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Original Article

Optimization of the preparation treatment to obtain the desired quality of canned cowpea (*Vigna unguiculata*, TN 5-78) variety grown in the Sahel region

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Abstract

Response surface methodology was used to optimize the preprocessing and processing parameters to obtain the best quality of canned cowpeas. The independent variables of central composite rotatable design were sodium hexametaphosphate [$(NaPO_3)_6$] concentration, soaking, blanching, and cooking time and temperature, whereas the dependent variables were hardness, moisture content, leached solid, and splitting seeds. Thus, the 5-factor, 3-level Box–Behnken design was used to establish the optimum conditions and generate regression quadratic polynomial models. The adequacy of each dependent variable were significant at P<0.05 with a regression coefficient of R^2>0.90, and there was no lack of fit. The sterilization value (F_0) was determined to evaluate the heat treatment efficiency under the necessary required conditions to obtain a canned cowpeas with optimum quality characteristics (i.e., soaking time of 12 h, $(NaPO_3)_6$ concentration of 0.5%, blanching time of 5 min, cooking time of 15 min, and processing temperature of 110 °C. However, the F_0 value of 1.18 min obtained with canned TN 5-78 cowpeas under the optimum conditions was not sufficient enough to provide commercially stable food.

Keywords: response surface methodology, optimization, canning, cowpea, heat treatment efficiency, sterilization value

1. Introduction

Cowpea (*Vigna unguiculata*) is one of the most popular grain legumes with an estimated world production of 5.39 million metric tons (FAO, 2010). It is one of the most important protein sources in the diet of tropical Africa, particularly in the Sahel regions. In a country such as Niger, cowpea is ranked the third food crop after millet and sorghum, and the first food legume consumed by the population (Hama, Amadou, Amza, & Zhang, 2017; Balla & Baragé, 2006). Cowpea is a highly nutritious crop with a dry seed protein content of about 25% and protein digestibility higher than that of other legumes (Adebooye & Singh, 2008). Therefore, cowpea-based food products are good sources of inexpensive protein, especially for the rural poor communities (Amonsou, Sakyi-Dawson, & Saalia, 2010). However, it is clear that the conservation of grains of that culture is a serious problem. Khadim and Mbacké (2011) reported that during storage, the grains are often attacked by the weevil *Callosobruchus maculate*. This weevil punctures stored seeds and is responsible for the low market and nutritional values of the cowpea. Moreover, after 8 months of storage 60% to 70% of pods were found degraded. This leads to huge economic losses to producers. Therefore, novel processing and preparation methods are needed to enhance the bioavailability

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of the micronutrients and to improve the quality of cowpea diets. Thus, research efforts have led to the gradual development and adaptation of various preservation methods to make cowpea available all year round. Even though the traditional drying method of cowpea is economically cheaper, canning was proven to give cowpea a longer shelf life (Cavalcante, Araújo, Rocha, & Moreira-Araújo, 2017; Amonsou, Sakyi-Dawson, & Saalia, 2010; Sasikala, Ravi, & Narasimha, 2011). However, canning of legumes is synonymous with the resolution of various constraints including, among others, the selection of pretreatment and thermal processes which result in the highest product quality retention**.** Soaking and blanching are usually applied to pre-canned cowpeas. Legumes that are cooked without presoaking have significantly higher oligosaccharide content, and therefore cause higher indigestion (Drago, Franco-Miranda, Cian, Betancur-Ancona, & Chel-Guerrero, 2016; Naviglio, Formato, Pucillo, & Gallo, 2013; White & Howard, 2012). Sodium hexametaphosphate [$(NaPO_3)_6$] can be added into the soaking water with the aim of stabilizing or improving the texture. The time of blanching depends on the texture and type of peas being blanched (Hama, Amadou, Amza, Daou, & Zhang, 2014; Annor *et al.,* 2010). Therefore, it's important to seek the best pre-processing and processing conditions that would result in the best quality canned product of TN 5-78 variety of cowpea.

Response surface methodology (RSM) is a statistical-mathematical method which uses quantitative data in an experimental design to determine and simultaneously solve multivariate equations, to optimize processes and products. It has been successfully used for optimization in many bioprocesses (Akkarachaneeyakorn, Suwakrai, & Pewngam, 2018; Hama, Amadou, Amza, & Zhang, 2017; Annor *et al.*, 2010). The objectives of this study were to describe the optimum pre-processing and processing conditions that would yield the best quality canned product from this cowpea variety (TN 5-78) and also determine the efficiency of the thermal treatment under optimal conditions to prove or disprove a possible industrial use of this variety of cowpea.

