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Comparison between conventional and alternative peeling methods on peeling efficiencies of Malaysian 'Chok Anan' mango (*Mangifera indica* L.) fruit

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Abstract

Fruit industries require convenient peeling method, especially during puree processing to prevent deterioration of fruit quality and product loss. Therefore, manual, chemical (sodium hydroxide/NaOH) and enzymatic (Pectinex Ultra SP-L) peeling methods were compared to determine the peeling efficiencies of 'Chok Anan' mangoes. The effect of different peeling parameters (concentrations [chemical peeling: 1.6-7.3% of 0.4M-1.83M; enzymatic peeling: 0.005-0.095%], temperatures [chemical peeling: 80-95°C; enzymatic peeling: 25-40°C], and duration of soaking [chemical peeling: 5-10 min; enzymatic peeling: 30-120 min]) were evaluated for peeling yield, peeling time, absorption of chemical and enzyme solution, the penetration depth of NaOH and enzyme activities (reducing sugar analysis). The enzymatic peeling had significantly ($p<0.05$) reduced the time (4.46 min) of mango peeling compared to manual (5.30 min) and chemical (6.49 min) peeling which were time-consuming. The parameters involved resulted in no significant difference ($p>0.05$) in peeling yield (>86%), but there was significant ($p<0.05$) effect on absorption of both NaoH and pectinase solutions at 0.84g/100g (enzymatic) and 2.50g/100 g (chemical), 0.45 mm penetration depth of NaOH and significant decrease in enzyme activities from 20.04g/100 mL to 4.92g/100 mL using reducing sugar analysis. The optimal enzymatic peeling conditions (concentration: 0.009%, temperature: 25°C, duration of soaking: 120 min) had made it possible to recycle the pectinase solution twice thus may be beneficial for the mango processing industry compared to chemical peeling.

Introduction

Peeling is performed before further process it as fruit or vegetable based products (Toker *et al.*, 2003; Srikaeo *et al*., 2011; Rock *et al.*, 2012). During the processing of any fruit or vegetables based products, it is important to minimize the loss of yield while retaining the quality of the products through ideal peeling methods (Garcia *et al.*, 2006; Srikaeo *et al*., 2011). In addition, Garcia *et al*. (2006) also stated that the peeling process often results in yield losses unless the temperature, pressure and residence time in the peeler are controlled. The peeling process involves a series of biochemical (chemical disintegration towards fruit skin), thermal (high temperature) and physical mechanisms (separation of the skin from biochemical and thermal effects) to adequately loosen and remove the skin of the fruits (Rock *et al*., 2012). Fellows (2000) observed that it is crucial to maximize the efficiency of processing equipment, while facilitating uniform thermal processing in order to get better palatability of the final product.

Various peeling methods have been utilized including the use of hand/manual or mechanical, steam or hot, lye or chemical, and enzymes (Fellows, 2000; Wongsa-Ngasri, 2004; Das *et al*., 2006; Rock *et al*., 2011; Li, 2012). Traditionally in the industrial fruit processing, hand or manual peeling is a common peeling method. In addition, manual peeling has the closest result of the ideal peeling process and the ability of retaining the fresh edible mesocarp (flesh) and damage-free (Somsen *et al*., 2004; Arazuri *et al*., 2010: Rock *et al*., 2012). However, it is not recommended to use this method since it causes high losses of yield (Emadi *et al*., 2007; 2008). Previously, studies on peeling of citrus fruits have widely being done. However, little information on peeling of stone fruits been applied which this come to our interest

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to investigate the applicability of different peeling methods used on mango fruit.

Several peeling alternatives have been conducted in the industry including chemical peeling using sodium hydroxide (NaOH) is also one of the most common methods used besides manual, for peeling of fruit and vegetables (Fellows, 2000; Kaleoglu *et al.*, 2004; Garcia *et al*., 2005). Furthermore, according to Rock *et al*. (2012), the chemical peeling is more preferred and widely applied among manufacturers due to its association with higher product yields and better product quality compared to manual peeling. Based on Pagán *et al.* (2005 and 2010), the industrial processes for peeling consist of manual skin removal and further chemical degradation of pericarp (skin) and mesocarp (flesh) of the fruits. This method removes the cuticle and some of the most external cell layers of fruits.

