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40 th Annivesary Faculty of Agriculture
Sriwijaya University

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Optimization Method for Aseptic Processing of Pineapple Juice Based on Kinetic Data and Linear Programming

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ABSTRACT

Optimization for aseptic processing was needed to enhance satisfy process which promise the best performance on quality simultaneously with minimize nutrient loss. Aseptic processing was concerned to choose the best combination of processing time (t) and temperature (T). Several models for optimization had been developed from kinetic models, i.e. $Y_i = 14.84 + X_1 + 6.08(X_2)$ for browning index development, $Y_c = 10.31 + X_1 + 4.56(X_2)$ for ascorbic acid loss, $Y_p = 28.58 + X_1 + 10.77(X_2)$ and $Y_n = 51.81 + X_1 + 18.37(X_2)$ respectively for inactivation of pectinesterase and L. plantarum. X_1 is defined as log (t) and X_2 as -0.001(1/T).

Linear programming approach was used to optimize that parameters, based on goal function of $G_b = 25.14 + 2X_1 + 10.64(X_2)$. There are observed five scenarios as optimization alternative. Result of the advances analysis show that second scenario, where temperature was set on 96 °C and processing time 4.1 second, presented satisfy result with small quality loss and limited ascorbic acid damaged.

I. INTRODUCTION

Aseptic processing is a continuous heating method based on high temperature in the short time process. There are basically could be categorized by two groups process, i.e. ultra high temperature (UHT) for sterilization and high temperature short time (HTST) for pasteurization. The main advantages of those process is on its possibility to use higher temperatures process that made possible to minimize processing time (Lund, 1987). The other advantages are described by Toledo and Chang (1990), especially the product could be better on quality, more trusty and energy saving production. On the other side, several restriction would come on implementation on wide range product because of material characteristics should be fluid based or pumpable. Fluid flow mechanism and characteristics was should be considered for determining the processing time, as well as temperatures and the goal process.

Minimum time process was recommended to minimize destruction of valuable component, but it was often lack time for destroying pathogenic or dangerous microorganism or other heat inactivation target of aseptic processing. Therefore, optimization was needed for taking guarantee that it has been chosen the best combination of processing time and temperatures for aseptic processing. Optimization is a procedure or the way that developed to observed the best choice for certainty case (Sidel and Stone, 1983). Linear programming is one of few popular optimizing method, but it was rarely used on food processing problem optimization especially related to the kinetics aspect. Saguy (1988) proposed some constraints to quality optimization in aseptic processing, but it was still based on single parameter quality for low acid food. In case of high acid food, such as pineapple juice, and not single parameter quality, the optimization method had not yet well developed. This paper proposed the method of optimization based on kinetics model and linear programming in the case of aseptic processing for pineapple juice.

II. THEORETICAL APPROACH

Aseptic processing that conducted for pineapple juice was typically high temperature short time (HTST) that categorized as pasteurization. The pineapple juice quality was changed during process, included its nutrition, appearance, microbiological and biochemical aspect. Browning index is an important quality parameter that indicated more dark when the I value increased. The quality measurement related to the appearance of pineapple juice, especially color, could be expressed by browning index. The quality related to nutrition could be expressed by ascorbic acid content. Because of its sensitive to heat damage, ascorbic acid was also used as indicator of chemical-nutrition retention during heat processing. Large amount of ascorbic acid damage shows that it had been happened over process.

Pectinesterase enzyme is very importance enzyme due to cloudy characteristic of pineapple juice. When it was not inactive, the cloudiness of pineapple juice significantly decreased or loss to be clearly fluid. This effect should be avoided, and heating process such as aseptic processing targeting this enzyme to be inactivated. Priyanto

(1997) had observed the kinetics model of quality changes of pineapple juice during aseptic processing. According his observation it is proved that browning index was increased during processing followed zeroth order kinetics model, and ascorbic acid content was decreased followed second order model.

