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Kinetics of Calcium Oxalate Reduction in Taro (*Colocasia esculenta*) Corm Chips during Treatments Using Baking Soda Solution

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Abstract

The oxalates content has caused limited utilizations of taro (*Colocasia esculenta*) as a food material. The insoluble oxalates, especially needle like calcium oxalate crystal may cause irritation, and swelling of mouth and throat. Removal of oxalates in food can be done by physical processes, such as soaking, boiling, and cooking or chemical process by converting them into soluble phases. The purpose of this research were to investigate the effects of baking soda concentration (0-10 % w/w) and temperatures (70-97 °C) on the reduction of calcium oxalate content in the taro corm chips and to develop a kinetic model of that process during boiling in baking soda solution. The kinetic model development was done by considering the dissolution of calcium oxalate, chemical reaction and thermal degradation that take place during boiling. The experimental results showed that increasing of baking soda concentration and temperatures were found to increase the reduction of calcium oxalate in the taro corm chips. Based on the product's functional properties, the best condition for calcium oxalate reduction was soaking in 10% w/w baking soda solution for 2 hours followed by boiling at 90 °C for 60 minutes. The kinetic modeling concluded that the calcium oxalate reduction was found to follow a pseudo first order reaction. The modeling results showed that the model is able to represent the phenomena quite well with the apparent reduction rate constant, $k = 15.77 \text{ Exp } (21.239)/RT$ minute^{-1}.

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Keywords: *modeling; dissolution; chemical reaction; thermal degradation; boiling*

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Nomenclature

A	Arrhenius equation pre-exponential factor (1/minute)
C_{AL}	concentration of calcium oxalate in the liquid phase (mol/L)
C_{AS}	concentration of calcium oxalate in the solid phase (mg/100g)
C_{AS0}	initial concentration of calcium oxalate in the solid phase (mg/100g)
C_{NL}	concentration of sodium bicarbonate in the liquid phase (mol/L)
E	activation energy (J/mol.K)
k	apparent reaction rate constant (1/minute)
k_{dec}	decomposition reaction rate constant (1/minute)
k_{diss}	dissolution rate constant (1/minute)
k_r	reaction rate constant (1/minute)
k_r'	combined reaction rate constant (1/minute)
N_{diss}	calcium oxalate dissolution rate (mg/minute)
N_r	reaction rate (mol/minute)
N_{dec}	calcium oxalate decomposition rate (mg/minute)
N_{red}	calcium oxalate reduction rate (mg/minute)
R	ideal gas constant (J/mol.K)
t	time (minute)
T	temperature (°C or K)

1. Introduction

Taros (*Colocasia spp*.) are stem tubers that are widely planted in both the tropical and subtropical regions of the world. In fact, among seven species of *Colocasia* which are originated from Asia, *Colocasia esculenta* is the most grown in Indonesia and other Southeast Asian countries[1]. In the eastern part of Indonesia, the corms are used as a staple food, while the people in the rest of the country use the corms as a raw material for animal feed and snacks. In addition, taros have also been important crops in Hawaii, Japan, Egypt, Ghana and Nigeria.

Most taro cultivars taste acrid and can cause swelling of lips, mouth and throat if they are eaten raw[2]. The acridity of taro is thought to be concentrated in the outer layers of the corm and may be largely removed by peeling off a thick layer followed by prolonged boiling[3]. This acridity is learned to be caused by calcium oxalate presents as fine needle-like crystals or raphides, which can penetrate soft skin[2]. Thereafter an irritant presents on the raphides, probably a protease can cause discomfort in the tissue[4]. The two common toxic effect of oxalate poisonings are (1) acute poisoning, resulting in hypocalcaemia after ingestion of high levels of soluble oxalates, and (2) (more commonly) chronic poisoning in which calcium oxalate crystals are deposited in the kidneys, resulting in renal disorder. In addition, the presence of oxalate in foods has also been implicated in reducing the bioavailability of essential minerals such as calcium[5].