Once the chemical (lye or caustic) solution is in contact with pericarp (skin) of the fruits, the epicuticular waxes are dissolved and the NaOH penetrates the epidermis and diffuses through the skin into the mesocarp (flesh) of fruit and, thus, separates the skin (Shi *et al*., 2000; Das *et al*., 2006; Kaleoglu *et al*., 2004). However, high cost of labor and large amount of water are required for washing stage which has caused severe damage to the environment due to the discharge of NaOH used during peeling process (Pretel *et al*., 2008; Rock *et al*., 2012). Furthermore, the environmental protection laws have a concern regarding the usage of chemical and its disposal. Thus, finding an alternative for chemical-free peeling methods has been a focus where it can effectively minimize peeling losses and improve product quality (Rock *et al*., 2012).

The above stated problems caused by the chemical peeling has led several researchers to study enzymatic peeling as an alternative. Enzymatic peeling is performed by treating the fruit with a high-activity enzymatic solution containing polysaccharide hydrolytic enzymes, especially pectinases, cellulases, and hemicellulases since pectin, cellulose and hemicellulose are the polysaccharides that are responsible for the adherence of the skin to the flesh (Pagán *et al.*, 2005; Pagán *et al*., 2010). The results showed that pectinases and cellulases were the enzymes that led to a more efficient peeling process. Many studies on enzymatic peeling have been done, such as on grapefruit by Rouhana *et al.* (1994) and Pagán *et al.* (2005), mandarin orange by Pretel *et al.* (1998), Cimbos fruit by Pretel *et al.* (2005), oranges, apricots, nectarines and peaches by Toker *et al.* (2003) and ginger by Srikaeo *et al*. (2011). Most of the studies mentioned above had different fruit characeteristics (citrus fruits) compared to the mango fruit (stone fruit) being studied in this experiment. The enzymes used in the citrus fruits studied were meant to degrade the albedo which this does not have in mango fruit. This method leads to a more efficient peeling process in the fruit and vegetable industries.

According to Pretel *et al.* (2007), who stated that the recyclability of the enzyme solution for 8 days in continuous periods of 8 h with storage of 16 h in a cool room has been studied for industrial process. The residual enzyme (pectinase and cellulase) activities present in the solutions were about 85% from the initial after 23 peeling cycles carried out in a week (Pretel *et al.*, 2007). Mango fruits requires skin peeling before further processes. Therefore, alternative methods using chemical and enzymatic peeling can be compared for efficient peeling in separating the skin.

Tomato products requires complete peel removal in order to receive a USDA grade A (Anon, 1995). Insufficient or improper peeling had caused the deterioration of fruit quality and product loss (Garcia *et al*., 2006; Milczarek *et al*., 2011). According to Garcia *et al.* (2006), peeling efficiency may vary with peeling conditions as well as with the cultivars used. It must be closely monitored to ensure the efficiency of peel skin removal without excessive flesh loss. Based on Barriero *et al.* (2007), the rate of peeling is a function of temperature and concentration, peeling time, peel thickness, fruit characteristics; and involves both chemical and thermal treatment.

The relationship between the variables (temperature, concentration, peeling time, and fruit characteristics) is critical to avoid high loss of pulp from over peeling. Therefore, this study aimed to determine the peeling efficiency of Malaysian 'Chok Anan' mango fruit using alternative methods (chemical and enzymatic peeling) compared to the conventional method (manual peeling).

Materials and Methods

Raw materials

Mango (*Mangifera indica* L. cv. 'Chok Anan') fruits were selected from Stage 4 (ripening stages) and purchased from a local orchard (Malaysian Department of Agriculture, Lekir, Perak).The 'Chok Anan' mango used in the study was selected due to its pleasant aroma, sweet taste, the yellow-orange flesh and one of the popular mango varieties planted in Malaysia (Ding *et al*., 2013). Three different batches of fully-ripened mangoes (8 kg each) with total soluble solids (TSS) range from 10 to 17°Brix

and pH range from 4.5 to 5.9 were used in this study. The mangoes were washed to remove dirt and wiped before further peeling process.

