Response surface methodology for optimizing the pre-processing conditions during canning of a newly developed and promising cowpea (Vigna unguiculata) variety

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Abstract

Cowpea (*Vigna unguiculata* L. Walp) seeds were canned with the objective of investigating the optimal pre-processing conditions that would yield the best quality canned product from the newly developed cowpea variety. Pre-canning procedures such as blanching time, soaking time and sodium hexametaphosphate ([NaPO3]6) salt concentration were used as the independent variables for a Central Composite Rotatable Design (CCRD). The pre-processing parameters obtained from the CCRD were used for the canning of the cowpeas and the quality characteristics (moisture content, pH of the drained liquid, drained weight, splitting of the seeds, leached solids and seed hardness) of the canned products were studied using response surface methodology. Regression models were generated using regression analysis and used for the plotting of response surface curves. Adequacy of the model equation for predicting optimum response values was tested in the experiment using the blanching time of 2–12 min, soaking time of 0–24 h and salt concentration ([NaPO3]6) of 0–1%. Three optimal processing conditions of the canning procedures of the cowpeas were determined from the mathematical models. The results revealed that the soaking time, blanching time and salt concentration all significantly (*p* < 0.05) influenced most of the quality indices of the canned cowpeas. The optimal conditions required to achieve the optimum moisture content, pH level and other quality indices studied on the canned cowpeas were blanching time of 5 min, soaking time of 12 h and [NaPO3]6 salt concentration of 0.5%.

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1. Introduction

Cowpea (*Vigna unguiculata* L. Walp) a grain legume, is a member of the family leguminosae and sub-family Fabaceae. It is one of the most important protein sources in the diet of tropical Africa particularly in the Sahel regions. It is a highly nutritious crop with a dry seed protein content of about 25% and protein digestibility higher than that of other legumes (Afoakwa, Sefa-Dedeh, & Cornelius, 2002; Olongbobo & Fetuga, 1983). Cowpea is cultivated extensively, mostly in the savannah areas of West Africa, and in Nigeria and Ghana it is referred to as beans. It has been found to contribute up to 80% of the total dietary protein intake in some parts of West Africa (Sefa-Dedeh, Frimpong, Afoakwa, & Sakyi-Dawson, 2000). Many varieties of cowpea seeds exist and are known by their different sizes, shapes and especially seed colour which can be either white, red, brown, black, cream and mottled (Sefa-Dedeh, Sakyi-Dawson, & Afoakwa, 2001; Afoakwa et al., 2002).

The most important difference in the use of cowpeas for food between the people of the tropics and the rest of the world is related to the physical form in which they are used and the procedures employed in preparing them...
for food. Although the processing of cowpea flour greatly simplified the task of paste preparation by eliminating the soaking, dehulling and milling steps, it was not well received by consumers due to its poor performance (Afoakwa, Sefa-Dedeh, & Sakyi-Dawson, 2004; Phillips & Mcwatters, 1991). Based on these findings, research efforts have led to the gradual development and adoption of various preservation methods to make cowpea available all year round. In most developed countries, cowpeas are packaged dry, either raw or pre-cooked, canned in water, tomato sauce or molasses; and canned in combination with other vegetables and meat or as constituents of soups, salads and dips. Even though traditional drying method of cowpea is economically cheaper, canning is proven to give cowpea a longer shelf life (Bressani, 1993; Afoakwa, Sefa-Dedeh, Kluvitse, & Sakyi-Dawson, 2003).

The canning industry is constantly improving processing methods, enhancing quality and product safety. Processing methods designed, heighten retention of nutrients and effective use of energy. Pre-canned cowpea is usually soaked in cold soft water for 10–12 h, although an occasional lot may require somewhat less soaking depending on the moisture content of the peas and the hardness of the water (Lopez, 1987). As well, the addition of 0.2% sodium hexametaphosphate has been found to be satisfactory in water having 26–29 grains total hardness per gallon. Sodium hexametaphosphate has the general purpose of stabilizing or improving texture. It softens texture of canned peas, beans, meat and poultry. The time of blanching depends on the texture and type of peas being blanched (Lopez, 1987). Over blanching or blanching at too high temperature may cause the peas to split their skins. However, some canners have been successful in packing cowpeas by giving them a short soak (2–4 h), followed by a somewhat longer blanch (10–15 min). If this is done, the fill-in weight of the peas will have to be adjusted to allow for a greater swell in the can, and usually a slightly longer process is required (Lopez, 1987). With some types of cowpeas, this long blanch procedure seems to give firmer and less mushy peas, and this procedure requires very careful control of soaking and blanching times, temperatures and careful checking of filling weights. As new cowpea varieties are developed, it is important to study the best pre-processing conditions that would yield the best quality canned products from them.