The oxalates are widely distributed in the plants in readily water-soluble forms, such as potassium, sodium, and ammonium oxalate and as insoluble needle like calcium oxalate crystal[6]. Since calcium may also present in the plants in the form of other than as insoluble calcium oxalate crystals, the mole ratio of oxalate to calcium is found to vary from 7 to less than 1[7]. Cooking can affect the soluble oxalate but not the insoluble oxalate content of the food. Boiling can reduce the soluble oxalate content of a food if the cooking water is discarded, while soaking, germination and fermentation will also reduce the content of soluble oxalates[8]. In contrast, baking a food will cause an effective concentration of oxalates in the food due to the loss of water from the baked food[8].

Taro corm is served either as staple or mixed with other vegetables, usually after cooking. Iwuoha and Kalu[9] suggested that appropriate cooking may reduce the harsh and sharp irritation in the throat and mouth. Cooking may improve digestibility, promote palatability, improves keeping quality, and also makes root crops safer to eat[10]. Unfortunately, the cooking processes may also alter the physical characteristics and chemical compositions of taro

corms, so that food home processing and/or preparation can strongly affect their nutritional value[11]. The types of cooking methods (boiling, pressure cooking and baking) differ in many areas of the world and also vary with the ethnic background of the family[12]. Fresh taro corm is difficult to store and is vulnerable to deterioration during storage. Because it is regarded as a health food and is a staple food extensively eaten in the Pacific Islands and in the eastern part of Indonesian archipelago, it is feasible to develop a stable form of taro products to fulfill the health food market. One of the best ways to preserve it is by processing it into flour and/or starch[13]. Therefore, it is important to investigate whether the calcium oxalate content in the taro corms can be reduced by preparation and cooking with sodium bicarbonate solution to a safe level.

The objective of this work was to investigate the effect of different soaking solution concentrations, times and temperatures on the calcium oxalate reduction during soaking and boiling of taro corm chips in baking soda solution. An acquisition of understanding of the taro corm processing to reduce calcium oxalate content to a safe level may demonstrate its further potential uses in the food industry as an alternative source to conventional forms of carbohydrates or in production of new food products.

2. Kinetic Modeling

2.1. The assumptions taken to simplify the real system

The real system of calcium oxalate reduction in taro corm chips during soaking and boiling using baking soda solution is very complicated. However, some assumptions can be taken to approximately represent the main mechanisms taking place during the process, such as:

- The reduction of calcium oxalate content in taro corm chips during boiling is a result of leaching (dissolution) and thermal degradation[14].
- The chips are highly porous that enables the fluid reactant (baking soda solution) and the fluid product (sodium oxalate) to pass freely or that the diffusivity of each fluid component through the chips is large. The solid reactant (calcium oxalate) is distributed homogeneously throughout the corm ships. Then, it is reasonable to consider that the reaction between fluid and solid reactants is taking place homogeneously throughout the solid phase[15].
- Because baking soda is an amphoteric compound, its aqueous solution is mildly alkaline. This alkaline condition will promote calcium oxalate as an insoluble weak acid salt in the taro corm chips to dissolve[16].
- The thermal decomposition rate of calcium oxalate obey the first order reaction[17]

$$CaC_2O_4.\,H_2O(s) \rightleftharpoons CaC_2O_4\,(s) + n\,H_2O\,(g) \quad (1)$$

$$CaC_2O_4(s) \longrightarrow CaCO_3(s) + CO\,(g) \quad (2)$$

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2\,(g) \quad (3)$$

2.2. The kinetic model development

Based on the approximations taken above, the kinetic of calcium oxalate reduction during soaking and boiling of taro corm chips in baking soda solution can be proposed as follows:

As the sodium carbonate solution fully filled the pores of the taro corm chips, some calcium oxalate started to dissolve in it. The rate of calcium oxalate dissolution in baking soda solution can be written as:

$$N_{diss} = \frac{dCA_s}{dt} = -k_{diss} \times \left(CA_s - CA_L\right) \quad (4)$$