Experimental design

Preliminary studies was carried out on different ranges of concentrations (chemical peeling: 1.6-7.3% of 0.4 M-1.83 M; enzymatic peeling: 0.005-0.095%), temperatures (chemical peeling: 80-95°C; enzymatic peeling: 25-40°C), and duration of soaking (chemical peeling: 5-10 min; enzymatic peeling: 30-120 min) using Response Surface Methodology (RSM). The selected optimized of chemical and enzymatic peeling method to compare with the manual peeling to determine the peeling efficiencies by conducting several analyses such as peeling yield, peeling time, absorption of chemical and enzyme solution, penetration depth (chemical peeling) and enzyme activities (reducing sugar analysis). The experiment was repeated twice using a total of 8 kg fruits for each peeling method and analyses (Toker *et al*., 2003; Kaleoglu *et al.*, 2004; Aydin *et al.*, 2010)

Preparation of manual-peeled mango fruit

For manual peeling, the 'Chok Anan' mango fruits were manually peeled with a stainless steel peeler and the total weight of mango fruits (8 kg) was used during the experiment (including chemical and enzymatic peeling) (Barry-ryan *et al.*, 2000).

Preparation of chemical-peeled mango fruit

Each group of mangoes was packed in a plastic net bag to manually removed from the solution after the elapsed peeling time. The mangoes were immersed in the 7.3% of 1.83 M of hot sodium hydroxide solution at 95°C for 8.5 min soaking duration. NaOH was used in this experiment due to its ability to rupture the skin of mango for efficient peeling during preliminary study. Approximately 146 g of NaOH were weighed for solutions preparation in 2 L volumes of distilled water. Then, the mangoes were neutralized by immersing in 3% of 0.16 M citric acid solution for 2 min and cooled rapidly under running tap water to avoid overcooking. The treated mangoes were left to dry for a few min and hand-peeled (modified from Barriero *et al*., 2007).

Preparation of enzyme-peeled mango fruit

Parameters used for enzymatic peeling were 0.009% of pectinase (Pectinex Ultra SP-L, Novozymes A/S, Bagsvaerd, Denmark) concentration at temperature 25°C with duration of soaking 120 min. Pectinase was used in this experiment because it helps in degraded the pectin which existed in the mango skin, thus efficient peeling could be obtained (based on the preliminary study). Pectinex Ultra SP-L were weighed 0.18 mL for solutions preparation in 2 L volumes of distilled water. After the elapsed soaking time, the enzyme in the sample was inactivated by heating at 90°C for 5 min in a water bath (modified from Bhattacharya *et al*., 1998).

Physicochemical analyses

Peeling yield

Peeling yield was analyzed to determine the effectiveness of peeling solutions (chemical and enzymatic peeling) to loosen the skin from the flesh of the fruits compared to manual peeling. The weight of each mango was measured before and after the skin of the mangoes was peeled off. Then, peeling yield from each peeling method were expressed in percentage (%) (Aydin *et al.*, 2010).

$$\text{Peeling yield (\%)} = \frac{\text{Weight of whole fruit before peeling}}{\text{Weight of whole fruit after peeling}} \times 100$$

Peeling time

Peeling time was taken using an analog stopwatch (Durac, USA) to determine the efficiency of each peeling methods involved. Three persons were used to carry out the experiment and the same three persons were assigned to peel the mango fruits manually, chemically and enzymatically. The results taken was expressed in minute or second (Aydin *et al*., 2010).

Absorption of chemical and enzyme solution

The increase in whole weight of each 'Chok Anan' mango was used to determine the amount of enzyme solution absorbed by the fruit during the reaction. The initial weight of the fruit before and after the peeling process was taken. The fruit was drained before peel skin removal after washing under running tap water (Toker *et al*., 2003).

