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# Potential and Simulation of Functional Compounds Recovery from *Clitoria ternatea* L. Extract during The Commercial Sterility Process

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**Abstract:** The butterfly pea flower (*Clitoria ternatea* L.) is a flower that is identical to blue to purple petals and contains various phytochemical compounds. Heat processing in butterfly pea flower extract can reduce its nutritional and sensory properties, which is indicated by a decrease in each quality parameter, namely color intensity, total anthocyanins, acid flavylium cation, purple quinonoidal base, blue anionic quinonoidal base, ferrulic acid, caffeic acid, p-hydroxybenzoic acid, procatechuic acid, gallic acid, vanillic acid, vanillin, procyanidin hexamer III, and delphinidin-3-glucosse. The thermal process can deactivate bacterial spores to maintain the quality of butterfly pea flower extract. This paper will review steps that can be used as a reference for researchers or industry to optimize commercial sterilization processes using heating process kinetics. The method studied to be adopted in this article is based on the heating process kinetics of each quality parameter (k and D values) combined towards temperature (Z value). The combination of temperature and time to optimize the process is determined by referring to the D and Z values. To optimize the heating process, the sterilization heater needs to be evaluated and the kinetics of the thermal process for each quality parameter need to be prescribed. This thermal process design will contribute greatly to the functional food business with commercial sterilization standards that aim to claim functional compounds at certain concentrations after processing.

## Introduction

Indonesia has a variety of traditional foods. According to the Indonesia Food and Drug Supervisory Agency, functional food is processed food that contains one or more components that perform certain physiological functions other than the basic function of food and has been proven not to be harmful or beneficial to health, according to scientific research. A diversification of food diet is needed for human health (Ghosh-Jerath et al., 2022). Traditional food, or called as local food, includes food and soft drinks as well as ingredients or mixtures that have been used traditionally and have developed specifically in certain regions or communities in Indonesia. Traditional food can be categorized into main food, snacks, and drinks. This traditional food is made using ingredients obtained from local sources and has a distinctive taste (Kurniahu et al., 2023; Simanjuntak et al., 2023). Some specific foods often provide the essential

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micronutrients required. A micronutrient is a crucial nutrient required in metabolic processes, albeit in small quantities (Ray et al., 2024). Plants are one of the oldest natural ingredients known to function as a functional food source (Chen and Luo, 2024). Butterfly pea flower *(Clitoria ternatea* L.*)* is one of the natural ingredients most often used in the daily lives of Indonesian people, either as an ornamental plant, raw material for drinks, natural dyes, or even traditional medicine (Marpaung, 2020). Butterfly pea flowers are increasingly popular in Indonesia because they have many pharmacological benefits for improving human health. Now, more and more people are buying butterfly pea flowers, both fresh and dried because it has antioxidant, antimicrobial, anti-depressant, anthelmintic, anti-cancer and anti-diabetic properties (Purba, 2020).

Butterfly pea flower *(Clitoria ternatea* L.*)* extract contains several phytochemical compounds, including anthocyanins (e.g., ternatin), flavonols (e.g., kaempferol, quercetin), triterpenoids and saponins (Multisona et al., 2023). Escher et al. (2020) discovered different phenolic acids (gallic, syringic, protocatechuic, p-coumaric, caffeic, ferulic acids), flavonoid (quarcetin-3-rutinoside, procyanidin A2, (-)-epicatechin, kaempferol, myricetin), and anthocyanins (delphinidin-3-glucoside). These active compounds really support its benefits for making ready-to-drink functional drinks. Nowadays, ready-to-drink beverages are very popular among the public because they are considered practical and can be consumed directly without having to be processed further (Tahosin et al., 2024). From the information previously mentioned, it is fascinating to study the bioactivity of the butterfly pea flower to find developments in its utilization into products that are in demand and have high selling value because of its various functional contents. For this reason, in developing the use of butterfly pea flower into a functional drink this time, it is still made in liquid form so that it can be consumed directly, using cans or tetra packs with Ultra High Temperature (UHT) through a commercial sterilization process as a safe processing method. The sterilization process strives to maintain the functional compounds in certain amounts to continue providing the expected health benefits. However, the implementation of commercial sterility could effectively decrease food waste. Waste is the surplus material not intended for human consumption (Kaur and Kaur, 2024). The purpose of this review article is to determine the functional compounds contained in butterfly pea flower *(Clitoria ternatea* L.*)* extract and the heating effect on the compound, which is accompanied by a kinetic profile of changes in its concentration due to the influence of heat. The butterfly pea flower is exclusively native to plants that grow naturally. Numerous extant studies solely investigate the physical and chemical characteristics of its extract. This review explores the feasibility of preserving butterfly pea flower extract at a commercial sterilisation level while considering the constraints on the degrading of bioactive compounds. The target is to extend the shelf life of butterfly pea flower extract products while ensuring the recovered bioactive compound content. Implementing the efforts to preserve the functional compounds contained in butterfly pea flower *(Clitoria ternatea* L.*)* extract through sterilization process optimization design is also presented in this article.

## Butterfly Pea Flower *(Clitoria ternatea* L.*)*

Butterfly pea flower *(Clitoria ternatea* L*)* is one of Indonesia's natural riches. This plant is thought to originate from tropical Asia and was first discovered on Ternate Island, Indonesia. Butterfly pea flowers grow in humid lowlands in Asia, Australia, Africa, the Pacific Islands, and America. In Indonesia, this plant grows well in tropical and subtropical environments (Ulimaz et al., 2020). The butterfly pea *(Clitoria ternatea* L.*)* flower is a member of the *Papilionaceae* family, also known as *Febaceae,* which includes legumes (Padmawati et al., 2022). The butterfly pea flower is often referred to as *conchitas* (Spanyol), *cunha* (Brasil), *kajroti* (India), *telang* flower (Malaysia), *celeng* (Bali), blue flower or *kelentit* flower (Sumatra), *talang* flower or *temen raleng* flower (Sulawesi), *bisi* (Moluccas), and *menteleng* or *teleng* flower (Java) (Purba, 2020). The character of this plant flower is very diverse. This flower has one to five petals and a crown of blue, dark blue, light blue, purple, violet, and white (Ulimaz et al., 2020). The utilization of butterfly pea *(Clitoria ternatea* L.*)* flower extract has been widely applied by people around the world. Apart from being widely used as a tea, this flower extract has been used in Asia to naturally color foods and drinks such as ice cream, jelly, bread, desserts and rice. Padmawati et al. (2022) also confirmed that butterfly pea flower extract can be used as a food coloring without affecting the taste or aroma of food. Butterfly pea flower extract is used in Malaysia to color rice cakes and the famous dish *nasi kerabu* (Gew et al., 2024). Due to its therapeutic properties, Butterfly pea flower extract is widely used to treat stress and depression (Su and Lu, 2024).