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 (Sefa-Dedeh, Cornelius, Sakyi-Dawson, & Afoakwa, 2003). This work was therefore aimed at studying the optimal pre-processing conditions for the canning of a newly developed cowpea variety (IT87D195Y) in West Africa using response surface methodology for varying soaking time, blanching time and sodium hexametaphosphate [(NaPO₃)₆] salt concentrations.

2. Materials and methods

2.1. Materials

The newly developed cowpea variety (IT87D195Y) was obtained from the Crop Research Institute of the Council for Scientific and Industrial Research (CSIR) of Ghana and used for the study.

2.1.1. Experimental design for response surface methodology

A Central Composite Rotatable Design (CCRD) of the experiment was set up using the Statgraphics software with experimental study variable number \( K = 3 \), for independent variables including blanching time \( X_1 \), soaking time \( X_2 \) and sodium hexametaphosphate concentrate \( X_3 \). The process variables to be used in the CCRD for \( K = 3 \) could be processed using the software. This will indicate the dependent variable limits and their values. The dependent variables studied included the following: moisture content of the canned cowpeas, pH of drained liquid, drain weight of canned product, seed splitting, leached solids and hardness of canned cowpeas. Twenty sample combinations were generated from the software in experimental design using the design matrix and variable combinations in experimental runs as shown on Tables 1 and 2 below.

The experiments conducted on the various combinations were then tabulated accordingly and analysed using stepwise regression analysis.

2.1.2. Sample treatments

Equal amount of cowpea was treated with sodium hexametaphosphate concentrations of 0%, 0.2%, 0.3%,
0.8% and 1%. The cowpeas were then soaked in the sodium hexametaphosphate solution respectively for 0, 5, 12, 19 and 20 h. The cowpeas prior to canning were blanched for 0, 2, 5, 8 and 10 min. The samples were then processed in a vertical retort for 20 min at 121 °C.

2.1.3. The optimization process

A stepwise multiple regression analyses was conducted on the data from the Central Composite Rotatable Design to relate blanching time, soaking time and sodium hexametaphosphate (salt) concentration, \([\text{NaPO}_3\text{]}) to moisture content, pH of drained liquid, drained weight, percent splitting, leached solids and mean hardness of the canned cowpeas. The response surface models were generated and presented as 3-dimensional plots in the function of 2 factors (blanching time and soaking time) whilst the salt concentration \([\text{NaPO}_3\text{]}) is kept constant. Adequacy of the model equation for predicting optimum response values was tested in the experiment using the blanching time of 2–12 min, soaking time of 0–24 h and salt concentration \([\text{NaPO}_3\text{]}) of 0–1%. Three optimal processing conditions of the canning procedures of the cowpeas were determined from the mathematical models. In order to get these optimal values, the first partial derivatives of the regression equations were done according to \(X_1\), \(X_2\) and \(X_3\) and sorted.

2.1.4. Fill of container

The standard of fill of container for canned cowpeas is a fill such that, when the cowpeas and liquid are removed from the container and returned thereto, the levelled cowpeas (irrespective of quantity of the liquid) 15 s after they are so returned, completely fill the container. The container with lid attached by double seam was considered to be completely filled when it was filled to the level 3/16 in. vertical distance below the top of the level of the double seam. It is generally assured in the canning industry that a container must be filled to not less than 90% of its total capacity. This means that, the net headspace of the container slid not be greater than 10% of its internal height. The fill-in weight was then calculated according to the equation below:

\[
\text{Percent fill} = \frac{\text{Inside height of can} - \text{net head space} \times 100}{\text{Inside height of can}}.
\]

2.2. Analytical methods

2.2.1. Moisture content determination

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

2.2.2. pH measurement

pH was measured exclusively with glass electrode pH meter. The determination was done on a small amount of syrup poured from the can into a beaker and the pH of the drained liquid was determined using the TOA pH meter.
2.2.3. Leached solids

A 10 ml aliquot of the drained water from samples after canning was dried at 105 °C in an air oven for 24 h. The weight of the residue was determined after drying. This was done in triplicate and the mean value reported as g/g dry sample.