The first order model for browning index development could be expressed by equation (1), while decreasing of ascorbic acid content could be expressed by equation (4). The rate of quality change (k) had been successfully expressed by Arrhenius approximation k=ko.exp.-Ea/RT. Then equation (1) and (4) could be developed to equation (3) and (5) in linear form.

$$I = I_o + k_i t \quad \text{.......... (1)}$$

$$\log (I - I_o) = \log k_i + \log t \quad \text{.......... (2)}$$

$$\log (I - I_o) = \log k_{io} - (E_{ai}/2{,}303R)(T^{-1}) + \log t \quad \text{.......... (3)}$$

$$C_A^{-1} = (C_{Ao})^{-1} + k_c t \quad \text{.......... (4)}$$

$$\text{Log } \{(C_{Ao}/C_A) - 1\} = \log k_{co} - \log (C_{Ao})^{-1} - (E_{ac}/2{,}303R)(T^{-1}) + \log t \quad \text{..........(5)}$$

The goal of aseptic processing in order to pasteurization rules is destroyed vegetative cells, microorganism and inactivation of enzyme, due to high acid product. *L. plantarum* was determined as indicator heating process target, as well as inactivation of pectiesterase. Both inactivation was has described by first order model, where in linear model with rate of quality change (k) could be presented as equation (6) and (7) below.

$$\text{Log } \{\log (P_o/P)\} = \log (k_{po}/2{,}303) - (E_{ap}/2{,}303R)(T^{-1}) + \log t \quad \text{.......... (6)}$$

$$\text{Log } \{\log (N_o/N)\} = \log (k_{no}/2{,}303) - (E_{an}/2{,}303R)(T^{-1}) + \log t \quad \text{.......... (7)}$$

Linear programming is usually used for optimizing production or selling product in order to obtain optimum profit. Saguy (1983) had promoted to implement this method in the food processing, although several researcher had used it several years before it. Some constraints had also published in case of aseptic processing at nonacid food (Saguy, 1988). There are three important component concerning optimization by linear programming procedures, i.e. decision variable, constraints factor and objective function. Optimal alternative is then defined as a feasible specification for decision variable that submit the best result for objective function. Standard format equation for objective function, decision variable, and constraint factor are describes by Asri and Widayat (1986).

III. METHODOLOGY

Optimization method for aseptic processing op pineapple juice based on kinetic data and linear programming was developed basically in three step procedures, i.e. data collection, model development, and optimization. Optimum solution was observed in order to obtain representative processing time and temperature for aseptic processing of pineapple juice.

1. Data collection

Data was collected from literature as secondary data, especially kinetics data of quality changes for pineapple juice during aseptic processing. Priyanto (1997) had observed significantly data in kinetics of quality change, which was browning index development and ascorbic acid loss represented for color and nutrition-chemical aspect of pineapple juice during aseptic processing. Kinetic data for *L.plantarum* inactivation was taken from Saguy and Karel (1980) and Nikdel *et al.* (1993).

2. Model Development

Kinetics data was used, analyzed and interpreted by approximation method as describe by Sweinbourne (1971) and Boekel (1996). The kinetics parameters, k and E_a or z value, are tabulated. Some of them are directly used on standard kinetics model, but the other one need to transfer with several adjustment on specified models for optimizing. The models are modified to be relevance with linear programming procedures. There are four steps from kinetic model to be modified on representative model for optimization using linear programming, i.e.:

a. Perform kinetic model of quality changes of pineapple juice during aseptic processing
b. Transfer kinetic model to be in linear form or linear equation.
c. Rearrangement variable or factor and redefined some variables or factor
d. Perform model in simple equation that contains only two variables (X_1 and X_2)

3. Optimization

Linear programming was used to optimize pineapple juice aseptic processing. Optimization was conducted to observed the optimum processing time and temperature. Variable of X_1 and X_2 was represented factor, respectively, for processing time and temperature in the optimization analysis. Determining those variables is the first step of optimization. The second step is construct the constraint factor or constraints model/equation. This model is developed from simple model that transferred from kinetics model, by considering sterilization effect needed for processing and tolerable quality changes of pineapple juice during aseptic processing. The third step is developed and determined the objective function, and used it for analyzing the critical point from any scenarios or combination of variables could be operated on aseptic processing of pineapple juice. The last step is transferred the value from optimization analysis to real value condition of the process.