2. Materials and Methods

2.1 Materials

The cowpea (*Vigna unguiculata*, TN 5-78) variety was obtained from Entreprise Semencière Alheri (Niamey, Niger) and transported to Wuxi, China by Dr Amadou Issoufou. The sample was free from foreign matter and inferior quality grains.

2.2 Experimental design for response surface methodology (RSM)

The software Design Expert 8.0.7.1 was used for designing this study. It was set up with five independent experimental variables including cooking time (X_1), processing temperature (X_2), soaking time (X_3), blanching time (X_4), and $(NaPO_3)_6$ concentration (X_5). In addition to these independent variables, there are four dependent variables that included moisture content of the canned cowpeas, leached solid, seed splitting, and seed hardness. Fifty sample combinations were generated from the software in the experimental design (Table 1 and 2). The experiments were carried out based on these various combinations and then tabulated and analyzed.

2.2.1 Sample treatments

Initially, the cowpea seeds were sorted and washed with deionized water. The cowpeas were soaked in a flask with double volume of the soaking solution which was $(NaPO_3)_6$. For each combination, The amount of 40 g of cowpeas were soaked in $(NaPO_3)_6$ solution concentrations of 0%, 0.25%, 0.5%, and 0.84% (w/v) for 8, 10, 12, and 13 h, respectively at room temperature (25 °C). Before canning, the cowpeas were blanched for 5, 7, 10, and 13 min. Finally, the samples were processed in an autoclave (LDZX-50FBS SHENAN, Shanghai, China) under different times of 15, 17, 20, and 23 min and temperatures of 106, 110, 112, 115, and 118 °C.

2.2.2 Optimization process

Multiple regression analysis was conducted on the data from the Design Expert to relate cooking time (X1), processing temperature (X2), soaking time (X3), blanching time (X4), and $(NaPO_3)_6$ concentration (X5). In addition, other analyzed parameters were moisture content, leached solid, seed hardness, and the percentage of seed splitting of the canned cowpeas. The response surface models were generated and presented as three dimensional plots. The optimal processing conditions of cowpea canning were determined from the mathematical models generated by the software using soaking time 10–12h, blanching time 5–10 min, $(NaPO_3)_6$ concentration 0–0.5%, cooking time 10–15min, and processing temperature 110–115 °C.

Table 1. Independent variable and levels used in the response surface design.

Independent variables	Code	Variable levels								
		-2.33	-1	-0.93	-0.23	0	0.23	0.93	1	2.33
Cooking time	X_1	11.55	15			17.5			20	23.45
Processing temperature	X_2	106.55	110			112.5			115	118.45
Soaking time	X_3		10	8.62		11		13.38	12	
Blanching time	X_4	1.55	5			7.5			10	13.45
$(NaPO3)_6$	X_5		0		-0.34	0.25	0.84		0.5	

Table 2. Design matrix and variable combinations in experimental runs.

Serial no.	Level codes				
	Cooking time X1	Processing temperature X2	Soaking timeX3	Blanching time X4	$(NaPO3)_6$ X5
1	0	0	0	0	0
2	1	1	-1	-1	1
3	1	1	1	1	1
4	-1	1	1	-1	1
5	0	0	0	0	0
6	0	-2.33	0	0	0
7	1	-1	1	-1	1
8	1	-1	1	-1	-1
9	-1	-1	1	-1	1
10	-1	1	-1	-1	1
11	1	1	-1	1	-1
12	0	0	0.93	0	0
13	0	0	0	2.33	0
14	0	2.33	0	0	0
15	-1	1	-1	1	1
16	1	1	-1	1	1
17	1	-1	1	1	-1
18	-1	1	1	1	-1
19	0	0	0	0	0
20	1	1	1	1	-1
21	0	0	0	0	0
22	1	-1	-1	-1	-1
23	1	1	-1	-1	-1
24	1	1	1	-1	-1
25	0	0	0	0	0.23
26	1	-1	-1	1	-1
27	-1	-1	1	1	-1
28	0	0	0	0	0
29	-1	-1	1	1	1
30	2.3	0	0	0	0
31	-1	-1	-1	1	1
32	-1	-1	1	-1	-1
33	0	0	0	0	0
34	1	-1	-1	1	1
35	-1	1	-1	1	-1
36	-1	-1	-1	1	-1
37	1	-1	1	1	1
38	0	0	0	0	0
39	-1	1	1	-1	-1
40	0	0	0.93	0	0
41	-1	1	-1	-1	-1
42	0	0	0	0	0
43	1	1	1	-1	1
44	-2.3	0	0	0	0
45	0	0	0	0	0.23
46	-1	-1	-1	-1	1
47	-1	1	1	1	1
48	0	0	0	-2.3	0
49	1	-1	-1	-1	1
50	-1	-1	-1	-1	-1