At the same time, some calcium oxalate also reacts with baking soda solution according to the following reaction:

$$CaC_2O_{4\,(aq)} + 2\,NaHCO_{3\,(aq)} \longrightarrow Na_2C_2O_{4(aq)} + CaCO_{3(aq)} + H_2O_{(l)} + CO_{2(g)} \quad (5)$$

Assuming that the reaction obeys elementary reaction, then it is plausible to write the reaction rate of calcium oxalate with baking soda solution as:

$$N_r = \frac{dCA_L}{dt} = -k_r \times CA_L \times CN_L^{\,2} \quad (6)$$

As the concentration of baking soda in the solution (CN_L) is very much higher than the calcium oxalate concentration (CA_L), then $kr \times CN_L^2$ will be nearly constant and can be simply denoted as kr'. Therefore, the reaction rate expression can be simplified as:

$$N_r = \frac{dCA_L}{dt} = -k_r' \times CA_L \quad (7)$$

With the presence of heat during boiling of taro corm chips in the baking soda solution, calcium oxalate may experience thermal degradation. According to Lozano et al. [18] the thermal decomposition rate of calcium oxalate follows first order reaction:

$$N_{dec} = \frac{dCA_s}{dt} = -k_{dec} \times CA_s \quad (8)$$

The reduction rate of calcium oxalate in the taro corm chips is then adequately represented by the following equations:

$$N_{red} = N_{diss} + N_r + N_{dec} \quad (9)$$

As a result, the reduction rate of calcium oxalate in the taro corm chips becomes:

$$N_{red} = \frac{dCA_s}{dt} = -k_{diss} \times \left(CA_s - CA_L\right) - k_r' CA_L - k_{dec} \times CA_s \quad (10)$$

Calcium oxalate and baking soda will undergo dissociation mechanism to form their respective ions in the liquid phase. Therefore, the reaction between both substances will be very fast. As a consequence, the concentration of calcium oxalate in the liquid phase (CA_L) will be always zero. Then the reduction rate of calcium oxalate in taro corm chips can be expressed as:

$$N_{red} = \frac{dCA_s}{dt} = -k_{diss} \times CA_s - k_{dec} \times CA_s = -(k_{diss} + k_{dec}) \times CA_s \quad (11)$$

Since both k_{diss} and k_{dec} are constant, then $(k_{diss} + k_{dec}) = k$

The final form of the reduction rate of calcium oxalate in the taro corm chips during soaking and boiling using baking soda solution can be simply written as:

$$N_{red} = \frac{dCA_s}{dt} = -k \times CA_s \quad (12)$$

$$\ln(CA_{s0}/CA_s) = k \times t \quad (13)$$

The apparent reaction rate constant (k) can then be evaluated by taking the slope of a plot between ln (CA_{s0}/CA_s) against (t). The effect of temperatures on the apparent reaction rate constant can be assumed to follow the Arrhenius equation:

$$k = A \times \exp(-E/RT) \quad (14)$$

$$\ln k = \ln(A) - (E/RT) \tag{15}$$

The Arrhenius equation pre-exponential factor (A) and activation energy (E) can then be obtained by taking the intercept and slope of a plot between ln (k) against ($-1/RT$).

3. Materials and Methods

3.1. Taro corms and chemicals

Taro corms were harvested at maturity (9 months after planting) from a botanical garden in the vicinity of Diponegoro University Tembalang Campus, Semarang, Indonesia. They were immediately sent to the laboratory and stored under prevailing tropical ambient conditions (26-31°C, 60-85% RH) before used in the experiments, normally within 1 week of harvesting. All chemicals and reagents used were of analytical grade and purchased from Sigma-Aldrich Pte. Ltd. (Singapore).

