Process optimization of emergency food originated from denatured whey protein concentrate and dried sweet potato puree

S Khairunnisa, R Andoyo, H Marta and G L U Saripudin
Department of Food Industrial Technology, Faculty of Agro-industrial Technology, Universitas Padjadjaran, Sumedang, 40600, Indonesia.

E-mail: r.andoyo@unpad.ac.id

Abstract. Denatured whey protein concentrate can be added into food products to increase protein content without changing the texture considerably. One food product that requires high protein content is emergency foods. The aim of this study was to determine the optimum parameters of emergency food processing based on denatured whey protein concentrate combined with dried sweet potato puree with high lethality of microbes and low physical change. Optimizing process has been conducted using Response Surface Method with Box-Behnken scheme. Emergency foods was prepared with containing 6.1-11.6% (w/w) protein, placed in three packaging materials e.g glass jar, nylon bag, and metallized bag and treated with 5.0 to 12.0 (D, decimal reduction time) thermal processing level. The optimum parameters of emergency food produced were 10.14% (w/w) protein content, placed in metallized pouch, and sterilized in 11.11 thermal processing level.

1. Introduction
Application of whey protein as food fortification had attracted a great attention. The purpose of addition of whey protein into various food products, such as sport drinks, baby foods, baked products, etc. is not merely for increasing the protein content of such products, but also may affect the physical characteristics. The change of the food characteristics is caused by functional properties of whey protein in native state, such as high solubility, high water holding capacity, and gel forming capability [1]. However, application of whey protein would usually generate negative sensorial for some food products. To prevent this change, the whey in native state is modified by some heat treatment. Different from the whey in native state, the whey in denatured state can increase protein content of food without changing the texture considerably [2].

Denatured whey protein can be added into emergency food specified processed for those whose impacted by disaster. Based on their function, the emergency foods must have high protein content to fulfill nutrition needs for certain victim category, such as children age of less than 5. The emergency foods must be ready-to-eat, have high energy and other important nutrition content, and can fulfill victim’s need for 15 days in emergency situation [3].

The emergency foods are also designed to have long storage period so can always be available in unpredicted situations. To prolonging such storage period, the emergency foods can be treated with thermal process. Heat treatment applied to foods can inactivate even kill spoilage microbes [4]. However, uncontrolled thermal process can degrade product characteristics. Therefore, in application
of the thermal processing we must consider its effect on food characteristics. It is expected that the change of characteristic of foods after thermal treatment should be as small as possible.

Different kind and ratio of raw materials will produce different thermal characteristics of products. Protein-based and carbohydrate-based foods have slight difference in thermal characteristic. For example, whey protein based food system has higher thermal conductivity and specific heat capacity compared to mashed potato [5]. In other words, food with high protein to carbohydrate ratio will have larger thermal penetration.

The thermal characteristics of food are also affected by packaging material. Different packaging material as well as different packaging geometry may generate different heat penetration into the foods [4]. Other than retort pouch that usually, foods that have been treated at high temperature can be packaged in glass jars.

Fortunately, the thermal process can be controlled through processing time. Shorter processing time is able to prevent overheating. In addition, the thermal processing level, i.e. longer shelf life due to reduction of microorganism, can be modified by varying the processing time.

The objective of this study was to investigate the optimum thermal processing parameters, namely protein content, packaging material, and thermal processing level for producing high protein emergency food. Response Surface Method (RSM) with Box-Behnken design was used to obtain optimum processing parameters for emergency foods with high lethality of microbes and low physical change.

2. Material and Methods

2.1. Raw Material Preparation
Denatured Whey Protein Concentrate (WPC-d) made of fresh cow milk was obtained from Laboratory of Dairy Cattle, Faculty of Animal Husbandry, Padjadjaran University. The material has been processed as reported reference [6]. Dried sweet potato puree made of sweet potato (Ipomoea batatas, var. Ace Putih) has been processed according to reference [7]. Each raw material was packaged in airtight container and placed in dry area at ambient temperature.

2.2. Emergency Food Preparation
Emergency food was made by mixing dry materials (WPC-d and dried sweet potato puree, at protein contents ranging from 6.1 to 11.6% (w/w)) with warm water (70 °C). The ratio of dry material and water was kept at 1:2 (w/w). The mixture was then packaged in nylon pouch, metallized pouch, or glass jar that obtained from local market.

2.3. Thermal Processing
The samples were then placed in autoclave (Astell Scientific), set at the coldest point of the autoclave. The sample temperature was recorded by a data logger (Lutron). The processing time was trial adjusted to reach 5.0-12.0 thermal processing level at 110 °C.

2.4. Experimental Design and Process Optimization
Experimental design and process optimization were conducted by Response Surface Method with Box-Behnken design using Design Expert 7.0.0 (Stat-Ease Inc.). Three factors were tested, namely protein content (6.11-11.6% (w/w)), packaging material (nylon pouch, metallized pouch, and glass jar) and thermal processing level (5.0-12.0). The experiment was conducted with 15 running includes 3 repetition of center point. The sample run are listed in table 1.