2.2.4. Drained weight

After determining the fill of the container, the contents of the container was distributed over the meshes of a circular sieve made with a specified number (No. 8), that is, 8 holes/in., woven wire cloth which complies with the specifications for such cloth set forth in “Standard specifications for sieves”. The diameter of the sieve used is 8 inches, without shifting the peas, the sieves were inclined to facilitate drainage. About 2 min after the drainage had began the cowpeas were removed from the sieve and weighed, and the drained weight of the cowpeas noted (Pearson, 1976).

2.2.5. Splitting

The content of each container was distributed over the meshes of a circular sieve made with a specified number (8 holes/in.) woven wire cloth for liquid to drain. The weight of splitted cowpea was taken and expressed as a proportion of the total weight of the canned cowpeas.

2.2.6. Seed hardness

The hardness of seeds after canning was determined using a TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, England). The test cell used was the Warner-Bratzler Blade. The peak force required to cut through five seeds was determined. The seeds were placed longitudinally across the groove in the sample holder and cut perpendicularly across the axis of the seeds. The test conditions used were: test speed of 1.5 mm/s and distance of 11 mm. The test was replicated five times and the average peak force recorded.

2.3. Statistical analysis

All the statistical analysis and graphical presentations were done using Statgraphics (Graphics Software Systems, STCC, Inc., Rockville, USA). The significant probability was set at $p < 0.05$.

3. Results and discussion

3.1. Effect of pre-process variables on the moisture content of canned cowpeas

The model obtained for moisture content when the IT87D195Y cowpea was used for the canning was:

$$Z = 35.71639 - 0.54502X_1 - 0.59761X_2 - 14.30610X_3$$
$$+ 0.01336X_1X_2 + 0.16250X_2X_3 + 0.04198X_1^2$$
$$+ 0.01908X_2^2 + 11.04050X_3^2$$

with an $R^2$ of 90.0%.

There was a strong and significant influence of the quadratic factors of soaking time, salt concentration and blanching time as well as linear factors of blanching time and salt concentration on the moisture content. Statistical analysis conducted on the data showed that salt concentration and blanching time both had significant ($p \leq 0.05$) quadratic and linear effects on the model, with soaking time having only quadratic effect. The model could explain 90.0% of the variations in moisture content, meaning only 10.0% of the variation was due to other factors not included in the model. The response plots (Fig. 1a–c) show that blanching time, soaking time and the salt concentration, all had significant effects on the moisture content of the canned cowpea with significant interaction between all the factors.

The response surface plots generated showed a curvilinear plots with both blanching time and soaking time (Fig. 1a–c). This implies that the moisture content of the cowpea seeds reduced slightly during the first few hours of soaking and then increased again till the end of the soaking time. Similar trends were observed for the blanching time with all the different salt concentrations used. Decreased moisture in canned food products have been reported to lowers the enzymatic deterioration as well as microbial and chemical activities in the product hence increases the shelf life of the product (Lopez, 1987). From the study, the optimal pre-processing conditions required to achieve the lowest moisture content were identified as blanching time of 5 min, soaking time of 12 h and salt concentration of 0.5%.

3.2. Effect on pH of canned cowpeas

The model obtained for pH of the canned cowpea was:

$$Z = 6.660304 - 0.08448X_2 - 2.30832X_3 + 0.00636X_1X_2$$
$$+ 0.08965X_2X_3 - 0.00793X_1X_2X_3$$
$$+ 1.73947X_3^2$$

with an $R^2$ of 79.5%.

There was a significant ($p \leq 0.05$) influence of the linear factors of soaking time and blanching time and the quadratic factor of the salt concentration. It was observed from the statistical analysis that both soaking time and blanching time had significant ($p \leq 0.05$) linear effect on the model, whilst the salt concentration had quadratic effect. The model could explain about 80% of the variations in pH. As shown in the response plots...
all the factors (blanching time, soaking time and salt concentration) had significant effects on the pH of the canned cowpeas. Increasing the salt concentration from 0.5% to 1.0% influenced the pattern of the pH with soaking times and blanching time, implying there were interactions between all the factors. At 0% and 0.5% salt concentrations, the influence of blanching was not pronounced on the pH of the samples, hence very low pH levels were observed at the initial periods of blanching (Fig. 2a and b) which levelled up with increasing blanching times. On the contrary, the plots obtained for the cowpea soaked with 1.0% salt concentration showed that soaking influenced the pH of the canned cowpeas. The plot indicated that increasing blanching time and soaking time led to slight decreases in the pH of the samples (Fig. 2c). From the study it was noted that the optimal conditions required to achieve the optimum pH level in the canned cowpeas were blanching time of...
5 min, soaking time of 12 h and salt concentration of 0.5%, pH is low at these conditions and such low pH is desirable for creating unfavourable environment for microbial activity and hence increases the shelf life of the product while maintaining the quality of the canned product.