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**Table 1. Dominant Phenolic Component of Butterfly Pea Flower Extract.**

| Identified compounds | *Total Phenolic Content* (TPC) in mg/100 g | Heating Temperature (°C) | Heating Time Duration (minute) |
|---|---|---|---|
| Phenolic Acid | | | |
| 2,4-Dihydroxy Benzoic Acid | 76.7 | 40 | 30 |
| Protocatechuic acid | 39.3 | 40 | 30 |
| Flavonoid | | | |
| Procyanidin A2 | 73.8 | 40 | 30 |
| Anthocyanin | | | |
| Delphinidin-3-glucoside | 38.3 | 40 | 30 |
| Other compounds | | | |
| Ellagic Acid | 64.7 | 40 | 30 |

Source: Escher et al. (2020a)

The butterfly pea (*Clitoria ternatea* L.) flower is identical to blue or purple petals. Butterfly pea flower contains various phytochemical compounds. Previous studies have isolated and identified various structures of polyacrylate delphinidin anthocyanins, named ternatins A1–A3, B1–B4, C1–C5, D1–D3; flavonols (e.g., kaempferol, quercetin, myricetin); triterpenoids; and saponins contained in butterfly pea flower extract (Multisona et al., 2023). Escher et al. (2020b) found different phenolic acids (gallic acid, syringic, protocatechuic, p-coumaric, caffeic, ferulic acids), flavonoid (quercetin-3-rutinoside, procyanidin A2, (-)-epicatechin, kaempferol, myricetin), and anthocyanins (delphinidin-3-glucoside). Using the Prussian Blue colorimetric method, a study was conducted to identify the main phenolic components in butterfly pea flower extract. Butterfly pea flower extract was filtered on filter paper, stored at 8°C, protected from light, and analyzed after 24 hours of extraction. Afterward, the extract was frozen at −80°C, and freeze-dried under vacuum at 830 µmL Hg (Liotop, model L202, Brazil) until further analysis (Escher et al., 2020b). Based on a study conducted by Escher et al. (2020a), the dominant phenolic components in butterfly pea flower extract analyzed using HPLC-PAD-UV are shown in Table 1.

One of the chemical compounds that is very important for giving color to butterfly pea flowers is the anthocyanin pigments (Handayani et al., 2024). Anthocyanins are flavonoid pigments that are usually water-soluble and found in many flowers, fruits, and leaves (e.g., butterfly pea flower, shallots, grapes, and purple corn) with pH-dependent colors ranging from orange (pelargonidin), red (cyanidin) to blue (delphinidin) (Handayani et al., 2024; Hariadi et al., 2024). Anthocyanins consist of anthocyanidin aglycones esterified with one or more sugar molecules (Avula et al., 2023). A unique feature of the anthocyanins found in butterfly pea flower is the presence of large amounts of the polyacylated anthocyanin known as ternatin, which is a polyacylated derivative of delphinidin 3,3′,5′-triglucoside (Gamage et al., 2021). The anthocyanin phytochemical compound contained in butterfly pea flowers can produce blue and red colors besides purple, which can be used as a local natural dye for the food industry (Hasanah et al., 2023). This anthocyanin also functions as an antioxidant that protects the body from free radicals (Suryana, 2021). Indigo dye, which is a natural blue color, is made from flower crowns and extracted from purplish blue flowers (Kalsum and Budiman, 2023). The antioxidant benefits individuals with a predisposition to cardiovascular disease, such as smokers, thereby reducing the global mortality risk (Jujjavarapu et al., 2024). Traditionally, anthocyanin is extracted by water extraction method because the pigment is soluble in water. Other solvents used for extraction are ethanol, methanol, acetone, chloroform, and others. Then, the extraction solvent is acidified to increase yield. Acidification aims to maximally denature the cell wall membrane where the anthocyanins are located (Netravati et al., 2022).

## Effect of Thermal Processing on Anthocyanin Stability

Heat treatment is one of the most frequently used techniques to preserve and increase the shelf life of food, as well as to ensure food safety (Zhao and Zheng, 2022). The anthocyanin stability in fruit and vegetables can be affected by heat processing, such as blanching, pasteurization, and heating duration (Oancea, 2021). For instance, blanching, boiling and steaming can reduce anthocyanins (Oancea, 2021). Furthermore, blue dye is currently the most difficult to obtain because the anthocyanin responsible for this color, namely delphinidin (containing a 3 –OH substitution), is often reported to be less stable and easily degraded after

extraction (Putra et al., 2021; Voss et al., 2023). As a result, the anthocyanin stability decreases as the temperature increases. Anthocyanin stability can be described in terms of color degradation and chemical degradation. Color degradation is related to the reversible balance between colored and colorless forms. Chemical degradation is associated with a decrease in total anthocyanins due to irreversible pigment degradation, mainly arising from the cleavage of chromophores to form phenolic acids and aldehyde derivatives (Enaru et al., 2021).

Several studies reported a logarithmic process of anthocyanin degradation. Thermal processing of food requires heating to temperatures between 50°C and 150°C, depending on the pH of the product and the desired shelf life (Blanch and Castillo, 2021). When the solids content increases during heating, the anthocyanin degradation rate increases. The final processing temperature function is not the only factor influencing the stability of anthocyanins. Intrinsic properties of the product and processing process, including pH, storage temperature, product chemical structure, anthocyanin concentration, light, oxygen and the presence of enzymes, proteins, and metal ions, also influence the anthocyanin stability in fruits, vegetables, and their products during preparation, processing, and storage (Cunha et al., 2023). It is important to remember that anthocyanins and other phenolic compounds are easily oxidized. As a result, anthocyanins are susceptible to oxidative degradation during processing and storage. With light heating, anthocyanins can be degraded by the polyphenol oxidase enzyme, which is the same as other polyphenols. Some studies have found that adding a blanching step (heating to around 50°C) can increase anthocyanin retention. Lower temperatures and short heating can achieve higher anthocyanin stability during processing and storage. This suggests that the thermal load involved in processing foods and beverages containing anthocyanins may make them easier to store (Ayvaz et al., 2023).