3.2. Proximate and elemental analysis of taro corms

The moisture contents were determined by AOAC approved method, which involves drying in an oven at 105 °C for 24 hours to constant weight[19]. The crude protein contents were calculated from nitrogen contents (N × 6.25) obtained using the Kjeldahl method provided by AOAC[19]. The crude fat contents were determined by continuous extraction in a Soxhlet apparatus for 8 hours using hexane as solvent, while the crude fiber contents were determined according to a standard method also suggested by AOAC[19]. The total ash contents were determined by incinerating in a furnace at 550 °C[19]. Therefore % carbohydrate = 100 - (% moisture + % crude protein + % crude fat + % crude fiber + % ash).

3.3. Calcium oxalate reduction study

Prior to calcium oxalate reduction study, taro corms were washed with clean water and peeled using a stainless steel knife. The peeled samples were then rewashed with clean water and cut into slices (2 cm × 2 cm × 0.2 cm). Physical reduction of calcium oxalate content was carried out by soaking 50 grams of taro corm chips in 200 mL baking soda solution for 10 hours. The concentrations of baking soda solution studied were 0, 2, 4, 6, 8 and 10 % w/w. Sample of taro com ships were withdrawn from the system at every 2 hours interval. While the physicochemical reduction of calcium oxalate content study was conducted by boiling of taro corm chips in 200 mL 10% baking soda solution for 60 minutes. The sample of boiled taro corm chips were withdrawn from the system every 10 minutes interval. The baking soda solution was drained off after each time interval and the hot samples were exposed to the air to allow the surface water to evaporate for 20 min. The taro corm chips were then mashed and subjected to calcium oxalate content analysis, while the swelling power and water solubility of the flour obtained from grinding and sieving of the treated taro corm chips were also analyzed as the additional responses.

3.4. Calcium oxalate content determination

The calcium oxalate content in the fresh and processed samples was determined using the AOAC analytical method[19]. The procedure involves three steps: digestion, oxalate precipitation and permanganate titration. Each sample was analyzed in triplicate and all data are presented as mg oxalate/100 g fresh weight (FM) as this is how this vegetable is normally consumed. Two grams of taro flour was dispersed in 190 mL of distilled water contained in a 250 mL volumetric flask. Ten milliliters of 6 M HCl was added and the suspension digested at 100 °C for 1 hour. The suspension was then cooled and then made up to 250 mL before filtration. The duplicate portions of 125 mL of the filtrate were measured into a beaker and four drops of methyl red indicator added, followed by the drop wise addition of concentrated NH_40H solution until the color of the solution changed from salmon pink to a faint yellow (pH 4-4.5). Each portion was then heated to 90 °C, cooled and filtered to remove precipitate containing

ferrous ion. The filtrate was again heated to 90 °C and 10 mL of 5% $CaCl_2$ solution was added with constant agitation. After heating, it was cooled and left overnight at 5 °C. The solution was then centrifuged at a speed of 2500 rev/min for 5 min. The supernatant was decanted and the precipitate completely dissolved in 10 mL of 20% (v/v) H_2SO_4 solution. The total filtrate resulting from digestion of 2 g of flour was made up to 300 mL. Aliquots of 125 mL of the filtrate were heated until near-boiling, and then titrated against 0.05 M standardized $KMnO_4$ solutions to a faint pink color which persisted for 30 s. The calcium oxalate content was calculated using the formula:

$$CA_s = \frac{T \times V_{me} \times DF \times 10^5}{ME \times mf} \tag{16}$$

where *T* is the titer of $KMnO_4$ (mL), *Vme* is the volume - mass equivalent (i.e. that 1 cm3 of 0.05M KMnO, solution is equivalent to 0.00225 g anhydrous oxalic acid), *DF* is the dilution factor *VTA (2.4,* where *VT* is the total volume of filtrate (300 mL) and *A* is the aliquot used (125 mL)), ME is the molar equivalent of $KMnO_4$ in oxalate ($KMnO_4$ redox reaction (5)) and *mf* is the mass of flour used.

