

Values in brackets in each column are input values of MFS and PT that optimized all outputs under SMF, PMF and AMF respectively.

3.2 Most appropriate optimized process conditions of SP and FPL

Tables 7 and 8 present the process conditions (type of magnetic field, magnetic field strength and pretreatment time) that optimized all the outputs according to the individual goal of optimization of each output for SP and FPL respectively. From Table 3, in order to achieve the individual goal of optimization stated for the output considered (fibre, vitamin C, K, TVC, and chroma) for SP, the values of MFS and PT to be combined under each type of magnetic field (SMF, PMF and AMF) are as stated in the brackets directly below SMF, PMF and AMF columns. SMF required 14.31 mT and 16.40 min; PMF required 18.42 mT and 14.36 min; AMF required 5.00 mT and 6.22 min for SP. Also, from Table 4 for FPL, SMF required 14.82 mT and 14.25 min; PMF required 19.57 mT and 10.94 min and AMF required 10.42 mT and 9.96 min. The possible reasons for variations in the optimized process conditions and outputs might be due to the effect of different unique characteristics and wave patterns of SMF, PMF, and AMF (Bird, 2010; Odewole et al., 2020); different values of magnetic field strength and pretreatment time used. Also, the two vegetables exist in different forms, SP is a fruit, and FPL is leaf; hence, there are tendencies that they will have different characteristics which will make them behave differently when processed under different or the same conditions. In addition, some yet to be identified or yet to be established reasons in this novel and emerging method of food processing (magnetic field) could be responsible for the trends of the results obtained in this study.

3.3 Best optimized process conditions of SP and FPL

The best optimized process conditions that encompassed all the outputs and their respective optimization goals after thorough inspection and comparison are SMF at 14.31 mT and 16.40 min for SP and AMF at 10.42 mT and 9.96 min for FPL. Although, literatures were not found on the optimization of magnetic field pretreatment process of food, however, optimization results of other food pretreatment process were used for comparison. Mitra et al. (2011) reported 58.66˚C drying temperature and 4.95 mm slice thickness as the optimum conditions for processing onion in vacuum dryer. In addition, Faisal et al. (2013) with the use of Design Expert software obtained 80°C drying temperature, 1cm thickness and KMS pretreatment solution as the processing factors that optimized rehydration ratio of potato to 4.584, shrinkage to 24.97 and sensory test to 5. Dehkordi (2010) obtained optimum water loss, solid gain, rehydration ratio and shrinkage of 63.3 g /100 g, 3.17 g /100 g, 2.2% and 7.15% respectively at 39°C osmotic solution temperature, 164 min osmotic process duration, 14% salt concentration, 53% sucrose concentration, 600 mbar pressure and 40°C drying temperature for osmo-convective drying of edible button mushroom.

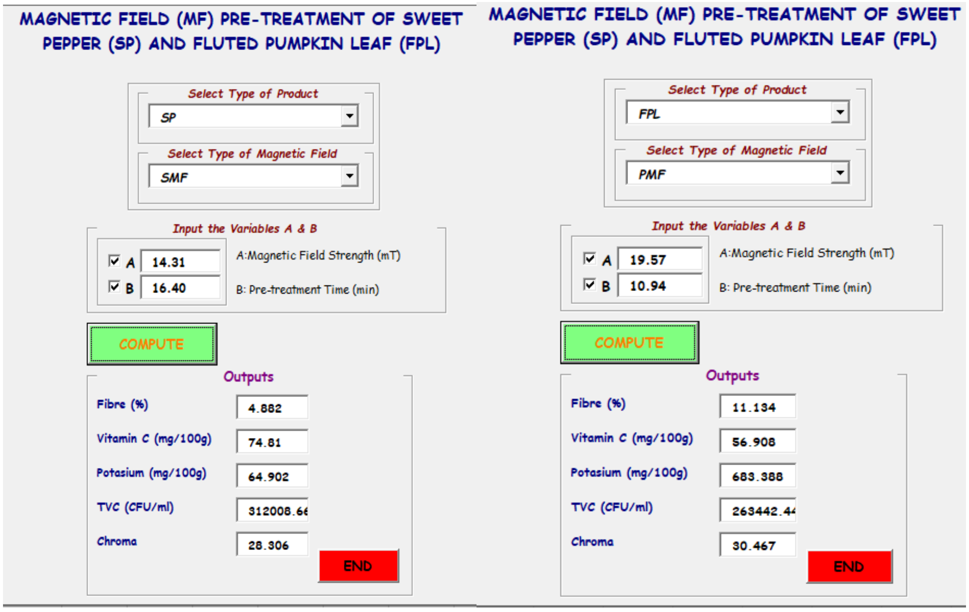
Table 8 Optimized process conditions of magnetic field pretreated FPL