Kinetic models are often used for objective, rapid, and cost-effective food safety assessments. Additionally, kinetic modeling can be used to predict the impact of processing on important quality parameters, such as reaction order, rate constants, and activation energy. Knowledge of these degradation kinetics is essential for predicting food quality degradation during storage and thermal treatment (Ursu et al., 2020). Anthocyanin degradation under isothermal heating is reported to be adequately explained by zero-order and first-order degradation kinetics. However, a better fit is given by the first order with the coefficient of determination ($R^2$) ≥ 0.90 (Voss et al., 2023). Most studies on anthocyanin degradation kinetics were conducted under isothermal conditions, including temperatures up to 100°C. However, degradation of anthocyanins in solid or semi-solid foods such as pomace, fruit, and vegetables is not isothermal, so kinetic modeling must include time and temperature estimates. The dependence of anthocyanin degradation on temperature is represented by the activation energy ($E_a$). A high activation energy value indicates the sensitivity of the reaction rate to higher temperatures. Therefore, butterfly pea flower extract is more heat-sensitive (Singh et al., 2022). Activation energy ($E_a$) is determined from the Arrhenius equation. The kinetic rate constant (k) of thermal degradation was determined by regression of experimental data from the initial concentration with increasing heating time (Yudianto et al., 2023b). To determine the temperature dependence of anthocyanin degradation resulting in loss of color, the activation energy was determined using the slope of a straight line obtained by plotting ln.k towards 1/T (Yudianto et al., 2023b).

## Commercial Sterilization Process Optimization Design Concept

The high market demand for sterile food has the potential to bring about disruptive technology in the field of commercial sterility (Gupta et al., 2024). Evaluation of the heating machine (retort) should be done to get the machine's capability to give sterilization temperature during operation (Yudianto et al., 2023a). Seeing the presence of bioactive compound components in the butterfly pea flower extract, there is a possibility of a degradation process of these bioactive compounds during the heating process, so optimizing the thermal process for commercial sterilization protocols is necessary. This particular approach is highly appropriate for a business incubator to foster the growth of entrepreneurs (Malhotra et al., 2024). Data on the degradation kinetics of all bioactive compounds contained in the butterfly pea flower extract using an order 1 approach is needed for optimization achievement. This kinetic data is used to design and optimize the sterilization process for the butterfly pea flower extract product. The most common methods used in commercial sterilization processes are container and UHT sterilization. The in-container method is sterilized after the product is packaged, while UHT is usually used for liquid products with a relatively short heating time first and then packaged. Seeing that the initial capital required to procure a UHT machine is very large, the in-container sterilization method is now easier to implement. Both process equipment and heat adequacy

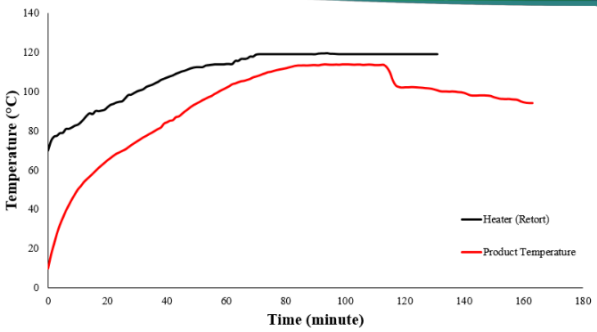


**Figure 1. Examples of Heat Distribution Graphs in Machine and Product.**

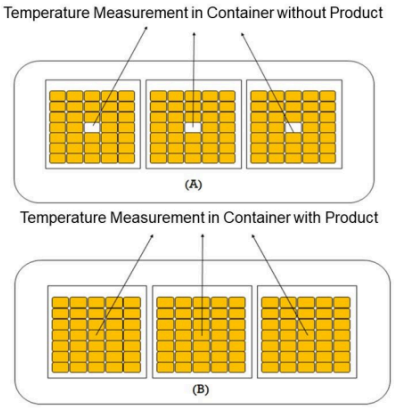


**Figure 2. Heat Distribution Test (A) and Sterilization Process Adequacy Test (B).**

test equipment are also relatively cheaper compared to using the UHT process (Sayekti et al., 2024).

In the process of inactivating bacterial spores, its effectiveness depends on the heat amount received by the butterfly pea flower extract product. Referring to this statement, each sterilization heater owns its heat distribution. Prior to evaluating the adequacy of the sterilization process, the property of sterilization machine in distributing heat until it is received by the butterfly pea flower extract product in parts is needed, especially on the difficult side for heat achievement. The sterilization machine was characterized by measuring the temperature received by the air inside the can but without the butterfly pea flower extract product content. Specifically, the part of the can that the air temperature inside wants to be measured is not filled with product. The other cans are all filled with products. The machine is operated with the largest capacity, or the machine is filled with as much product as possible to determine the heat transfer capability of the product if it is operating at the heaviest load. From the heat distribution test results, the come-up time or the time to reach stability at the target temperature will be known.

### Adequacy of Sterilization Process ($F_0$)

The temperature at the coldest point of the product that the heating machine has given heat will not be able to match the desired reference temperature, therefore, the $F_0$ calculation is carried out using the Z-value according to the reference (Sayekti et al., 2024). Temperature measurement is carried out like the heat distribution test in engine characterization for the coldest point. Still, the can installed by the temperature measuring sensor is filled with product. This measurement assumes that the coldest point is the point that is most difficult for heat to

reach, so if the coldest point has reached the temperature and time required for sterilization, then the other points have reached the temperature and time of sterilization first.

$$\text{Lethal Rate} = 10^{\left(\frac{\text{Processing Temperature} - \text{Reference Temperature}}{\text{Z-value}}\right)}$$

$$F_0 = \textit{Lethal rate} \times \text{Process Time}$$

**Note:**

- Commercial sterilization reference temperature is 121.1°C or 250°F
- *C. botulinum* Z-value is 10°C or 18°F