2.2.3 Analytical methods

1) Moisture content determination

The moisture content of samples was determined according to the AOAC (1990) method 950.40 of oven drying at 105 °C for 6 h. All the experiments were conducted in triplicate and the mean value was determined.

2) Leached solids

The amount of soluble solids lost after cooking was determined using the method proposed by Yeung, Ehlers, Waniska, Alviola, and Rooney (2009) by determining °Brix using a refractometer. Initially, the broth was swirled to disperse the solids that settled to the bottom then a drop was placed on the prism surface for measurement. Soluble solid loss was calculated using Equation 1.

Soluble solids loss = (°Brix) (final broth weight) × 100/initial seed weight (1)

The final broth weight was determined after passing the broth through a sieve.

3) Seed hardness

After canning, the hardness of the seeds was determined using a texture analyzer (TA-XT2i, Stable Micro Systems Ltd., Godalming, UK). Seven beans were selected for the hardness test. A cylindrical shaped probe with a 35 mm end diameter was used. The hardness value was considered as the mean peak compression force and expressed as force in grams. The tests were conducted through a distance of 20 mm, pretest speed of 1.0 mm/s, and test speed of 0.5 mm/s.

4) Splitting

The weight of split seeds was taken from the peas obtained after the drainage and expressed as a proportion of the total weight of the canned cowpeas.

5) Heat treatment efficiency determination

The efficiency of the heat treatment was determined through the estimation of F_0. Cowpeas were canned under the optimum conditions after optimization. Time and temperature measurements were taken at 30-s intervals throughout the retort using a digital thermometer (UT325 thermometer, Uni-Trend Technology Limited, Dongguan, China) and thermocouples (type K, 1.0 mm diameter, with an accuracy of ±0.1 ºC). F_0 determinations were made with the recorded time temperature values using Microsoft Excel. This experiment was performed two times and three bags were used for each run. The Bigelow, Bohart, Richardson, and Ball (1920) formula was used to calculate F_0.

$$Fo = \int_0^t 10^{\frac{(T-Tr)}{z}}\, dt$$

was evaluated in this study by

$$\sum_i 10^{\frac{(Ti-121.1)}{10}} . \Delta t$$

where F_0 is the sterilizing value, T is temperature for sterilization, T*i* is the temperature at each time interval, T*r* is reference temperature, usually 121.1 ºC for thermal sterilization, z is the temperature change required to traverse one logarithmic cycle of the thermal death time curve (10 °C), and Δt is the time interval at which temperatures were recorded.

3. Results and Discussion

Canned cowpeas were processed considering cooking time, processing temperature, soaking time, blanching time, and $(NaPO_3)_6$ concentration as the important variables. Response surface methodology as applied to the experimental data. Regression analysis and ANOVA were conducted for fitting the model and to examine the model terms. The lack of fit, the coefficient of variation and the F_0 values are given in Table 3. In this study the lack of fit was found to be insignificant which indicated that the models are sufficiently accurate to predict the responses.

3.1 Effect of pre-processing and processing variables on the moisture content of canned cowpeas

The model obtained for moisture content when TN 5-78 cowpea was canned is given in Equation 2.

$$\begin{aligned} Z=&+74.49+0.35X_1+0.13X_2-0.13X_3-0.75X_4+0.33X_5 \\ &+0.79X_1X_2-0.39X_1X_3+0.12X_1X_4+0.066X_1X_5 \\ &+1.05X_2X_3+0.66X_2X_4+0.12X_2X_5+0.21X_3X_4 \\ &+0.50X_3X_5+0.45X_4X_5+0.45X_1^2-0.36X_2^2 \\ &-0.10X_3^2-0.17X_4^2-0.70X_5^2 \\ &\text{with } R^2 \text{ of } 93.01\%. \end{aligned} \quad (2)$$