Penetration depth of sodium hydroxide (NaOH)

A penetration depth analysis of 'Chok Anan' mango was carried out to determine the depth of the chemical penetration into the flesh of the mango. The high penetration depth of NaOH refers to high diffusion of chemical into the fruit flesh which helps in easy peeling of the fruit skin. The mango was cut into two identical parts from the center (divided into half). A few drops of phenolphthalein solution (0.1%) were applied directly from outer skin to the center of the cut mango flesh (Figure 1) as an indicator. After formation of permanent pink color appeared,

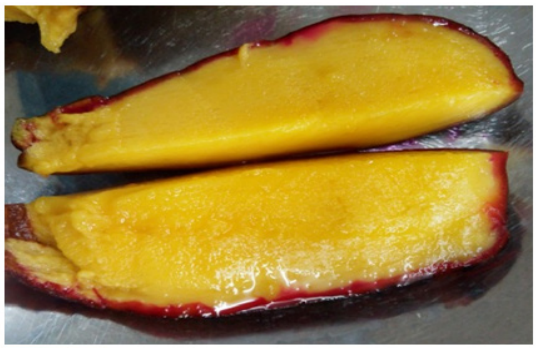

Figure 1. Penetration depth of NaOH analysis on 'Chok Anan' mango fruit

a magnifying glass was used to measure the depth of NaOH penetration (mm) (Kaleoglu *et al*., 2004).

Enzyme activities (Reducing Sugar analysis)

The Nelson-Somogyi (NS) for reducing sugars is widely used in measurements of carbohydrate activities against different polysaccharides. High level of reducing sugar present in pectinase solution refers to high enzymic activities. Diluted pectinase solution was reacted with 2 ml of copper reagent and heated for 10 min in a vigorously boiling water bath. Then, the heated pectinase solution was cooled under running water for 5 min. About 1 ml of arsenomelybdate reagent was added to the sample followed with dilution to 10 ml using a volumetric flask. Diluted pectinase solution was let to stand for at least 15 min and not more than 40 min before the absorbance was read at 520 nm using Lambda 25 UV/VIS spectrophotometer (Perkin-Elmer, Shelton, USA). The amount of reducing sugar was calculated using formula below (Southgate, 1976):

Amount of sugar in the sample,

$X_2 = X_1 \times$ DF of solution A $\times$ DF of solution B $\times$ DF of solution in tube

where,

X_1 = concentration of sugar from the standard curve

DF = dilution factor

Statistical analysis

One-way analysis of variance (ANOVA) at a significant level of $p<0.05$ was carried out. The triplicate data were analyzed using Minitab (Version 16.0) statistical package (Minitab Inc., PA, USA).

Table 1. Yield and peeling time of 'Chok Anan' mango using different peeling methods

Type of peeling method	Yield (%)	Peeling time (min)
Manual	86.01 ± 0.62^a	5.30 ± 0.26^b
Chemical	88.27 ± 1.44^a	6.49 ± 0.09^a
Enzymatic	86.68 ± 2.09^a	4.46 ± 0.11^c

Values in the column with different letters (a, b, c) were significantly different at $p<0.05$.

Results and Discussion

Peeling yield (%) and peeling time

Table 1 shows no significant difference ($p>0.05$) of peeling yield obtained from three different peeling methods. This shows that the alternative methods (chemical and enzymatic peeling) used may replace conventional manual peeling without decreasing or affecting the yield of mango flesh. Nevertheless, there was a significant difference ($p<0.05$) in peeling time between all peeling methods. Enzymatic peeling has the shortest duration of skin peeling at 4.46 min followed by manual peeling with 5.30 min. Meanwhile, the longest peeling method was chemical peeling with peeling time of 6.49 min. Enzymatic peeling has effectively reduced the time of peeling. Shorter time taken for enzymatic peeling showed that the method was more efficient compared to manual and chemical peeling.

The hot solution (NaOH) used in chemical peeling dissolved the epicuticular waxes in the epidermis by cleaving the α 1–4 bonds in the galacturonic units in pectin, then, release the skin (tomato) from the pericarp (Das *et al*., 2006; Rock *et al.*, 2012). However, due to the high temperature used in this study, which was at 95°C has ruptured the skin of the mango fruits into pieces which made it hard to completely remove the skin from the flesh. Hence, longer peeling time was needed compared to enzymatic peeling.