IV. RESULT AND DISCUSSION

Kinetics model as stated on the theoretical approach that basically represented by zero, first, and second order models would be transferred to linear model as equation (3), (5) and (7). However, it not yet simple enough to be used on linear programs in order to optimize. If it was defined the variable of Y, W, X, and E as stated on Table 1, it could be rearranged and found equation (3), (5), (6) and (7) to be simplified as equation (8) until (11).

Table 1. Defined variable of X, Y, W and E for quality parameters of pineapple juice

No	*)	Browning index I, (i)	Ascorbic acid A, (c)	Inac. P-esterase** P, (p)	Inac. L-plantrm*** N, (n)
1.	X	$X_1 = \log t$ $X_2 = -10^3\,(T^{-1})$	$X_1 = \log t$ $X_2 = -10^3\,(T^{-1})$	$X_1 = \log t$ $X_2 = -10^3\,(T^{-1})$	$X_1 = \log t$ $X_2 = -10^3\,(T^{-1})$
2.	Y	$Y_i = \log\{(I/I_o)-1\}$	$Y_c = \log(C_{Ao}/C_A - 1)$	$Y_p = \log\{\log(P_o/P)\}$	$Y_n = \log\{\log(N_o/N)\}$
3.	W	$W_i = \log(k_{io}/I_o)$	$W_c = \log(k_{co}.C_{Ao})$	$W_p = \log(k_{po}/2{,}303)$	$W_n = \log(k_{no}/2{,}303)$
4.	E	$E_i = 10^{-3}E_{ai}/(2{,}303R)$	$E_c = 10^{-3}E_{ac}/(2{,}303R)$	$E_p = 10^{-3}E_{ap}/(2{,}303R)$	$E_n = 10^{-3}E_{an}/(2{,}303R)$

Notes: * Variable defined and symbol (index) of quality parameters, ** inactivation of pectinesterase
***) inactivation of *L.plantarum*

$$Y_i = W_i + X_1 + E_i X_2 \quad \text{(8)}$$
$$Y_c = W_c + X_1 + E_c X_2 \quad \text{(9)}$$
$$Y_p = W_p + X_1 + E_p X_2 \quad \text{(10)}$$
$$Y_n = W_n + X_1 + E_n X_2 \quad \text{(11)}$$

The above equation should be validated by kinetic data parameters submitted on Table 2 below (Priyanto, 1997) and it could be arranged the proposed model as described on Table 2 below. The proposed model tells us in linear form the effect of time and temperatures during aseptic processing of pineapple juice.

Table 2. Kinetic data parameters for optimization of pineapple juice aseptic processing

No	Parameters	Kinetics Data	Initial Value	Proposed model developed
1.	Browning index development *	E_{ai} = 28.01 Kcal/mole $\text{Log } k_{io}$ = 14.01	I_o = 0.126 A_{420nm}	$Y_i = 14.84 + X_1 + 6.08(X_2)$
2.	Ascorbic acid loss *	E_{ac} = 20.89 Kcal/mole $\text{Log } k_{co}$ = 9.38	C_{Ao} = 8.48 mg/100 mL	$Y_c = 10.31 + X_1 + 4.56(X_2)$
3.	Inactivation of Pectinesterase *	E_{ap} = 49.28 Kcal/mole $\text{Log } k_{po}$ = 28.94	-	$Y_p = 28.58 + X_1 + 10.77(X_2)$
4.	Inactivation of L.plantarum **	E_{an} = 84.00 Kcal/mol $\text{Log } k_{no}$ = 62.05	-	$Y_n = 51.81 + X_1 + 18.37(X_2)$