Both, quadratic and linear factors of $(NaPO_3)_6$ concentration and cooking time had a strong influence ($P<0.01$) on the moisture content of canned cowpea while blanching time and cooking temperature showed only linear ($P<0.01$) and quadratic ($P<0.01$) influence respectively. The model could explain 93.01% of the variation in moisture content, meaning only 6.99% of the variation was due to other factors not included in the model. Table 3 shows that the significant interactions ($P<0.01$) were: cooking time and cooking temperature; cooking time and soaking time; cooking temperature and soaking time; cooking temperature and blanching time; soaking time and $(NaPO3)_6$ concentration; and blanching time and salt concentration. The response surface plots (Figure 1) showed that the moisture content of the canned cowpeas increased substantially by increasing two processing factors, namely the cooking time and the processing temperature. The response surface plots indicated that the moisture content decreased as the blanching time increased while the moisture content increased as both the soaking time and salt concentration increased. This agreed with the findings of Afoakwa, Yenyi, and Sakyi-Dawson (2006). They found that the moisture content of canned cowpeas was affected by different pretreatments. Lowering the moisture content in the canned product can lower enzymatic deterioration, as well as microbial and chemical activities which leads to a longer shelf life (White & Howard, 2012; Yeung, Ehlers, Waniska, Alviola, & Rooney, 2009). From this current study, the optimal preprocessing and processing conditions required to achieve the lowest moisture content were soaking time (12 h), salt concentration (0.5%), blanching time (5 min), processing temperature (110 °C), and cooking time (15 min).

3.2 Effect of pre-process and process variables on leached solids of canned cowpeas

The model obtained for leached solids when TN 5-78 cowpea was canned is given in Equation 3.

$$\begin{aligned} Z =& +4.71+0.77X_1+0.58X_2+0.030X_3+-0.28X_4 \\ &+0.26X_5+0.40X_1X_2+6.563E\text{-}003X_1X_3 \\ &+-0.11X_1X_4-0.19X_1X_5-0.40X_2X_3-0.22X_2X_4 \\ &-0.19X_2X_5-0.25X_3X_4+0.37X_3X_5-0.37X_4X_5 \\ &+0.019X_1^2+0.46X_22+0.14X_32+0.33X_42 \\ &-0.033X_52 \quad \text{with } R^2= 98.13\% \end{aligned} \quad (3)$$

Table 3. Lack of fit, coefficient of variation, and total effect (F_0 value) of parameters at various levels of the responses.

Variables	Moisture content	Leached solid	Seed hardness	Seed splitting
X_1	11.48***	435.79***	620.16***	393.22***
X_2	1.62	249.65***	185.29***	23.41***
X_3	1.66	0.67	558.41***	62.21***
X_4	53.42***	56.39***	271.50***	2.36
X_5	10.08***	49.22***	739.45***	38.19***
X_1^2	24.46***	0.34	463.30***	322.74***
X_2^2	15.81***	203.37***	336.84***	26.37***
X_3^2	1.25	18.46***	6.81**	16.30***
X_4^2	3.36*	101.69***	224.17***	5.740E-003
X_5^2	59.60***	1.06***	45.62***	1.04
$X_1 X_2$	42.86***	86.12***	2324.21***	192.97***
$X_1 X_3$	10.51***	0.024	31.94***	1.37
$X_1 X_4$	1.07	6.99**	5.49**	27.47***
$X_1 X_5$	0.30	20.29***	11.89***	7.86***
$X_2 X_3$	76.08***	86.67***	56.00***	322.67***
$X_2 X_4$	30.63***	27.58***	0.011***	2.65
$X_2 X_5$	0.97	20.03***	10.08***	4.35**
$X_3 X_4$	3.14*	33.91***	82.03***	1.15
$X_3 X_5$	17.16***	77.12***	4.36**	1.86
$X_4 X_5$	14.10***	73.56***	555.33***	41.19***
Lack of fit	0.96	1.64	0.64	1.59
CV (%)	0.92	4.39	2.21	0.69

*Significant at P<0.1
**Significant at P<0.05
***Significant at P<0.01
CV=coefficient of variation