During enzymatic peeling; pectinase helps to degrade the pectin substances present in the cell walls of the mango fruits (Pretel *et al*., 2005; Pretel *et al*., 2007). The pectinase used in this study increased the peeling efficiency and improved the separation of skin from the flesh of mango fruits. Mechanistically, during enzymatic peeling; the network of the structural carbohydrates in the skin of the fruit is broken down as a result of hydrolysis by corresponding enzymes such as pectinases, cellulases and hemicellulases, respectively (Rock *et al*., 2012).

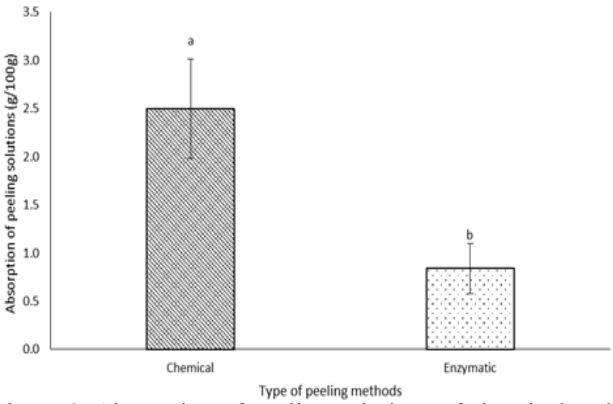

Figure 2. Absorption of peeling solutions of chemical and enzymatic peeling methods

As stated by Kashyap *et al.* (2001), pectinase is responsible for the degradation of long and complex molecules in the middle lamella and the primary cell walls of the plant cells. Pectin is located in the cell wall and it may be interlined with other structural polysaccharides and proteins to form insoluble proto-pectin (Kashyap *et al*., 2001; Pagan *et al*., 2005; Piatka *et al.*, 2010). In this study, heating at 95°C used for the purpose of pectinase inactivation. If a higher temperature than 40°C is used, the pectinase will denature and loses effectiveness during the soaking duration (Kasyap *et al*., 2001). Madden (2000) stated that in the citrus juice extraction, pectinase was inactivated to reduce cloudiness. Therefore, a heating method which involves high temperature of 90°C was meant for the denaturation of the pectinase (Madden, 2000; Jakób *et al*., 2009).

According to Pretel *et al.* (2008), there are several parameters that may affect the quality of the finished product and the success of peeling during enzymatic preparation. For examples, the physical characteristics of fruits, such as skin adherence and thickness are important factors which determine the enzymatic peeling efficiency (Pretel *et al.* 1997, 2001; Barriero *et al.*, 2007).

Absorption of peeling solutions

The efficiency of peeling methods can be determined by the uptake of the peeling solutions into the mango fruit. Figure 2 shows the absorption capacity of 'Chok Anan' mango fruit for both chemical and enzymatic peeling. According to Toker *et al*. (2003), the high absorption capacity helps in peeling efficiency. The chemical peeling method had significantly ($p<0.05$) the highest (2.50g/100 g) absorption of the peeling solution compared to enzymatic peeling with only 0.84g/100 g.

The preliminary study showed the different ranges of selected temperatures (80-95°C) used had significantly ($p<0.05$) affected the absorption of NaOH solution. Therefore, the temperature (95 oC) applied for the peeling solution in this study had strongly ($p<0.05$) affected the absorption of solution that led to the penetration of both NaOH and pectinase solution into the mango flesh. Kaleoglu *et al.* (2004) stated that the effect of temperature change is greater than a change in concentration. They explained that the penetration of chemical (NaOH) solution via diffusion and chemical reactions depends strictly on temperature.