	SMF	PMF	AMF				
	*MFS (14.82 mT) and *PT (14.25 min)	*MFS (19.57 mT) and *PT (10.94 min)	*MFS (10.42 mT) and *PT (9.96 min)				
Outputs				OG	Blanched	Fresh	OP
Fibre (%)	11.01	11.13	10.74	Maximized	10.84	10.42	PMF
Vitamin C (mg /100 g)	56.77	56.91	56.95	Maximized	56.82	56.16	AMF
K (mg /100 g)	685.73	683.40	695.90	Maximized	670.80	684.50	AMF
TVC (CFU ml^{-1})	225,099	263,411	150,000	Minimized	100,000	220,000	AMF
Chroma	21.59	30.47	23.34	Maximized	20.60	20.67	PMF

Note: Selected best optimized process condition is AMF: same as AMF at 10.42 mT and 9.96 min

3.4 Developed user-friendly platform

Figures 1 and 2 are the samples of results obtained from the developed user-friendly platform. The outputs obtained (as displayed in Figure 1 (a-b) and Figure 2 (a-b) are relatively in agreement with the results of optimization (earlier presented Tables 3 and 4) obtained for processing of SP and FPL under SMF and PMF types of magnetic field, and for SP and FPL under AMF type of magnetic field with their respective optimum values of A and B. The same procedures can be used on the platform when other pretreatment factors are to be combined. This short computation time and relatively accurate and precise results will not be possible with the manual approach of direct substitution of numerical variables into the equations.



MAGNETIC FIELD (MF) PRE-TREATMENT OF SWEET PEPPER (SP) AND FLUTED PUMPKIN LEAF (FPL)

Select Type of Product: SP

Select Type of Magnetic Field: SMF

Input the Variables A & B

☑ A 14.31 A:Magnetic Field Strength (mT)

☑ B 16.40 B: Pre-treatment Time (min)

Outputs

Fibre (%) 4.882

Vitamin C (mg/100g) 74.81

Potasium (mg/100g) 64.902

TVC (CFU/ml) 312008.66

Chroma 28.306

(a)

MAGNETIC FIELD (MF) PRE-TREATMENT OF SWEET PEPPER (SP) AND FLUTED PUMPKIN LEAF (FPL)

Select Type of Product: FPL

Select Type of Magnetic Field: PMF

Input the Variables A & B

☑ A 19.57 A:Magnetic Field Strength (mT)

☑ B 10.94 B: Pre-treatment Time (min)