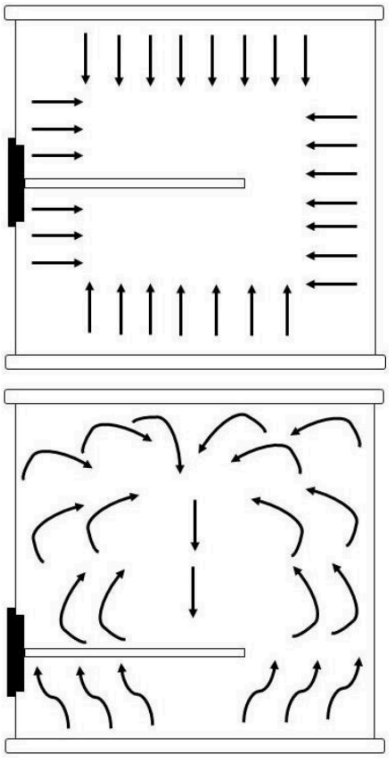

**Figure 3. Heat Transfer in the Canning Process (Conduction: Up, Convection: Buttom).**

The process temperature or material temperature is measured using a thermocouple placed at the coldest point or the most difficult to reach by heat (Yudianto et al., 2023a). In Figure 3, figure A is a picture of heat transfer in the solid product canning process. The thermocouple is placed in the middle. Meanwhile, figure B is a picture of heat transfer in the canning process for liquid products. The thermocouple is placed on the 1/3 bottom. F0 usually denotes the adequacy of the commercial sterilization process. This value is calculated because various machines will be used in the heating process, so for simplicity, the value is calculated directly using the time duration that is usually done by in. $F_0$ is the time needed to kill the target microbe until it reaches a certain level using a certain temperature. The $F_0$ calculation is based on heat penetration in cans containing products, which is always slower than heat penetration in empty cans, as shown in Figure 2. The temperature of cans containing products is always lower than that of empty cans. Therefore, the temperature of the material cannot match the temperature of the machine, so the temperature of the material cannot reach 121.1°C. $F_0$ calculation is carried out to ensure sufficient sterilization time to achieve sterilization goals or kill certain microbial targets (Sayekti et al., 2024).

## Materials and Methods

### Materials

This study used appropriate references that provide thermal kinetic coefficient data of butterfly pea flower (*Clitoria ternatea* L.) extract deterioration quality parameters. The quality parameters were color intensity, total anthocyanins, red flavylium cation, purple quinonoidal base, blue anionic quinonoidal base, ferrulic acid, caffeic acid, p-hydroxybenzoic acid, procatechuic acid, gallic acid, vanillic acid, vanillin, procyanidin hexamer III, and delphinidin-3-glucosse. The data was cited from appropriate reputable articles that provide various k values as thermal kinetic coefficient data for Z value calculation as heat sensitivity of k value change.

### Evaluation of the k or D Values and Z Value on the Kinetics of Changes in Quality Parameters

For suggestion in a real experiment, all kinetics of changes in quality parameters during the thermal process (color intensity, total anthocyanin, red flavylium cation, purple quinoidal base, blue anionic quinonoidal base, ferulic acid, caffeic acid, p-hydroxybenzoic acid, protocatechuic acid, gallic acid, vanillic acid, vanillin, procyanidin hexamer III, delphinidin-3-glucose) calculated the k or D value as the change of time during the number of quality parameter units at a certain temperature are changed (Yudianto et al., 2023b). The k values were cited in this article from an appropriate reputable international journal article. Our study developed these k values for the design of commercial

sterility process optimization. Optimization design was established by mapping thermal kinetic data of all quality parameters (Yudianto et al., 2023b). The test result values for each quality parameter for each time interval for certain heating are plotted on a graph as the y-axis, while the heating time is plotted in the abscess (x-axis). The ordinate (y-axis) is converted into a log for calculating the D value (minutes) or can also be converted into Ln for calculating the k value (change in concentration/minute). The slope is the 1/D or k. However, the D and k values are related and can be mutually converted using the equation below. The Z value could be calculate form the slope of log D and temperature relation. Plot the log D as y-axis and temperature as x-axis. The slope of that regression is 1/Z. The Z Value could be calculated

$$D = \frac{2.303}{k}$$

### Design of Commercial Sterilization Process Optimization for Butterfly Pea Flower Extract

Optimization design is carried out in several stages. Firstly, determine the fastest degrading quality parameter that still could inactivate 12D *Clostridium botulinum* spores by being limited by the degradation of all bioactive components that have been determined to a minimum within the process time and temperature accepted by the product (Sayekti et al., 2024). The minimum concentration of degraded bioactive components usually refers to internal industry standards (Pietrzyck et al., 2021). Because industries have their own business interests or may have special product claims that require a certain concentration of functional compounds (Rais et al., 2021). On this occasion, a commercial sterilization process will be designed with a predetermined degradation limit for all bioactive components with a maximum reduction of 50%. Secondly, the length of the sterilization process is required to achieve a 50% reduction in all bioactive components of butterfly pea flower extract, which has been determined at the commercial sterilization temperature (121.1°C). An order 1 kinetic equation is needed for each bioactive component with a t value of 0.693/k (using the half-life concept) to calculate this. This calculation obtained 1 combination of time and temperature for the sterilization process with a 50% reduction in all bioactive components. From Z value, two more checks are made on the graph to either increase or decrease the temperature received by the product. The second and third points are given by the combination (change (added and subtracted) of Z value as x: change of 1 log time (added and subtracted) as y).

Give a line of each parameter based on 3 points arranged. The optimization area is formed in the limit between 12D inactivation of *Clostridium botulinum* spore and the fastest quality parameter reduction line. The first point combination was made with a duration of 3 minutes as an $F_0$ value and a temperature of 121.1°C. Then, 3 combination points of temperature and time were added similarly to bioactive components using the Z value. From here, the main dividing line in the bacterial reduction parameters would be gotten in the graph (thermal process time as ordinate and temperature as abscess). The sterilization process optimization design for butterfly pea flower extract can be viewed in Figure 4. This sterilization process was conducted based on the 12D C. botulinum spore inactivation standard and low degradation of anthocyanin compounds due to thermal process (Feng et al., 2024).