### 3.3. Effect of process variables on leached solids of canned cowpea

The regression model obtained for leached solids when the IT87D195Y cowpea was used for the canning was:

Fig. 2. pH of the canned cowpea at (a) 0%, (b) 0.5% and (c) 1% salt concentration.
\[ Z = 1.322319 - 0.24665X_1 - 0.12834X_2 - 2.53147X_3 \\
+ 0.01121X_1X_2 + 0.28909X_1X_3 + 0.12619X_2X_3 \\
- 0.01726X_1^2X_3 + 0.00567X_1^2 + 0.00181X_2^2 \\
+ 0.45173X_3^2, \] with an \( R^2 \) of 91.4%.

There was a significant \( (p \leq 0.05) \) influence of the quadratic factor of soaking time. It was observed from the statistical analysis that soaking time had significant \( (p \leq 0.05) \) quadratic effect on the model, but no linear effect. The model could explain about 91.0% of the variations in the leached solids level. Thus about 9.0% of the variation was due to other factors not included in the model. As shown in the response plots (Fig. 3a–c), soaking time had significant effects on the leaching of solids from the cowpea seeds into the soaking medium. The

Fig. 3. Leached solids of the canned cowpea at (a) 0%, (b) 0.5% and (c) 1% salt concentration.
leached solids were found to increase with increasing soaking time. It has been reported that soaking cowpea seeds for 12 h removes 65% of anti-nutrients, which are leached into the soaking water (Phillips, 1993). It is therefore suspected that some dissolved solids leaves the cowpea seeds when the plant cell comes into contact with a solution of lower water potential for at least 12 h. From these 3-dimensional plots the optimal conditions required to achieve the optimal leaching were blanching time of 5 min, soaking time of 12 h and salt concentration of 0.5%. Even though the leaching might remove some anti-nutrients from the cowpea seeds prior to canning, too high amount of leached solids can bring about low quality and fast deterioration of the canned cowpeas.

3.4. Effect of process variables on drained weight of the canned cowpeas

The regression model obtained for drained weight when the IT87D195Y cowpea was used for the canning was:

\[
Z = 53.601654 + 0.31378X_2 + 30.6495X_3 \\
- 0.66225X_1X_3 + 0.02646X_1^2 - 0.01126X_2^2 \\
- 0.01126X_3, \quad \text{with an } R^2 \text{ of 81.8%}.
\]

There was a strong and significant \((p \leq 0.05)\) influence of both the quadratic and linear factors of soaking time. It was observed from the statistical analysis that soaking time had significant \((p \leq 0.05)\) quadratic and linear effect on the model. The model could explain about 82.0% of the variations in drained weight. The response plots (Fig. 4a–c) show that soaking time and blanching time had significant effects on the drain weight of the canned cowpeas. However, increasing salt concentration brought about slight differences in the plot patterns. The trend was that, the higher the salt concentration, the higher the drained weight. This indicates that the cowpea absorbs more of the salt at higher salt concentration. This is suspected to be resulted from the fact that plant cell in contact with a solution of lower water potential than its own content experiences water leaving its cell by osmosis through the cell membrane, since osmotic gradient cause the movement of molecules or ions from a region of higher concentration (salt solution) to lower concentration. However, with the exception of the product soaked in 1.0% salt concentration which showed decreases in drained weight with increasing blanching time, increasing soaking times led to increasing drained weight in the canned cowpea products (Fig. 4a and b). The study revealed that the optimal conditions required to achieve the highest drained weight in the canned products were blanching time of 5 min, soaking time of 12 h and salt concentration of 0.5%. The implication is that canned cowpeas with higher drained weight appear more palatable thereby influencing consumer acceptability of the product.