Measured responses were consists of total microbial numbers, water activity, color, texture, and energy content. The total microbes number was analysis according to reference [8]. The water activity was measured by Aw meter (AquaLab LITE). The texture was measured by texture analyzer (Stable Micro System TA.XT) installed by P1Ks probe with marmalade project. The texture analysis was
conducted with speed of 2 mm/min using adhesiveness, gel strength, and brittleness indicators. The color response was analyzed by spectrometer (Minolta CM-5) using Hunter color system.

We also estimated the response model equation. From the equation, we can predict value of response when inserting the desired variables. We used the model equation as following

\[ y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=2}^{k} \beta_{ij} x_i x_j + \varepsilon \]  

(1)

with \( y \) is the response, \( x_i \) is the controlled parameter, \( \beta_0 \) is the independent response, \( \beta_i \) is the coefficient contributed by linear response, \( \beta_{ii} (i = 1, 2, \ldots, k) \) is the coefficient generated by quadratic response, and \( \beta_{ij} (j = 1, 2, \ldots, k) \) is the coefficient contributed by interaction between different parameters, and \( \varepsilon \) is the random error [9].

| Run | Protein content (%) | Packaging | Thermal processing level (D) |
|-----|---------------------|-----------|-----------------------------|
| 1   | 6.1                 | Glass jar | 8.5                         |
| 2   | 8.9                 | Nylon pouch | 5.0                        |
| 3   | 8.9                 | Metallized pouch | 8.5                     |
| 4   | 8.9                 | Metallized pouch | 8.5                 |
| 5   | 6.1                 | Nylon pouch | 8.5                         |
| 6   | 11.6                | Nylon pouch | 8.5                         |
| 7   | 8.9                 | Metallized pouch | 8.5                     |
| 8   | 11.6                | Metallized pouch | 12.0                  |
| Run | Protein content (%) | Packaging | Thermal processing level |
| 9   | 6.1                 | Metallized pouch | 12.0          |
| 10  | 8.9                 | Nylon pouch | 12.0                       |
| 11  | 6.1                 | Metallized pouch | 5.0          |
| 12  | 8.9                 | Glass jar | 5.0                        |
| 13  | 11.6                | Metallized pouch | 5.0         |
| 14  | 11.6                | Glass jar | 8.5                        |
| 15  | 8.9                 | Glass jar | 12.0                       |

3. Results and Discussion

Generally, the objective of this work was to identify the optimum process for producing emergency food originated from WPC-d with dried sweet potato puree. The factors investigated at the present work include the protein content (6.1%, 8.9%, and 11.6% (w/w)), packing material (nylon pouch, metallized pouch, and glass jar), and thermal processing level (5.0, 8.5, and 12.0).

3.1. Thermal Processing Time

Prior to identification of the optimum process, trial and error thermal processing steps were conducted to obtain the optimum holding time because of unavailability of data found in references. The thermal processing was kept at temperature of below standard commercial sterilization (110°C) to prevent appreciable damage to product. Modification of the processing temperature was also expected to modify processing time. When using the standard process at 121 °C, the holding times at thermal levels of 5.0, 8.5, and 12.0 were 1.05, 1.79, and 2.52 minutes, respectively. The \( F \) values that processed at 110 °C was calculated by a trapezoidal method. This method measures the total surface area under curve of thermal processing time to sample temperature [10]. At arbitrary temperature \( T \), the \( F \) value satisfies

\[ F = \int 10^{(T-T_{ref})/z} \, dt \]  

(2)

with \( F \) is the thermal processing time, \( T \) is temperature, \( T_{ref} \) is standard temperature, and \( z \) is the characteristic temperature for reducing the microbe by one log. It was observed that the thermal process at 110 °C at different thermal levels of 5.0, 8.5, and 12.0 required the holding times of 15, 25, and 35 minutes, respectively.
3.2. Process Optimization
Optimization of process was conducted by using parameters as listed in table 1. It was obtained the relationship between the measured responses and the corresponding controlled parameters are given by equation (2) with the best factors were listed in table 3. Y, A, B, and C represent, respectively, the response, the protein content, the thermal processing level, and the packaging types.

Based on optimum constants listed in table 2 figure 1 showed the examples of 3D plot of total microbes’ response in sample packaged with (a) nylon pouch (b) metallized pouch (c) glass jar. Using ANOVA analysis, it was identified 4 of 7 tested responses, i.e. total microbes number, color, brittleness, and energy content, exhibited significant equation model. By the significant equation model, it meant 3 responses affected 3 tested factors. To the contrary, the water activity, adhesiveness, and gel strength provided only minor effect.