Outputs

Fibre (%) 11.134

Vitamin C (mg/100g) 56.908

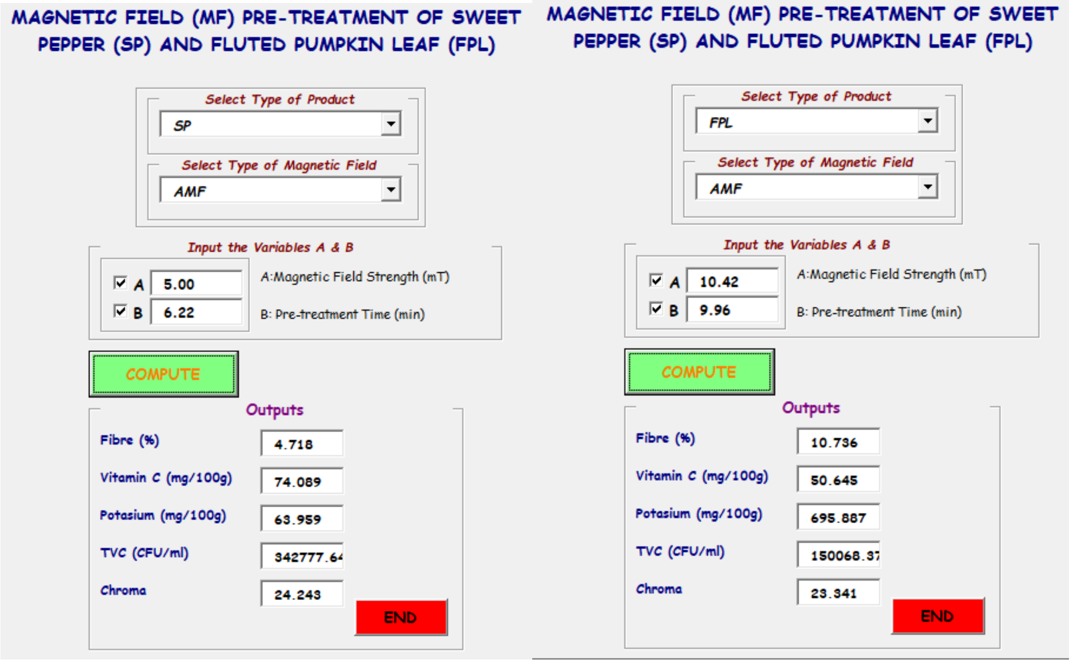
Potasium (mg/100g) 683.388

TVC (CFU/ml) 263442.44

Chroma 30.467

(b)

Figure 1 Samples of results obtained with the user-friendly platform for SMF and PMF



MAGNETIC FIELD (MF) PRE-TREATMENT OF SWEET PEPPER (SP) AND FLUTED PUMPKIN LEAF (FPL)

Select Type of Product: SP
Select Type of Magnetic Field: AMF
Input the Variables A & B
☑ A 5.00 A:Magnetic Field Strength (mT)
☑ B 6.22 B: Pre-treatment Time (min)
Outputs
Fibre (%) 4.718
Vitamin C (mg/100g) 74.089
Potasium (mg/100g) 63.959
TVC (CFU/ml) 342777.64
Chroma 24.243

MAGNETIC FIELD (MF) PRE-TREATMENT OF SWEET PEPPER (SP) AND FLUTED PUMPKIN LEAF (FPL)

Select Type of Product: FPL
Select Type of Magnetic Field: AMF
Input the Variables A & B
☑ A 10.42 A:Magnetic Field Strength (mT)
☑ B 9.96 B: Pre-treatment Time (min)
Outputs
Fibre (%) 10.736
Vitamin C (mg/100g) 50.645
Potasium (mg/100g) 695.887
TVC (CFU/ml) 150068.37
Chroma 23.341

(a) (b)

Figure 2 Samples of results obtained with the user-friendly platform for AMF

4 Conclusion

Thirty (30) empirical model equations that validly described the characteristics of the magnetic field pretreatment process of SP and FPL were established. The best optimized process conditions are SMF at 14.31 mT and 16.40 min for SP and AMF at 10.42 mT and 9.96 min for FPL. Developed model equations were converted to a user-friendly platform for faster computation, higher accuracy and higher precision of results. Magnetic field (non-thermal) pretreatment achieved all the optimization goals better than blanching (thermal) pretreatment in most cases. Therefore, magnetic field pretreatment is a possible substitute for the replacement of blanching in vegetable processing value chain.

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