3.5. Effect of the process variables on splitting of canned cowpeas

The model obtained for seed splitting when the IT87D195Y cowpea was used for the canning was:

\[
Z = 5.479413 - 1.60609X_1 + 2.16948X_3 - 0.16385X_2X_3 \\
+ 0.11321X_1^2, \quad \text{with an } R^2 \text{ of 78.2%}.
\]

There was a strong and significant \((p \leq 0.05)\) influence of the linear factors of soaking time and \([\text{NaPO}_3\text{]}_6\) and the quadratic factor of blanching time. It was observed from the statistical analysis that soaking time and \([\text{NaPO}_3\text{]}_6\) had significant \((p \leq 0.05)\) linear effect on the model, whilst blanching time had quadratic effect. The model could explain about 78.0% of the variations in the splitting level.

As shown in the response plots (Fig. 5a and b), blanching time, soaking time and salt concentration had significant effects on the splitting of the cowpea seeds during the canning operation. Even though the trends were similar, higher salt concentrations led to relatively high seed splitting. Blanching time however had no effect on the splitting of the seeds soaked in 0.5% and 15 salt concentration. On the contrary, soaking time showed consistent increases in the splitting of the cowpea seeds from the onset of soaking till the end of the soaking period (Fig. 5a–c). This agrees with the report by Lopez (1987) that cowpeas are usually soaked for 12 h in water at 180°F to 200°F, and over-soaking causes splitting of the seeds. Therefore, soaking the newly developed cowpea seeds for 12 h in 0.5% salt concentration and blanched for 5 min would cause only minimal splitting of the seeds. Canned cowpeas with minimal splitting can increase consumers' preference.

3.6. Effect of process variables on hardness of canned cowpeas

The model obtained for hardness of the cowpea was:

\[
Z = 215.618596 + 13.54530X_1 - 30.4813X_2 \\
+ 577.9810X_3 - 3.94670X_1X_2 - 102.0100X_1X_3 \\
- 55.1591X_2X_3 + 8.09087X_1X_3X_3 + 3.34582X_1^2 \\
+ 32.1208X_3^2, \quad \text{with an } R^2 \text{ of 75.8%}.
\]

There was a strong and significant \((p \leq 0.05)\) influence of the quadratic factor of blanching and linear factors
of soaking time, salt concentration \([\text{NaPO}_3\text{H}_6]\) and blanching time. It was observed from the statistical analysis that soaking time and salt concentration \([\text{NaPO}_3\text{H}_6]\) had significant \((p \leq 0.05)\) linear effect on the model, whilst blanching time has both quadratic and linear effect. The model could explain about 76.0\% of the variations in the hardness level. As shown in the response plots (Fig. 6a–c), all the 3 factors had significant effects on the texture (hardness) of the canned cowpeas. The variations in the salt concentration brought about slight changes in the pattern of the response plots, which is an indication of the fact that increasing the salt concentration influences the hardness of the cowpeas (Fig. 6a–c). The plots revealed that increasing soaking time resulted in consistent decreases in the hardness of the canned cowpeas. According to Lopez (1987), cowpeas soaked
for longer periods of time tend to become soft. On the other hand, the decrease in hardness as a result of the increasing soaking and blanching times were due to the fact that, there is a disruption of cell integrity as a result of an ion exchange reaction between sodium ions and the divalent ions in the intracellular cement during soaking (Pearson, 1976). Again, if cowpeas remain in water for a long time they become soft (Lopez, 1987). From the study, it was observed that the optimal pre-processing conditions required to achieve the optimum hardness that would not make the canned cowpeas too soft or hard after processing were blanching time of 5 min, soaking time of 12 h and \([\text{NaPO}_3\text{]}_6\) salt concentration of 0.5%.

Fig. 5. Seed splitting of the canned cowpea at (a) 0%, (b) 0.5% and (c) 1% salt concentration.
4. Conclusions

Central Composite Rotatable Design (CCRD) and Response Surface Methodology (RSM) can effectively be used to estimate the effect of blanching time, soaking time and sodium hexametaphosphate, [(NaPO₃)₆] salt concentration and their interactions on the optimal processing conditions of cowpeas prior to canning. The results revealed that the soaking time, blanching time and salt concentration all significantly \( p < 0.05 \) influenced most of the quality indices of the canned cowpeas. Increasing salt concentration had a significant effect on the physical characteristics on the cowpea variety. From the study, it was observed that the optimal pre-processing conditions required to achieve the optimum quality of the newly developed cowpea were blanching time of 5 min, soaking time of 12 h and [(NaPO₃)₆] salt concentration of 0.5%. These conditions give the best quality canned product from the IT87D195Y cowpea with acceptable quality characteristics.

![Graphs showing seed hardness of the canned cowpea at different salt concentrations.](image_url)