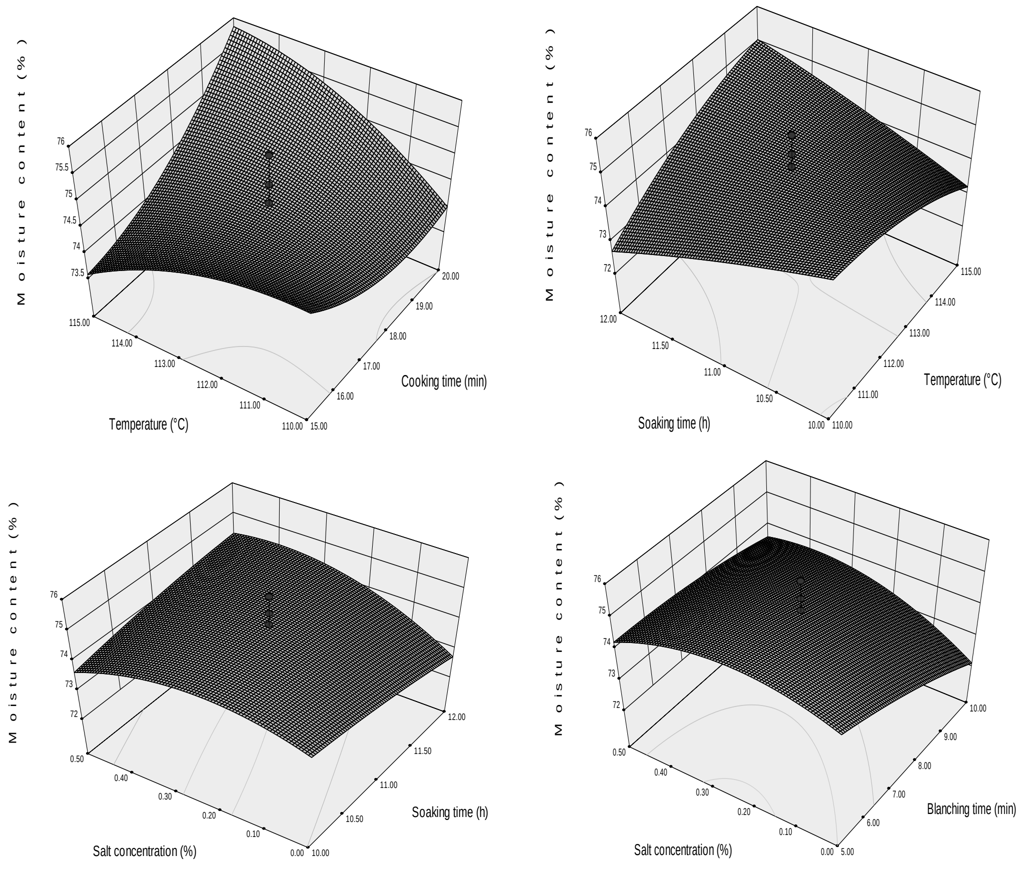

Figure 1. Variation of moisture content depending on preprocessing and processing parameters.

There was a strong and significant (P≤0.01) influence of the linear factors (i.e., cooking time, cooking temperature, blanching time, and salt concentration). The statistical analysis conducted on the data showed that all interactions except between cooking time and soaking time had significant (P≤0.01) influence. Among the quadratic factors only three of them that included cooking temperature (P≤0.01), soaking time (P≤0.01), and blanching time (P≤0.01) significantly influenced the leached solids of canned cowpeas. The model could explain 98.13% of the variation in leached solids, meaning only 1.87% of the variation was due to other factors not included in the model. The plots generated (Figure 2) showed that the leached solids of the drained liquid increased with the increase in both pre-processing and processing conditions which were taken into account in this study. It can be observed that the variations induced by the processing factors were higher than the preprocessing factors. This fact means that the cooking time and temperature are the two important parameters that must be predetermined in order to limit the loss of solids during cowpea processing. If the amount of leached solids is too high, this can bring about low quality and fast deterioration of the canned cowpeas (Afoakwa, Yenyi, & Sakyi-Dawson, 2006). Kayitesi, Duodu, Minnaar, and De Kock (2013) reported that the constituents that leached out of cowpeas were mostly starch during the cooking which resulted in a 'mash like' paste. The results from this study indicated that the optimal conditions necessary to obtain optimal leaching were soaking time (12 h), salt concentration (0.5%), blanching time (5 min), processing temperature (110 °C), and cooking time (15 min).