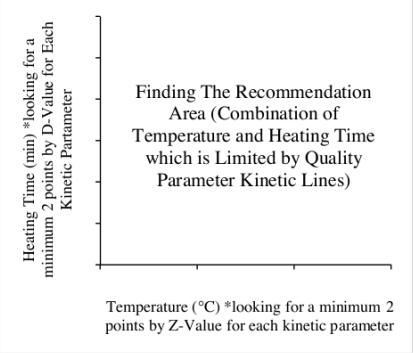


**Figure 4. Sterilization Process Optimization Design for Butterfly Pea Flower Extract.**

### Results and Discussion

All of the designs could be evaluated well if they use first order. The thermal process that will be carried out on the butterfly pea flower extract will allow the degradation of its bioactive components. Optimization needs to be carried out in the sterilization process, namely, inactivating spores according to the target. However, the process is limited to 50% degradation of bioactive compounds (the percentage can be adjusted to industry needs) (Yudianto et al., 2023b). In process optimization design, data on target spore inactivation kinetics, color intensity, total anthocyanin, red flavylium cation, purple quinonoidal base, blue anionic quinonoidal base, ferulic acid, caffeic acid, p-hydroxybenzoic acid, procatechuic

**Table 2. Kinetic Data and Arrhenius Equation for Degradation of Bioactive Compounds by Thermal Processes.**

| Parameter | Temperature (°C) | 1/T | k Value (The Quality Change/minute) | Ln.k | D Value (minute) | Log ($Dt/D_0$) | D Value Log | Z Value | Arrhenius | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Slope | Intercept |
| Color Intensity* | 45 | 0.00314 | 0.000016 | -11.04 | 144187.83 | 0.00 | 5.16 | 25.95 | -10168.24 | 20.64 |
| | 60 | 0.00300 | 0.000036 | -10.23 | 63775.38 | -0.35 | 4.80 | | | |
| | 75 | 0.00287 | 0.000147 | -8.83 | 15717.16 | -0.96 | 4.20 | | | |
| | 90 | 0.00275 | 0.000847 | -7.07 | 2720.53 | -1.72 | 3.43 | | | |
| Total Antosianin* | 45 | 0.00314 | 0.000016 | -11.04 | 144187.83 | 0.00 | 5.16 | 26.52 | -9971.08 | 20.14 |
| | 60 | 0.00300 | 0.000047 | -9.96 | 48769.41 | -0.47 | 4.69 | | | |
| | 75 | 0.00287 | 0.000157 | -8.76 | 14673.98 | -0.99 | 4.17 | | | |
| | 90 | 0.00275 | 0.000822 | -7.10 | 2803.31 | -1.71 | 3.45 | | | |
| Red Flavylium Cation* | 45 | 0.00314 | 0.000009 | -11.62 | 255101.54 | 0.00 | 5.41 | 32.07 | -8274.47 | 14.30 |
| | 60 | 0.00300 | 0.000022 | -10.75 | 106978.06 | -0.38 | 5.03 | | | |
| | 75 | 0.00287 | 0.000083 | -9.39 | 27636.00 | -0.97 | 4.44 | | | |
| | 90 | 0.00275 | 0.000208 | -8.48 | 11054.40 | -1.36 | 4.04 | | | |
| Purple Quinonoidal Base* | 45 | 0.00314 | 0.000015 | -11.14 | 157920.00 | 0.00 | 5.20 | 26.88 | -9819.48 | 19.47 |
| | 60 | 0.00300 | 0.000032 | -10.35 | 72093.91 | -0.34 | 4.86 | | | |
| | 75 | 0.00287 | 0.000132 | -8.93 | 17454.32 | -0.96 | 4.24 | | | |
| | 90 | 0.00275 | 0.000658 | -7.33 | 3498.23 | -1.65 | 3.54 | | | |
| Blue Anionic Quinonoidal Base* | 45 | 0.00314 | 0.000019 | -10.85 | 118440.00 | 0.00 | 5.07 | 24.94 | -10573.37 | 22.09 |
| | 60 | 0.00300 | 0.000044 | -10.02 | 51817.50 | -0.36 | 4.71 | | | |
| | 75 | 0.00287 | 0.000187 | -8.59 | 12328.33 | -0.98 | 4.09 | | | |
| | 90 | 0.00275 | 0.001218 | -6.71 | 1890.72 | -1.80 | 3.28 | | | |
| Ferulic Acid** | 70 | 0.00292 | 0.000470 | -7.66 | 4900.00 | 0.00 | 3.69 | 48.28 | -5946.06 | 9.69 |
| | 80 | 0.00283 | 0.000820 | -7.11 | 2808.54 | -0.24 | 3.45 | | | |
| | 90 | 0.00275 | 0.001220 | -6.71 | 1887.70 | -0.41 | 3.28 | | | |
| Caffeic Acid** | 70 | 0.00292 | 0.000370 | -7.90 | 6224.32 | 0.00 | 3.79 | 44.15 | -6506.98 | 11.11 |
| | 80 | 0.00283 | 0.000710 | -7.25 | 3243.66 | -0.28 | 3.51 | | | |
| | 90 | 0.00275 | 0.001050 | -6.86 | 2193.33 | -0.45 | 3.34 | | | |
| p-Hydroxybenzoic Acid** | 70 | 0.00292 | 0.000560 | -7.49 | 4112.50 | 0.00 | 3.61 | 51.06 | -5617.31 | 8.90 |
| | 80 | 0.00283 | 0.000910 | -7.00 | 2530.77 | -0.21 | 3.40 | | | |
| | 90 | 0.00275 | 0.001380 | -6.59 | 1668.84 | -0.39 | 3.22 | | | |
| Protocatechuic Acid** | 70 | 0.00292 | 0.000600 | -7.42 | 3838.33 | 0.00 | 3.58 | 52.60 | -5431.09 | 8.36 |
| | 80 | 0.00283 | 0.000800 | -7.13 | 2878.75 | -0.12 | 3.46 | | | |
| | 90 | 0.00275 | 0.001440 | -6.54 | 1599.31 | -0.38 | 3.20 | | | |
| Gallic Acid** | 70 | 0.00292 | 0.000580 | -7.45 | 3970.69 | 0.00 | 3.60 | 50.26 | -5672.72 | 9.00 |
| | 80 | 0.00283 | 0.000710 | -7.25 | 3243.66 | -0.09 | 3.51 | | | |
| | 90 | 0.00275 | 0.001450 | -6.54 | 1588.28 | -0.40 | 3.20 | | | |
| Vanillic Acid** | 70 | 0.00292 | 0.000460 | -7.68 | 5006.52 | 0.00 | 3.70 | 40.11 | -7138.56 | 13.10 |
| | 80 | 0.00283 | 0.000770 | -7.17 | 2990.91 | -0.22 | 3.48 | | | |
| | 90 | 0.00275 | 0.001450 | -6.54 | 1588.28 | -0.50 | 3.20 | | | |
| Vanillin** | 70 | 0.00292 | 0.000470 | -7.66 | 4900.00 | 0.00 | 3.69 | 36.85 | -7767.05 | 14.95 |
| | 80 | 0.00283 | 0.000800 | -7.13 | 2878.75 | -0.23 | 3.46 | | | |
| | 90 | 0.00275 | 0.001640 | -6.41 | 1404.27 | -0.54 | 3.15 | | | |
| Procyanidin Hexamer III (B-Type)*** | 85 | 0.00279 | 0.002200 | -6.12 | 1046.82 | 0.00 | 3.02 | 25.03 | -13785.99 | 32.42 |
| | 90 | 0.00275 | 0.003900 | -5.55 | 590.51 | -0.25 | 2.77 | | | |
| | 100 | 0.00268 | 0.010900 | -4.52 | 211.28 | -0.70 | 2.32 | | | |
| | 120 | 0.00254 | 0.073600 | -2.61 | 31.29 | -1.52 | 1.50 | | | |
| | 135 | 0.00245 | 0.256000 | -1.36 | 9.00 | -2.07 | 0.95 | | | |
| | 140 | 0.00242 | 0.380000 | -0.97 | 6.06 | -2.24 | 0.78 | | | |
| | 145 | 0.00239 | 0.559000 | -0.58 | 4.12 | -2.40 | 0.61 | | | |
| Delphinidin-3-Glucose**** | 75 | 0.00287 | 0.002020 | -6.20 | 1140.10 | 0.00 | 3.06 | 47.56 | -6201.68 | 11.62 |
| | 85 | 0.00279 | 0.003350 | -5.70 | 687.46 | -0.22 | 2.84 | | | |
| | 95 | 0.00272 | 0.005320 | -5.24 | 432.89 | -0.42 | 2.64 | | | |
| | **Source :* (Marpaung et al., 2017); ** (Chen et al., 2022); *** (Paepe et al., 2014); **** (Mitić, 2020)** | | | | | | | | | |