*) data from Priyanto (1997), ** data from Saguy and Karel (1980) and Nikdel *et al.* (1993)

The proposed models (Table 2) show that using maximum time of 60 second for aseptic processing, it is found that browning index was developed 52 percent from the initial value when temperature on 87 °C, but the amount of ascorbic acid loss was less then 50 percent although the temperature was maximized to 96 °C. The models proposed at Table 2 was also tell us that on maximum processing time of 60 second, pectinesterase had not yet inactivated (3D concept) at temperature 87 °C, but *L. plantarum* had been inactivated (6D concept). Any condition at various temperatures and time of aseptic processing could be developed or derived by simulating its models to perform processing effect diagram. However, there are many alternatives could be chosen concerning any combination of processing time and temperature of pineapple juice aseptic processing. Optimization was needed to observe optimum condition where time and temperature combination process could destroyed significantly pectinesterase and *L. plantarum*, but not for browning index and ascorbic. Linear programming is one of effectively method in optimization, but it was restricted by linear form based models. The proposed models that established on Table 2 were developed for optimization the aseptic processing of pineapple juice. Based on those equation, where variable had determined and described on Table 1, it would be developed constraint and objective function for the optimization.

Aseptic processing for acid food was actually of HTST process. It was basically designed to inactivate vegetative cells that disturbing food stability during storage (Lund, 1977). Inactivation of microorganism on acid food by HTST processing was commonly used minimum sterilization effect of 6D (Toledo and Chang, 1990). At the other hand, according to Saguy *et al.* (1990) it was recommended on sterilization effect of 3D for enzyme inactivation.

The sterilization effect of 6D for *L.plantarum* inactivation was given value of $Y_n = 0.7782$, and 3D for pectinesterase inactivation was given value of $Y_p = 0.4771$. Therefore, constraint function concerning inactivation of *L.plantarum* and pectinesterase, respectively, could be expressed by equation (12) and (13) below.

$0 < 51.03 + X_1 + 18.37 (X_2)$ ....(12)

$0 < 28.10 + X_1 + 10.77 (X_2)$ ....(13)

Another constraints were developed by considering the destruction quality that not rejected by consumers. In this case, it is assumed that ascorbic acid loss maximum of 15 percent and browning index development of 30 percent is still received by consumers. Therefore, it could be expressed constraints function for ascorbic acid loss and browning index development, respectively, as equation (14) and (15) below.

$0 > 11.05 + X_1 + 4.56 (X_2)$ ....(14)

$0 > 15.36 + X_1 + 6.08 (X_2)$ ....(15)

The value of variable was also considered as constraint for this optimization with linear programming method. Aseptic acid food process, such as pineapple juice, it recommended to be used temperature less then 100 °C with maximum time of 60 second. In this case, aseptic processing was designed on temperature range of 87-96 °C with maximum time of 60 second. In order to minimized destruction of nutrient and other product quality needed by consumers. Therefore, constraints function concerning variables could be expressed by $2.78 < X_2 < -2.71$ and $0 < X_1 < 1.78$, respectively, for processing temperature and time.

The goal of pineapple juice aseptic processing optimization is minimize the change of pineapple juice quality during aseptic process. There are, in this case, two quality parameters would be considered together with sterilization effect based. When the ascorbic acid content was changed minimum, consequently the value of Y_c was also minimum. It was also shown by the change of browoning index of pineapple juice, where Y_i would be minimum if the changes of browning index to be minimized.