Table 2. Chemical penetration of NaOH applied on 'Chok Anan' mango fruit

Type of peeling	Penetration depth of NaOH (mm)
Manual	NA
Chemical	0.45±0.02
Enzymatic	NA

NA= not applicable

For enzymatic peeling in this experiment, longer duration of soaking (2 h) has helped in the efficiency of skin peeling. As stated by Toker *et al.* (2003), the capacity of the fruit skin to absorb the enzyme solutions (combination of pectinase, cellulase and hemicellulase) as a function of temperature (20°C, 35°C, 50°C) and duration of soaking (20, 40, 60 min) is important for peeling efficiency. However, they also mentioned that this absorption capacity was also a function of peel thickness (<1mm, in the case of stone fruits), which relate to the same type of fruit used in this experiment.

Penetration depth of chemical (NaOH) solution

Table 2 shows the chemical penetration depth of NaOH through the skin and into the flesh of mango. During the soaking duration, the NaOH diffuses through the scoring mango fruits, hence, splitting the skin from the flesh. A complex process occurs during the soaking duration which involved diffusion and chemical reactions. According to Kaleoglu *et al*. (2004), the amount of NaOH residual and its penetration (0.15-0.76 mm) into the sample (hazelnuts) were considered in conjunction with peeling efficiency. In addition, they also stated that penetration of the chemical or lye solution was significantly affected by the time (soaking duration; 2 to 12 min) of the peeling.

Additionally, high temperature used which was at 95°C during the chemical peeling also gave a significant role in the release of the mango skin from the flesh itself. Similar mechanisms were found as exhibited in steam/hot water peeling due to high temperature may result in the formation of pressurized vapor under the skin forcing it to rupture

Table 3. Recyclability of pectinase in enzymatic peeling on 'Chok Anan' mango fruits by determination of reducing sugar analysis

Pectinase cycle	Absorbance at 520nm	Amount of reducing sugar (g/100mL)
Before cycle	0.63±0.11[a]	20.04±0.84[a]
Cycle 1	0.50±0.13[ab]	7.78±0.28[ab]
Cycle 2	0.48±0.28[b]	4.92±0.11[b]

Values in the column with different letters (a, b, c) were significantly different at $p<0.05$.

(Das *et al.*, 2006; Rock *et al.*, 2012). Furthermore, NaOH used in this study helped in the efficiency of the peeling process. Chemical solutions such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) has been used as a pretreatment agent at varying concentrations (8–25%) to depolymerize the external layer of tomato skin facilitating its splitting (Shi *et al*., 2000).

Enzyme activities (Reducing sugar analysis)

Enzyme activities are determined via reducing sugar analysis method. This method is simple and fast which can help in determining the enzyme activities by calculating the concentration of reducing groups released (Spagnuolo *et al*., 1999; Silva *et al*., 2005). Table 3 showed the enzyme activities by determining the amount of reducing sugar obtained in the peeling solution after each cycle of enzymatic peeling. The results from each cycle were determined by reading the absorbance value at 520 nm wavelength. Originally, pectinase activities of the solution before the peeling process was at 20.04±3.84g/100 mL, but, it decreased significantly ($p<0.05$) to 7.78±2.28g/100 mL on the second cycle and decreased further until the last cycle which at 4.92±3.11g/100 mL. From this experiment, a higher amount of reducing sugar in the original solution compared to the solution after cycle 1 and 2 showed high pectinase activities, which has helped in the efficient peeling of the mangoes' skin.

Conclusion

Enzymatic peeling is suggested as an alternative to manual or chemical peeling of mango fruits. The main advantages of this enzymatic peeling technology were good quality (physicochemical characteristics) of the final product, as well as no heat treatment involved. The pectinase solution can be recycled for two times, which can reduce the cost of the industry compared to chemical peeling, whereby, NaOH solution can only be used once throughout the peeling process. In contrast, chemical peeling involved harsh treatment (high temperature at 95°C) and increased the cost due to the need of a separate place or space to discharge the waste disposal of NaOH. Enzymatic peeling had significantly ($p<0.05$) reduced the time (4.46 min) of mango puree production compared to both manual (5.30 min) and chemical (6.49 min) peeling. The development of effective peeling methods for mango could be useful for the fruit processing industries.

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