acid, gallic acid, vanillic acid, vanillin, procyanidin hexamer III, delphinidin-3-glucose by thermal process are required. In Table 3, there are kinetic data on changes in color intensity, total anthocyanin, red flavylium cation, purple quinonoidal base, blue anionic quinonoidal base, ferulic acid, caffeic acid, p-hydroxybenzoic acid, procatechuic acid, gallic acid, vanillic acid, vanillin, procyanidin hexamer III, delphinidin-3-glucose to certain time changes at several heating temperatures. These kinetic data were cited from 4 different literature sources. This paper will review steps that can be used as a reference for researchers or industry to optimize commercial sterilization processes. For the business, the researcher could be calculating by the preference in terms of cost reduction.

It is important to evaluate the tolerable reduction of quality parameters. This study uses a 50% reduction of all parameters during sterilization process. The product could not be accepted if the quality parameters are reduced by more than 50%. Because of 12D commercial sterility has been established, the rate of quality parameter reduction needs to be calculated firstly by the equation below:

$$\text{Rate of decline equation } Q \longrightarrow v = -\frac{\Delta(Q)}{\Delta t}$$

$$\text{Rate law} \longrightarrow v = k(Q)^1$$

$$v = v$$

$$k(Q) = -\frac{\Delta(Q)}{\Delta t} = -\frac{d(Q)}{dt}$$

$$-k * dt = \frac{d(Q)}{(Q)}$$

$$\int_0^t -k * dt = \int_{(Q)}^{(Q)_t} \frac{1}{(Q)} * d(Q)$$

$$-k(t-0) = \ln(Q)_t - \ln(Q)_0$$

$$-k * t = \ln(Q)_t - \ln(Q)_0 \text{ atau } -k * t = \ln\left(\frac{Q_t}{Q_0}\right)$$

$$\ln(Q)_t = -k * t + \ln(Q)_0$$

From equation $\boldsymbol{ln(Q)_t = -k * t + ln(Q)_0}$ can be changed into Log as follows:

$$2.303 \text{ Log}\left(\frac{Q_t}{Q_0}\right) = -k * t$$

$$\text{Log}\left(\frac{Q_t}{Q_0}\right) = -\frac{k * t}{2.303}$$

$$\text{Log}(Q)_t = -\left(\frac{k}{2.303}\right)t + \text{Log}(Q)_0$$

Based on that equation, it is a log linear equation with $\boldsymbol{\text{Log}(Q)_t}$ as ordinate and time as abscess. The slope of $-\left(\frac{k}{2.303}\right)$ is equal with $-\left(\frac{1}{D}\right)$. That variables in the equation could be adjusted based on our data needed. The equation is similiar with (Yudianto et al., 2023b):

$$\text{Log}(N)_t = -\left(\frac{1}{D}\right)t + \text{Log}(N)_0$$

Based on the similarity of the slope value, the D value could be determined by the calculation below:

$$-\left(\frac{k}{2.303}\right) = -\left(\frac{1}{D}\right)$$

$$D = \frac{2.303}{k}$$

From Table 3, the Z value could be determined. The log D value and temperature are plotted as ordinate and abscess, respectively. The slope is 1/Z. This means that the Z value of each quality parameter can be calculated. All D and Z values could be viewed in Table 3. Figure 5 shows the graphs of the relation between log D value and temperature process from all quality parameters.