| Response               | Model Equations                                           |
|------------------------|-----------------------------------------------------------|
| Total microbe number   | $Y = 3.245 \times 10^3 + 1.111 \times 10^2 A - 6.780 \times 10^2 B + 8.147 \times 10^3 C + 1.405 \times 10^4 AB - 2.459 \times 10^4 AC - 5.714 \times 10^5 BC - \ldots$ |
| Water activity         | $Y = 1.173 - 7.159 \times 10^2 A + 1.346 \times 10^2 B + 1.278 \times 10^3 C - 1.223 \times 10^3 AB + 8.197 \times 10^3 AC + 8.197 \times 10^4 BC + \ldots$ |
| Color (*L)             | $Y = 51.544 + 0.928 A - 0.797 B + 0.378 C$               |
| Color (*a)             | $Y = 5.211 + 0.202 A + 0.253 B - 0.334 C$                |
| Color (*b)             | $Y = 18.029 + 0.211 A - 0.078 B - 0.031 B$               |
| Adhesiveness           | $Y = -38.637 - 0.330 A - 1.146 B - 4.932 C + 0.118 AB - 0.144 AC + 0.683 BC$ |
| Gel strength           | $Y = 34.896 - 5.835 A - 1.451 B - 2.223 C + 0.226 AB + 0.219 AC + 0.142 BC + 0.212 A^2 - 0.034 B^2 + 1.193 C^2$ |
| Brittleness            | $Y = 18.469 - 0.954 A - 1.804 B + 1.644 C + 0.207 AB - 0.492 AC + 0.360 BC$ |
| Energy content         | $Y = 3210.537 + 95.036 A + 18.821 B - 137.250 C$         |

It was identified from figure 1, that the dominant factor affecting the total microbes number in emergency food was the thermal processing level. By increasing the thermal processing level, the total microbes number in the emergency food decreased. Heat treatment applied to the food product was able to kill microbes through different mechanism, such as destruction of cell membrane and substantial organs in cells such as ribosome, RNA, and DNA [11]. High temperature resistant and spore forming bacteria could remain exist after thermal process and continue to grow in necessary condition [12].

![Figure 1. 3D plots of total microbes response in sample packaged with (a) nylon pouch (b) metallized pouch (c) glass jar](image-url)
High Aw value on emergency foods containing WPC-d at higher ratio compared to dried sweet potato puree has been observed. This WPC-d was made by initially heating the whey in liquid state at high temperature prior to centrifugal separation and drying process. Applying high temperature heating at protein caused the water holding capacity of the protein decreases. This circumstance was similar to that reported in reference [13], where heating treatment to the whey has lowering the water holding capacity on yoghurt compared to yoghurt made by untreated whey. The thermal process will form hydrophobic chain to imply the whey having lower water holding capacity and solubility [14].

The emergency food that has been treated by thermal process became darken, more reddish, and yellowish. The change of color was caused by non-enzymatic browning as a result of interaction between reducing sugars with amino acids. The use of high temperature accelerated reaction of the two compounds. Furthermore, presence of reducing sugar at high content will conduct high non-enzymatic browning [15].

After thermal processing, the brittleness values increased and the adhesiveness decreased, while gel strength decreased only slightly. Adhesiveness determines the force needed to pull the probe from the food surface, while brittleness measures the fracture of the food [16]. Decreasing of adhesiveness caused by the forming of whey aggregates implied to lowering food’s ability to stick other object. The adhesiveness of emergency foods decreased with protein content. This circumstance is similar to yoghurt substituted by heat-denatured whey and buttermilk, where the adhesiveness decreases when increasing whey substitutions. It caused by decline of sample’s capability to adhere to probe by increase of denatured whey [17]. Brittleness increased because of the presence of interaction in between food components such as protein, carbohydrate and water. Such interaction was also observed to cause hardening of snack bar produced added with whey [18]. The energy was measured to range between 3762 – 4625 cal/g in dry matter. Different energy content in each samples mainly caused by different nutrient content in each treatment, where carbohydrates could present higher Gross Energy Value than protein [19].

### 3.3. Model Validation

Based on observed responses, Design Expert 7.0.0 suggested the optimum process for producing the emergency foods was protein content of 10.14% (w/w), packaged in metallized pouch, and processed at 11.11 thermal level. Validation of the proposed optimum value was conducted by experiment. The result can be seen at table 3. As seen in table 4, the responses having very high reliability are water activity, color changes, brittleness and energy content. However, the adhesiveness has only high reliability, while then total microbe number and gel strength has low reliability.

| Table 3. Validation of optimum process |
|---------------------------------------|
| **Response** | **Prediction** | **Result** | **Validation** |
| Total microbes number | 42.56 cfu / mL | 10 cfu / mL | 11.75 |
| Water activity | 0.88 | 0.81 | 94.32 |
| Color (*L) | 52.11 | 18.32 | 97.49 |
| Color (*a) | 10.06 | 9.67 | 96.07 |
| Color (*b) | 19.30 | 17.63 | 91.32 |
| Adhesiveness | -41.41 gsec | -51.49 gsec | 77.11 |
| Gel strength | 2.74 g | 4.85 g | 34.80 |
| Britteness | 12.08 g | 10.32 g | 97.76 |
| Energy content | 4381.82 cal/g | 4239 cal/g | 96.78 |

### 4. Conclusion

The present study showed that the optimum process of emergency food producing from denatured whey protein concentrate and dried sweet potato puree performed on product’s formulation in 9.84% (w/w) protein content which packaged in metallized pouch and processed under 11.11 log cycle of
thermal process. Among responses that measured in this study, protein content, package material, and thermal processing level affected significantly toward total microbes, color, brittleness, and energy content.

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