3.3 Effect of pre-processing and processing variables on hardness of canned cowpea

The model obtained for drained weight when TN 5-78 cowpea was canned is given in Equation 4.

$$
\begin{aligned}
Z = {} & +463.49-46.37X_1+25.35X_2-44.00X_3+30.68X_4 \\
& -50.64X_5-104.44X_1X_2+12.24X_1X_3-5.07X_1X_4 \\
& +7.47X_1X_5-16.21X_2X_3+0.23X_2X_4-6.88X_2X_5 \\
& -19.62X_3X_4-4.53X_3X_5-51.05X_4X_5+35.39X_1^2 \\
& +30.17X_2^2+4.29X_3^2+24.61X_4^2+11.10X_5^2 \\
& \text{with } R^2 = 99.54\% \qquad (4)
\end{aligned}
$$

All five parameters taken into account in this study had strong and significant (P≤0.01) influence in terms of linear effect as well as quadratic effect on the model. The model explained up to 99.54% of the variation in the hardness level of canned cowpea. The response plots (Figure 3) show that increasing two of the processing parameters (i.e., cooking time and temperature) resulted in important decreases of seed hardness of the processed cowpeas. It was reported that the process continues the decomposition of pectic substances and the connections between the cells weaken and the shearing strength decreases (Guo & Wang, 2018; Kayitesi, Duodu, Minnaar, & De Kock, 2013; Sasikala, Ravi, & Narasimha, 2011). The seed coat and microstructure of seeds may be responsible for facilitating a rapid softening of the seeds during the soaking stage. A similar phenomenon was observed with the preprocessing parameters. These results corroborated with the work of Afoakwa, Yenyi, and Sakyi-Dawson (2006) and Zamindar, Baghekhandan, Nasirpour, and Sheikhzei-

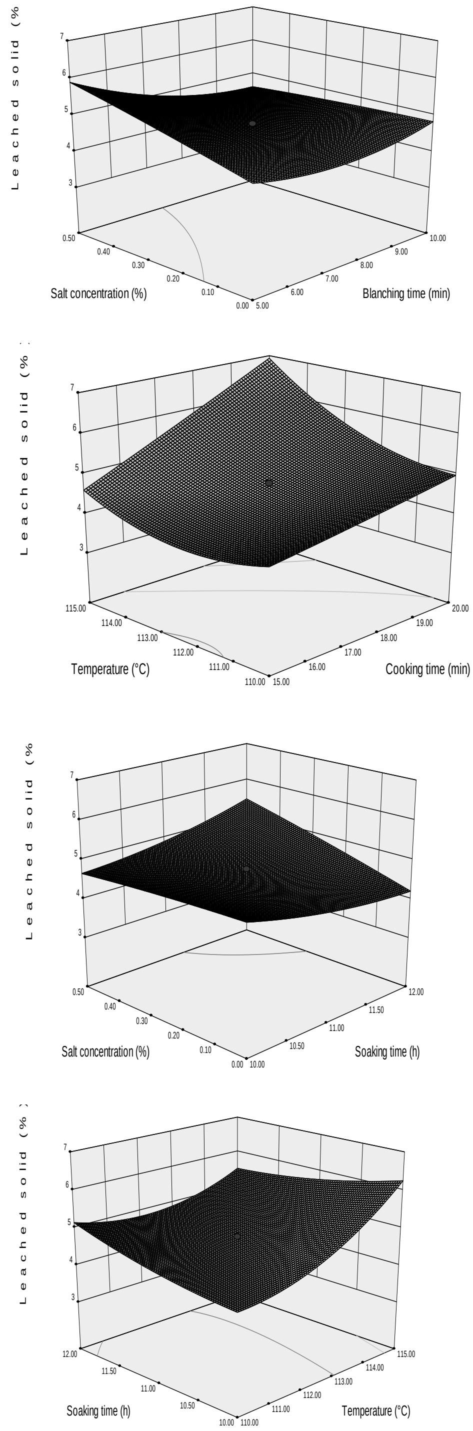

Figure 2. Variation of leached solid depending on preprocessing and processing parameters.

noddin (2013). Indeed, the decrease in hardness that resulted from increased soaking and blanching times were due to the fact that, there is a disruption of cell integrity as a result of an ion exchange between the sodium ions and the divalent ions in the intracellular cement during the soaking step (Afoakwa,