Z value is used to determine and calculate the temperature variable in optimization graph. The graph needs time and temperature data, including the Z value change. Meanwhile, the 50% reduction of all quality parameters could be calculated to know the time process in commercial sterility temperature, 121.1°C. This calculation needs the Arrhenius equation to calculate the k value in commercial sterility temperature. The equation is as follows (Yudianto et al., 2023b):

$$k = A * e^{-\frac{Ea}{R*T}}$$

$$\ln k = \ln\left(A * e^{-\frac{Ea}{R*T}}\right)$$

$$\ln k = \ln A + \left(-\frac{Ea}{R*T}\right)\ln e$$

$$\ln k = \ln A - \left(\frac{Ea}{R*T}\right) * 1$$

$$\ln k = -\frac{Ea}{R}\left(\frac{1}{T}\right) + \ln A$$

Based on that equation, it is a linear equation with the -(Ea/R) slope. The ln k value could be plotted as ordinate, and the temperature in Kelvin could be plotted as an abscess. The slope of that Arrhenius equation could be used to determine the k value in commercial sterility temperature (Yudianto et al., 2023b). The regression graph of Arrhenius equation from all quality parameters can be viewed in Figure 6.

The slope data from Arrhenius equation of all quality parameters are available in Table 3. The k value on 121.1°C temperature process should be gained. The k value in 121.1°C is used to calculate the point of heating time value during the temperature process to reach a half concentration. The k value in 121.1°C could be used to determine the D value in a similar temperature process. The D value is needed to know the heating time process variable, especially the change of 1 log cycle caused by

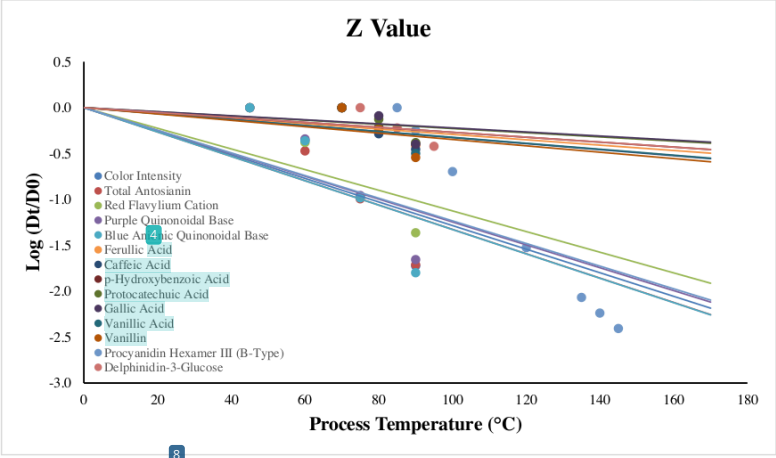


**Figure 5. Changes in Log D Value for Quality Parameters as a Function of Changes in Temperature.**

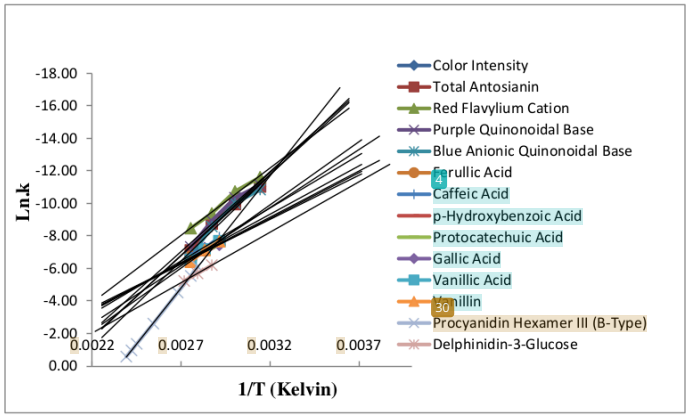


**Figure 6. Arrhenius Curve for Quality Parameters.**

the change of temperature process by Z value (Yudianto et al., 2023b). All k values of quality parameters in 121.1°C temperature process can be viewed in Table 3. The reduction time to reach 50% from the initial concentration of all quality parameters follows the first order below:

$$-\ln\left(\frac{Q_t}{Q_0}\right) = k * t$$

$$\ln\left(\frac{Q_0}{Q_t}\right) = k * t$$

$$\ln\left(\frac{Q_0}{\frac{1}{2}Q_0}\right) = k * t\frac{1}{2} \longrightarrow \text{because } t = t\frac{1}{2}, \text{ then } Q_t = \frac{1}{2}Q_0$$

$$t\frac{1}{2} = \frac{1}{k} * \ln\left(\frac{Q_0}{\frac{1}{2}Q_0}\right)$$

$$t\frac{1}{2} = \frac{1}{k} * \ln 2$$

$$t\frac{1}{2} = \frac{0.693}{k}$$

**Table 3. Combination of Temperature and Time of the Commercial Sterilization Process Optimization for Butterfly Pea Flower Extract.**

| Parameter | Process Optimization | | |
|---|---|---|---|
| | $k_{T.121.1}$ | Heating Temperature (°C) | Heating Time (minute) |
| Color Intensity* | 0.0057 | 95.15 | 1206.74 |
| | | 121.10 | 120.67 |
| | | 147.05 | 12.07 |
| Total Antosianin* | 0.0057 | 94.58 | 1210.88 |
| | | 121.10 | 121.09 |
| | | 147.62 | 12.11 |
| Red Flavylium Cation* | 0.0012 | 89.03 | 5592.60 |
| | | 121.10 | 559.26 |
| | | 153.17 | 55.93 |
| Purple Quinonoidal Base* | 0.0043 | 94.22 | 1603.49 |
| | | 121.10 | 160.35 |
| | | 147.98 | 16.03 |
| Blue Anionic Quinonoidal Base* | 0.0087 | 96.16 | 794.88 |
| | | 121.10 | 79.49 |
| | | 146.04 | 7.95 |
| Ferulic Acid** | 0.0045 | 72.82 | 1524.57 |
| | | 121.10 | 152.46 |
| | | 169.38 | 15.25 |
| Caffeic Acid** | 0.0045 | 76.95 | 1541.76 |
| | | 121.10 | 154.18 |
| | | 165.25 | 15.42 |
| p-Hydroxybenzoic Acid** | 0.0047 | 70.04 | 1469.83 |
| | | 121.10 | 146.98 |
| | | 172.16 | 14.70 |
| Protocatechuic Acid** | 0.0044 | 68.50 | 1562.36 |
| | | 121.10 | 156.24 |
| | | 173.70 | 15.62 |
| Gallic Acid** | 0.0045 | 70.84 | 1526.88 |
| | | 121.10 | 152.69 |
| | | 171.36 | 15.27 |
| Vanillic Acid** | 0.0067 | 80.99 | 1038.91 |
| | | 121.10 | 103.89 |
| | | 161.21 | 10.39 |
| Vanillin** | 0.0085 | 84.25 | 811.06 |
| | | 121.10 | 81.11 |
| | | 157.95 | 8.11 |
| Procyanidin Hexamer III (B-Type)*** | 0.0776 | 96.07 | 89.36 |
| | | 121.10 | 8.94 |
| | | 146.13 | 0.89 |
| Delphinidin-3-Glucose**** | 0.0163 | 73.54 | 425.50 |
| | | 121.10 | 42.55 |
| | | 168.66 | 4.26 |