In the evaluation process, storage and shelflife analysis, commonly, it was basically predicted under single based assumption that product quality was measured and represented by only one quality parameter. When it was more than one quality parameters, the assumption was failed. Therefore, Priyanto (1997) promote Quality Changed Number with symbol G_b, (abbreviated from Gatot's Number) that was defined as the sum or accumulation of relatives changes of quality index. These symbol was no dimension and could be expressed as function of many quality parameters. In the case of pineapple juice aseptic processing, it was the sum of the change of ascorbic acid and browning index, that is $G_b = Y_i + Y_c$ and could be expressed by variables of X_1 and X_2 as equation (16) below.

$G_b = 25.14 + 2 X_1 + 10.64 (X_2)$ .... (16)

Equation (16) shows that G_b would minimum if fraction 2 X_1 + 10.64 (X_2) to be minimum. According to Asri and Widayat (1986), the objective function was defined as $Z = c_i X_i$, where c_i was a constant and X_i was independent variable X_i. Therefore, the objective function (Z) for optimization using linear programming of pineapple juice aseptic processing could be expressed by minimize function (equation 17) or maximize function (equation 18).

$$Z_{min} = 2 X_1 + 10.64 (X_2) \quad \ldots\ldots\ldots\ldots (17)$$

$$Z_{max} = -2 X_1 - 10.64 (X_2) \quad \ldots\ldots\ldots\ldots (18)$$

The objective function in the form of maximize function was used for analysis of alternative observed in optimization. There are five alternative, namely scenario (SCEN) one to five, based on inactivation target of sterilization effect for pectinesterase enzyme on 3D,1D, 3D, 4D and 5D. Those sterilization effect are not influence variables, objective function and constraints inexception it related to pectinesterase inactivation. It should be corrected on intercept side following sterilization effect factor. Solution of the optimization using linear programming was solved by diagram approach method where it could be located any critical point based on the value of its variables X_1 or X_2. There are several temperatures observed as alternative, but the highest (96 °C) is considered to be priority. The critical point and Z_{max} value and the output process condition at that temperature are presented on Table 3 below.

Table 3. Critical point and condition solved from diagram linear programming optimization

Alternatives condition or scenario	Linear Programming Optimization Analysis Output			Real Condition on Pineapple Juice Aseptic Processing			
	Critical point		Z_{max} Value	Process Condition		Changes quality*	
	X_1	X_2		t (sec)	T (° C)	dI (%)	dA (%)
SCEN 1	1.558	-2.716	26.59	10.0	95.1	29.51	10.49
SCEN 2	0.607	-2.710	27.62	4.1	96.0	9.12	3.40
SCEN 3	0.907	-2.710	27.02	8.1	96.0	18.21	6.60
SCEN 4	1.207	-2.710	26.42	16.1	96.0	36.32	12.36
SCEN 5	1.307	-2.710	26.22	20.3	96.0	45.78	15.08

*) Notes: dI browning index development, dA ascorbic acid loss

CONCLUSSION

Optimization method through linear programming using kinetic model approach for pineapple juice aseptic processing has been found. Kinetic data should be collected, and transferred to linear model. Variables, constraints and objective function for optimization was determined by considering sterilization effect and tolerable quality changes. Further analyzed for five scenario, it was observed that scen 2 where processing time was set on 4.1 second at processing temperatures 96 °C show the satisfy result with ascorbic acid loss less then 3.4 percent and browning development 9.12 percent. The other combination recommended is performed by scen 1 where processing time set on 10 second at 95.1 °C. This combination destroyed ascorbic acid ascorbic acid smaller 'than 11 percent and browning index development less then 30 percent while sterilization effect reached to 3D for pectinesterase enzyme inactivation and 6D for *L.plantarum* inactivation.

NOMENCLATURE

A: ascorbic acid	C :concentration	N : microorganism amount
D: thermal dead time	P : pectinesterase	*Index:*
d: amount of change	T : temperature	c : ascorbic acid loss
E_a: activation energy	t : time	p : pectinesterase inactivation
I : browning index	X : independent variable	n : *L.plantarum* inactivation
k: constant or rate	Y : dependen variable	o : initial or intercept.
R: Gas constant	Z : objective function	i : browning index development

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