Swelling power (*SP*) and water solubility (*WS*) were determined using the method previously described by Tattiyakul et al.[20]. A known amount of dry taro flour (M_0; 0.5 g) was dispersed in 15 mL of water. The dispersion was heated under mild agitation at 80 °C for 30 minutes. The gelatinized dispersion was then centrifuged at 3000 × g for 15 minutes. After which, the supernatant was decanted and dried at 100 °C until a constant weight (*Ms*) was reached. While the weight of swollen starch granules (M_{sw}) was measured. The swelling power and solubility were calculated following Equations (17) and (18).

$$WS = M_s / M_0 \tag{17}$$

$$SP = M_{sw} / \left[M_0 . (1 - WS) \right] \tag{18}$$

4. Results and Discussion

4.1. The proximate composition of taro corm

Prior to calcium oxalate reduction study, a proximate analysis of the fresh taro corm was conducted. The results of this analysis and its comparison with data from literatures are presented in Table 1. As seen in Table 1, taro corm contains a moderate carbohydrate content as such they are a good source of energy. However, the energy content of taro corm in this work was slightly lower than the taro grown in Ghana[21], but slightly higher than taro grown in other parts of Africa[22]. Unfortunately, taro corm was relatively low in protein and fat contents, which is similar to many other tuber crops. It contains a fair amount of fiber and minerals as indicated by its high ash content. High fiber content indicates that taro corms could help treat constipation and hence may improve the general health and well being[23]. Dietary fiber has recently gained much attention as it is said to reduce the incidences of colon cancer, diabetes, heart disease and some other digestive diseases[24]. The analysis also revealed that freshly harvested taro corm has high moisture content, which is a very well-known characteristic feature of roots and tubers crops[25].

Table 1. Proximate composition of taro corm per 100g edible portion

Component	This work	Literature[22]	Literature[21]
Energy (cal)	145.04	131.97	152.01
Carbohydrate (g)	31.49	13-29	32.5
Protein (g)	2.62	1.4-3.0	2.98
Fat (g)	0.37	0.1-1.5	0.64
Ash (g)	1.23	0.6-1.3	1.56
Moisture (g)	61.29	73-78	59.3
Fiber (g)	3.0	0.4-2.9	3.0

Unfortunately, taro corm also contains a considerable amount of calcium oxalate as a harmful antinutrient. The calcium oxalate content in the fresh taro corm investigated in this study was 770 mg/100g. This value agrees well to

the data reported in the literature, which is 367-710 mg/100g for raw taro corm from Africa[9]. Other roots and tubers also mostly contain calcium oxalate of less than 100 mg/100g. Calcium oxalate content in taro corm depends on the cultivars, fertilizers and environmental condition, especially during drought[26]. Since the allowable calcium oxalate content in food is only 71 mg/100g [21], therefore taro corms require proper processing method to reduce the calcium oxalate content to a safe level.

4.2. The effect of baking soda concentration and soaking time on calcium oxalate concentration in taro corm chips

The public opinion that any food processing method will be more economical if it is carried out with the absence of energy from fossil fuel has encouraged us to do an attempt to reduce the calcium oxalate content in the taro corm by soaking taro chips into baking soda solution at ambient temperature (± 30 °C). The presence of Na^+ ion in the baking soda solution is expected to promote the decomposition of calcium oxalate into calcium oxide[27] as well as to increase the solubility of calcium oxalate. Without the addition of sodium salt, the solubility of calcium oxalate in water is only 0.67 mg/g at ambient temperature[28]. The profile of calcium oxalate content in the taro corm chips at various concentrations of baking soda solution and soaking time is presented in Fig.1 (a).