Source : * (Marpaung et al., 2017); ** (Chen et al., 2022); *** (Paepe et al., 2014); **** (Mitić, 2020)

From Table 3, the first point in the optimization graph is known. The two other points are needed to make a line limit process from each quality parameter process. Calculation of the others point needs the Z value. The

other points are created by the change of temperature based on the Z value followed by the change of 1 log cycle of the time process. The temperature change could be calculated by increasing or reducing the temperature followed by the change of 1 log cycle heating time. The Clostridium botulinum spore inactivation line is determined by 12 log cycles from its D value inactivation, which is 3 minutes (Sayekti et al., 2024). The change of Z value follows the 10°C which is the change of 1 log cycle heating time. All combinations of temperature and time processes of quality parameters are available in Table 3. All data from Table 3 are plotted in a graph. The time process is ordinated while the heating temperature is an abscess. The plotting can be viewed in Figure 7. The process should be conducted in combination with time and temperature processes above the 12D *Clostridium botulinum* spore inactivation and compounds. By the first order, the time process from 10% reduction of functional compounds could be calculated by:

$$-\ln\left(\frac{Q_t}{Q_0}\right) = k * t$$

$$\ln\left(\frac{Q_0}{Q_t}\right) = k * t$$

$$\ln\left(\frac{Q_0}{\frac{1}{1.11}Q_0}\right) = k * t\frac{1}{1.11} \longrightarrow \text{because } t = t\frac{90}{100}$$

$$= t\frac{1}{1.11}, \text{ then } Q_t = \frac{1}{1.11}Q_0$$

$$t\frac{1}{1.11} = \frac{1}{k} * \ln\left(\frac{Q_0}{\frac{1}{1.11}Q_0}\right)$$

$$t\frac{1}{1.11} = \frac{1}{k} * \ln 1.11$$

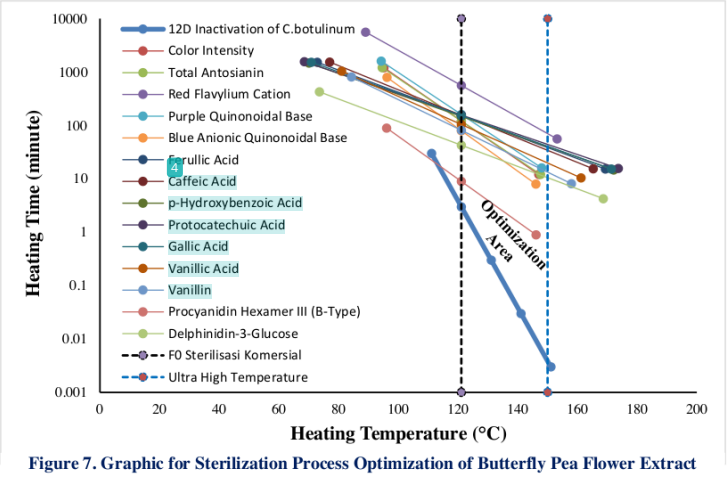


**Figure 7. Graphic for Sterilization Process Optimization of Butterfly Pea Flower Extract Beverages.**

below the Procyanidin Hexamer III (B-Type) lines.

The process should be maintained for the time and temperature processed in the recommendation area. The product is not safe if the process combination is below the 12D *Clostridium botulinum* spore inactivation. The product could also not be accepted if the process combination is more than Procyanidin Hexamer III (B-Type) lines. Sometimes, the process is adjusted to recover more functional compounds for the health product claim. Conversely, the processing cost could also be reduced by reducing the processing time. This last discussion will show the way for 10% reduction of all functional

$$t\frac{1}{1.11} = \frac{0.10436}{k}$$

The k value still uses in 121.1°C temperature process. From the results of this equation, the time that was originally reduced by a maximum reduction of 50% can be adjusted to a maximum length of time reduced by 10%. The other steps are still the same: determining combination points in the sterilization process optimization design using D and Z value concepts (Yudianto et al., 2023b). The potential limitation in this study is the use of butterfly pea flowers as ready-to-drink beverage in room temperature storage, which is

commonly difficult to produce by small and medium enterprises. Because the ready-to-drink product needs a thermal process validation. This requirement needs a pricey cost, nobody in small and medium enterprises understands it. This review solves that issue, explaining the commercial sterilization process as fulfilling the requirement of thermal process validation. Areas for improvement in this study involve the development of butterfly pea flower downstream products as ready-to-drink beverages. This could potentially be adopted for other local indigenous products in Indonesia, such as a soymilk product from a special Grobogan soybean variety (Sayekti et al., 2021). The commercial sterility concept is adopted to improve the product performance to the extent of a long time storage at room temperature without special or certain treatments.

## Conclusion

Heating process kinetics data on all specified bioactive components has succeeded in illustrating the optimization design of a commercial sterilization process. To process butterfly pea flower extract with commercial sterilization standards and a maximum reduction limit for bioactive compounds of 50%, it is mandatory to carry out the process in accordance with the recommended area for a temperature and time combination for sterilization process more than 12D inactivation line for *Clostridium botulinum* spores and below the bioactive compound reduction line at maximum of 50%. This thermal process design will make a major contribution to the functional food business with commercial sterilization standards aimed at claiming functional compounds at certain concentrations after processing. The future research direction as a specific recommendation for industry practice is the verification process of these results for commercial sterility optimization process design. This will produce a ready-to-drink butterfly pea flower extract using a recommendation process based on the optimization design. Thus, all quality parameters should be evaluated to ensure that all values are still in the design result from this study.

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## Conflict of Interest

The authors declare no conflict of interest.

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