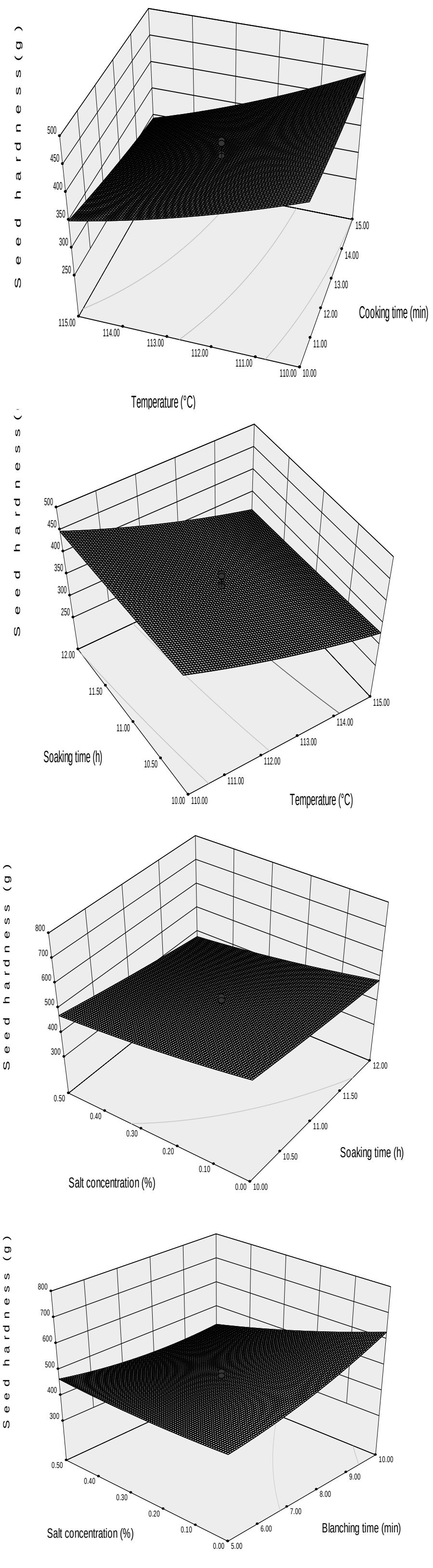

Figure 3. Variation of seed hardness depending on pre-processing and processing parameters.

Yenyi, & Sakyi-Dawson, 2006; Annor *et al.*, 2010). Cowpeas soaked for long time tend to become soft (Sasikala, Ravi, & Narasimha, 2011; White & Howard, 2012). From this study the optimal conditions necessary to obtain the optimal seed hardness were: soaking time of 12 h; salt concentration of 0.5%; blanching time of 5 min; processing temperature of 110 °C; and cooking time of 15 min.

3.4 Effect of pre-processing and processing variables on splitting of canned cowpeas

The model obtained for the drained weight when TN 5-78 cowpeas were canned is given as Equation 5.

$$Z = +31.92 + +0.65X_1 - 0.16X_2 + 0.26X_3 - 0.050X_4 + 0.20X_5 + 0.53X_1X_2 + 0.045X_1X_3 + 0.20X_1X_4 + 0.11X_1X_5 - 0.69X_2X_3 - 0.062X_2X_4 - 0.062X_2X_5 - 0.041X_3X_4 + 0.052X_3X_5 + 0.25X_4X_5 - 0.52X_{1}2 - 0.15X_{2}2 + 0.12X_{3}2 + 2.197.10^{-003}X_{4}2 + 0.030X_{5}2, \text{ with } R^2 = 98.12\% \quad (5)$$