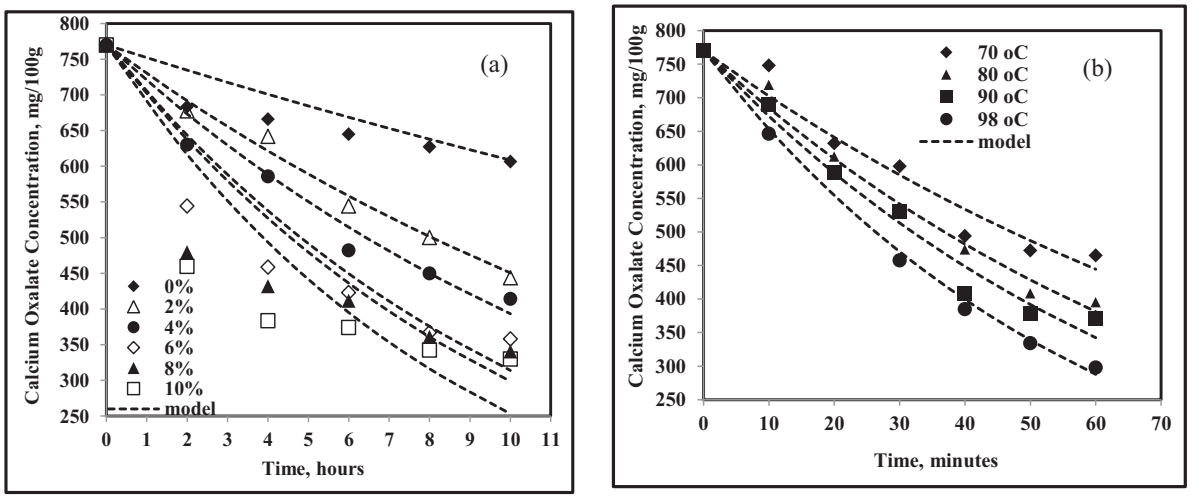

Fig. 1. Comparison between experimental and modeling results of calcium oxalate concentration in taro corm chips (a) at various concentrations of baking soda solution and (b) at various temperatures

In Fig. 1(a), one can observe that soaking the taro corm chips in water (0% baking soda concentration) at ambient temperature for 10 hours may only reduce calcium oxalate content from 770 to 606.39 mg/100g, or about 21.25%. Unfortunately, this value remains far higher than the threshold calcium oxalate level in food, which is 71 mg/100g[21]. At this condition, the reduction rate of calcium oxalate content in the taro corm chips is very slow because the solubility of calcium oxalate is only 0.67 mg/g[28]. In addition, no agitation was performed to create turbulence of the system, which might enhance the mass transfer rate of solubilized calcium oxalate. Therefore, mass transfer in this system is only consisted of natural diffusion.

In accordance with the increased in baking soda concentration in the soaking medium, the calcium oxalate content in the taro corm chips also decreased. In addition, the longer the soaking time also caused further decrease in calcium oxalate content in the taro corm chips. However, the reduction rate of calcium oxalate in the taro corm chips was found to be faster at the beginning of the process (0-2 hours). Unfortunately, extending the soaking time did not significantly reduce the calcium oxalate level. Soaking of taro corm chips in 10 % w/w baking soda solution for 10 hours at room temperature (± 30 °C) was still unable to reduce the calcium oxalate content to a safe level. Processing taro corm chips with this condition can only reduce the calcium oxalate content to about 330 mg/100g.

Fig. 1(a) also shows that the reduction rate of calcium oxalate in the taro corm chips by soaking in baking soda solution was faster at higher baking soda concentration. This is due to higher concentration of Na^+ ions in the system, which increases the solubility of calcium oxalate. However, large deviations between calcium oxalate content obtained from experiments and modeling was observed. This phenomenon may occur because the taro corm was sliced into chips that create broken and intact cells before being soaked in baking soda solution. While our model assumed that no broken cells in the taro corm chips so that the diffusion of calcium oxalate and baking soda solution in the chips will be very slow. Slicing taro corm into chips caused some of the calcium oxalate is located at the outer surfaces of the chips or in ruptured cells and thus can be readily accessible to the baking soda solution while the rest is deep down in the pore structure or in intact cells and then less accessible. Leaching of easily accessible calcium oxalate is very fast with a rate controlled by its diffusion in the baking soda solution, while the leaching of the less accessible calcium oxalate from intact cells is much slower and the mass transfer resistance is high. Resistance to mass transfer in non-agitated system considered includes both the baking soda solution film around the chips and the solid phase (i.e., within the chips). The former determines the rate of leaching of the easily accessible calcium oxalate while the latter controls the rate of mass transfer of the less accessible calcium oxalate.

4.3. *The effect of temperature on the calcium oxalate concentration in taro corm chips*

Literature study has revealed that the solubility of calcium oxalate in water increases with increasing temperature[28] and that the decomposition reaction of calcium oxalate crystals into calcium oxide also occurs rapidly at high temperatures[27]. Therefore, a study on the effects of temperature on the calcium oxalate content reduction rate in taro corm chips during boiling in 10 % w/w baking soda solution was conducted. The experimental results their comparison with those results from calculation using the proposed model (Equation (12)) of the study are presented in Figures 1 (b). The figure confirms that the proposed model may describe the real mechanisms in the whole process fairly well. The calcium oxalate content in the taro corm chips reduced almost linearly in the first 30 minutes of boiling at all studied temperatures. As expected, the slopes of the calcium oxalate content versus boiling time plots were steeper at higher temperatures. As a result, the final calcium oxalate content in the taro corm chips was lowest for taro corm chips boiled in 10% w/w baking soda solution at 98 °C for 60 minutes, which is 297.80 mg/100g. Again, these results suggest that boiling of taro corm chips in 10 % w/w baking soda solution for 60 minutes is still not sufficient to reduce the calcium oxalate content to safe level, which is 71 mg/100g[21].

The calcium oxalate reduction rate constants (k) at various temperatures are tabulated in Table 2. The k values were found to be higher at higher temperature, which agree well with the Arrhenius equation. The effect of temperature on k values was then evaluated using Equation (15), from which the activation energy (E) and the pre-exponential factor (A) can also be obtained. The other way to find both parameters is by plotting ln (k) against (-1/RT) and take the intercept and slope of the plot as pre-exponential factor and activation energy as shown in Fig. 2.

Table 2. Effect of temperature on the calcium oxalate reduction rate constants

Temperature (°C)	$k \times 10^3$ (1/minute)	Error (%)
30	1.930	0.9921
70	9.188	0.2528
80	11.755	0.1748
90	13.550	0.2689
98	16.456	0.1827

From Fig. 2, it is obvious that the pre-exponential factor and activation energy of the system were 15.77 (1/minute) and 21.239 (J/mol.K), respectively. Recalculation of calcium oxalate content in the taro corm chips at various temperatures and boiling times using Equations (13) and (14) results in very close values with calcium oxalate content in the taro corm chips from experiments with only less than 1.00% average errors.

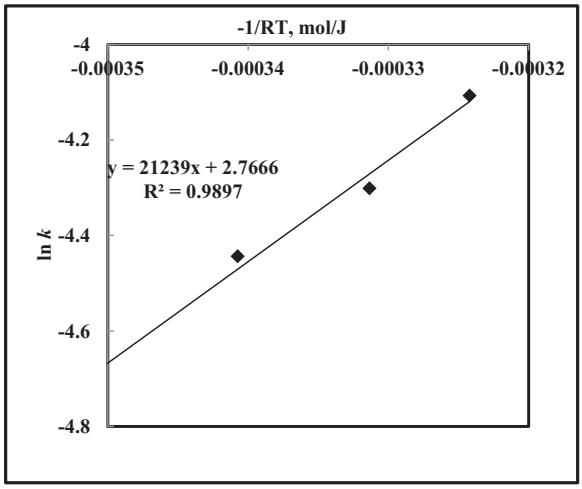

Fig. 2. Plot of ln *k* versus (-1/RT)

4.4. The functional properties of taro flour processed using baking soda solution

The functional properties, namely the waster solubility (*WS*) and Swelling power (*SP*) of flours obtained from taro corm chips after being treated using baking soda solution were determined and the results are reported in Table 3. The water solubility and swelling power of untreated taro flour (control sample) obtained in this work are comparable to that of untreated taro flour from Thailand[20]. The slight difference between the two is more likely due to corm maturity and regional variability of the cultivation area such as fertilizer, climate and soil properties.