There was a significant ($P \leq 0.01$) influence of the linear factors (i.e., cooking time, processing temperature, soaking time, and salt concentration) and the quadratic factors (i.e., cooking time, processing temperature, and soaking time). It can be pointed out that only the blanching time did not have any significant influence on the level of seed splitting. The model could explain around 98.12% of the variations of canned cowpeas splitting. The response surface plots (Figure 4) showed that the level of canned cowpea splitting increased substantially when two of the processing parameters, namely cooking time and processing temperature, were increased. These observations were contrary with the findings of Zamindar, Baghekhandan, Nasirpour, and Sheikhzeinoddin (2013) where the level of splitting decreased as the cooking time increased. This may be due to differences in the varieties of cowpeas studied. The preprocessing parameters revealed that increasing the blanching time led to a slight increase of TN 5-78 cowpea seed splitting during the canning process. On the other hand, the soaking time showed consistent increases in the splitting of cowpea seeds. This agreed with a report by Lopez (1987) that stated that the cowpeas were usually soaked for 12 h in water at 82–93 °C, and over-soaking caused splitting of the seeds. Kayitesi, Duodu, Minnaar, and De Kock (2013) reported that consumers considered excessive splitting of cooked cowpeas as an undesirable characteristic. However, this study found that the optimum process conditions that could lead to minimal seed splitting of canned cowpeas were soaking TN 5-78 cowpea for 12 h with $(NaPO3)_6$ at a concentration of 0.5%, blanching for 5 min, and cooking for 15 min at 110 °C.

3.5 Heat treatment efficiency

A typical temperature-time profile is presented in Figure 5. The value of F_0 obtained after sterilization of TN 5-78 cowpea at 110 °C for 15 min was only 1.18±0.02 min. Usually, the primary concern in low-acid foods (pH>4.5) is destruction of *Clostridium botulinum* spores as minimum basis for establishing the process, even though it might cause undesirable colour and texture changes in the product, such as browning and softening. The minimum time required for process lethality (F_0) is 2.52 min as reported by Ramaswamy

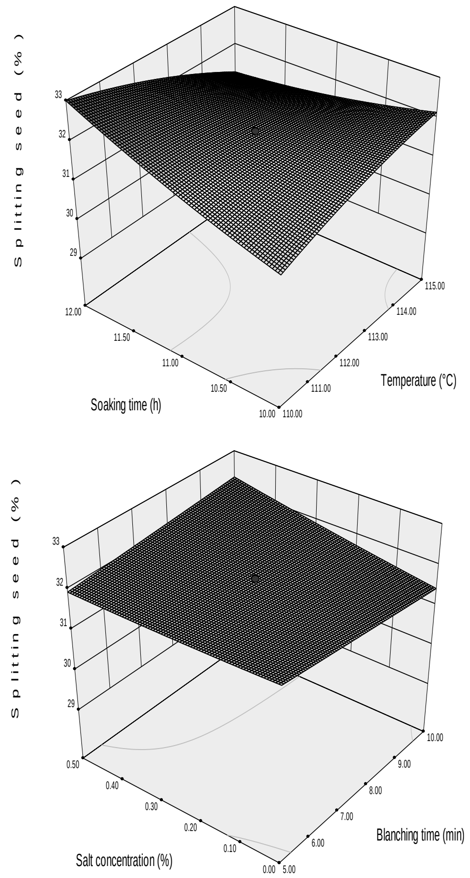

Figure 4. Variation of seed splitting depending on preprocessing and processing parameters.

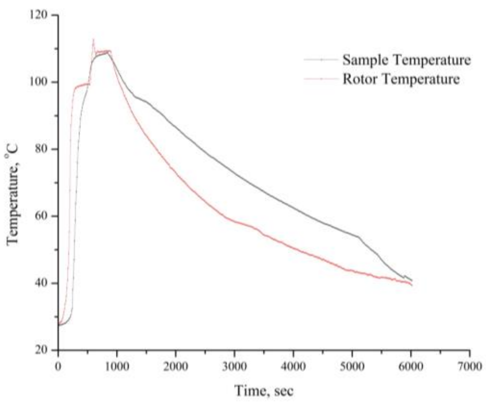

Figure 5. Typical temperature-time profile for retorted TN 5-78 cowpea samples.

and Chen (2004). The process lethality obtained in this study was below the reported minimum value and, therefore, may not provide ambient stability in the food.

4. Conclusion

This study shows that RSM is a good way to optimize the pre-processing and processing conditions of TN 5-78 cowpea. The data analysis revealed that all factors considered in this study had a substantial influence on most of the qualitative parameters of the product. The optimum conditions obtained from the study resulted in an end product with acceptable quality parameters that were cooking time of 12 h, salt concentration of 0.5%, blanching time of 5 min, processing temperature of 110 °C, and cooking time of 15 min. However, these processing parameters (cooking temperature and time) did not reach the level required for low acid food to provide a safe product for consumers. Thus, this cowpea variety (TN 5-78) may not be suitable for industrial use unless heat treatment is combined with other treatments.

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