Table 3. Effect of boiling temperature on the functional properties of taro flour

Temperature (°C)	*WS* (g/g)	*SP* (g/g)
Untreated (control)	0.060	14.5
Untreated [20]	0.070-0.13	11-17.4
American wheat [32]	0.063	6.8-7.9
70	0.021	12.09
80	0.021	5.92
90	0.033	6.48
98	0.042	7.65

Table 3 also shows that water solubility of control sample is very close to that of American wheat flour, while the swelling power is almost twice of that of American wheat flour. Boiling of taro corm chips using 10 % w/w baking soda solution at 70 and 80 °C caused reduction of water solubility to within one third of that of control sample, while the swelling power also decreased but without regular trend. The gelatinization temperature of taro flour is between 78-87 °C[20], therefore gelatinization of taro starch is likely to occur when taro corm chips are boiled at temperature of 80 °C or higher. Changes in water solubility and swelling power as a result of boiling can be related to changes in amylose to amylopectin ratio. High amylose content caused reduction in swelling power due to inhibition of water diffusion into the starch granules[29]. In addition, high fat content in flour also may form a complex with amylose and the linear part of the amylopectin, and hence inhibit swelling[30,31]. Proximate analysis has shown that taro tuber contains very little fat; therefore an increase in amylose to amylopectin ratio may be the most possible reason of reduction in swelling power.

Table 3 indicates that the solubility of taro corm flours was observed to be a function of temperature between 70-98 °C. A similar result was also reported in the literature[33]. Taro flour obtained from taro corm chips treated below

gelatinization temperature was less soluble, while those obtained from taro corm chips treated at 80 °C or above with excessive quantity of water was more soluble and complete gelatinization was also observed. The high solubility of these pregelatinized starches at lower temperature may be attributed to loss of granular structure and release of amylose fraction of the starch as the amylose molecules are preferentially solubilized and leached from swollen starch granules[34].

The partial solubilization of amylose during the high moisture-high temperature treatment below the gelatinization temperature of starch may help in absorption of more water[33]. As a result of high moisture-high temperature treatment, up to 70 °C, treated flour thus showed greater swelling than the untreated flour (control sample). At 80 °C or higher, however, these flours swelled less than the control did. Similar result was also reported by Alam and Hasnain[33]. This may occur partly because the granule structure is essentially lost during gelatinization at temperature higher than the gelatinization temperature. Therefore, control sample would swell more as it has more amylose embedded in the starch granules to absorb moisture. It also has a greater capacity for swelling as it may reach its gelatinization point without releasing much of its starch contents into the surroundings.

Processing of taro corm chips using 10 % w/w baking soda solution by soaking for 10 hours and boiling for 60 minutes resulted a good quality taro flour with water solubility and swelling power of 0.042 (g/g) and 7.65 (g/g), respectively. The functional properties of this flour are very similar to American wheat flour[32].

5. Conclusions

An effort on the reduction of calcium oxalate content from taro corms through soaking and boiling of taro corm chips in baking soda solution has been carried out. Soaking and boiling of taro corm chips in baking soda solution is still unable to reduce the calcium oxalate content to safe level. A mathematical model, which involves dissolution, reaction and decomposition mechanisms has been developed and well verified its accuracy by comparing with experimental data. From the technical and economics point of views, a relatively good condition to reduce calcium oxalate content is by soaking taro corm chips in 10 % w/w baking soda solution at ratio 1:4 (w/v) for 10 hours at ambient temperature followed by boiling at 98°C for 60 minutes to obtain taro flour with similar functional properties of American wheat flour.

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