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Vinegar production from pickled mango peel waste

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Abstract The pickled mango industry was found to reduce waste by fermenting pickled mango peel into vinegar. The results revealed that a 1:4 ratio of mango pickle peel to water resulted in the highest ethyl alcohol content production, with a significant difference ($p \leq 0.05$). Moreover, a 15 % (v/v) acetic acid culture showed significantly ($p \leq 0.05$) high acetic acid content. The produced pickled mango peel vinegar was then subjected to sensory evaluation and compared with commercial apple cider vinegar. Interestingly, the produced vinegar exhibited significantly ($p \leq 0.05$) higher aroma, taste, and overall acceptability compared to the commercial vinegar, although there were not significant differences in color and texture. Overall, this study represents a novel approach to vinegar production from pickled mango waste, contributing to waste reduction and environmental sustainability.

Keywords: Vinegar, Pickled mango peel, Waste, Value-added

Introduction

Vinegar is a liquid product resulting from the fermentation of a carbohydrate source, with a requirement of containing at least 3.75 to 5 %(w/v) acetic acid (Ho *et al.*, 2017). Vinegar, a fundamental ingredient in the culinary customs of European, Asia, and other regions, boasts a rich historical background that can be traced back to ancient civilizations. The term "vinegar" itself translates to "sour wine". For millennia, vinegar has been crafted and used for its ability to enhance and conserve food items, commonly found in salad dressings, marinades, and various dishes. It is also used as a cleaning agent (Hailu *et al.*, 2012). Vinegar can be produced from various carbohydrate sources such as amylaceous and sugary substrates using two consecutive fermentation processes. These processes involve alcoholic fermentation by yeast and acetic fermentation by acetic bacteria (Luzon-Quintana *et al.*, 2021). The properties of vinegar are influenced by the raw materials utilized in its creation. Acetic acid is the primary

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volatile compound found in vinegar, contributing to its distinct sour scent and taste. It also contains alcohol, acids, esters, aldehydes, and ketones among other volatile compounds (Ho *et al*., 2017). Natural vinegar is considered a more effective food additive compared to synthetic vinegar due to its essential amino acids derived from fruit sources and its purported medicinal properties for alleviating aches and gastric issues (Hailu *et al*., 2012). Its functional properties are well-known for their antimicrobial, antioxidant, nutritional, antitumoral, antidiabetic, and cardiovascular disease prevention qualities (Budak *et al*., 2014). The bioactive components include acetic acid, gallic acid, catechin, ephicatechin, chlorogenic acid, caffeic acid, ρ-coumaric acid and ferulic acid (Budak *et al*., 2014).

Currently, there has been a rise in the quantity of scholarly publications focusing on vinegar research (Luzon-Quintana *et al*., 2021). Vinegar can undergo fermentation using a variety of raw materials, including different fruits, fruit peels, and various agricultural waste materials. Raw materials like wine fruit, berries (i.e. apple, different berries, persimmon, strawberry), pineapple, cherry, orange, or banana, cider, alcohol, grain, malt, beer and honey have been reportedly used by Kulkarni (2015) and Luzon-Quintana *et al*. (2021). In the recent studies of Coelho *et al*. (2017), four fruit distinct varieties of fruit vinegars, including orange, mango, cherry and banana were examined. Their findings revealed that the antioxidant activity of these vinegars closely matched that of the respective fruits, and was significantly higher—ranging between 8 and 40 times—compared to the levels found in commercial cider vinegar.

Nowadays, there is a growing trend of increased waste generation from various industrial sectors (Chiemchaisri *et al*., 2007). For mango processing, 35-60%w/w of the fruit is discarded without undergoing any treatment, resulting in environmental concerns and economic setbacks. The by-products of the industrial mango processes are peel and seed, amount to 123,000 tons per year. Moreover, the fruit industry's by-product output is forecasted to rise from 2.10% to 2.60 % in the following year (García-Mahecha *et al*., 2023). Thus, there have been many various research explored to reuse and recycle the waste produced by different industries. In a recent study by Mongkontanawat *et al*. (2023), the cultivation of *S. cerevisiae* in fermented mango wastewater was explored as a means to produce β-glucan. Similarly, Roda *et al*. (2014) investigated the potential of pineapple waste in the production of vinegar. In addition, the pineapple peel vinegar displayed a substantial number of total phenols and showcased significant antioxidant properties (Kulkarni, 2015). Furthermore, Prisacaru and Oroian (2018) evaluated the utilization of banana peel waste for vinegar production. Giuffre *et al.* (2019) also investigated the process of creating vinegar from the by-products of bergamot (*Citrus bergamia*).

However, no study on vinegar production from pickled mango peel has yet been found. Hence, it was aimed to investigate the suitability of the ratio of pickled mango peel and water for producing wine by using *Saccharomyces cerevisiae*. Subsequently, the best condition was selected to further assess the impact of the amount of acetic starter on the production of vinegar. Lastly, various properties of the resultant product were analysed.

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Materials and methods

Materials

The pickled mango peel sourced from Woraporn Limited company in Chachoengsao province, Thailand, was then transferred to the laboratory and stored in a refrigerator at -20 °C prior to being used.

Strains and culture

Acetobacter pasteurianus TISTR 102 was sourced from the Microbiological Resources Center at the Thailand Institute of Scientific and Technological Research in Pathum Thani, Thailand. The cultures were grown in a coconut water broth (dextrose 1.00 g/l and yeast extract 0.10 g/l) which was sterilized at 121 °C for 15 minutes. This coconut water medium was then combined with 3 loops of acetic starter culture, incubated at 37 °C for 72 hours, and used as an inoculum. The *Saccharomyces cerevisiae* in Active Instant Dry Yeast (Proma) was purchased from Thongpitak Trading Limited Partnership in Thailand.

Physical, chemical, and microbiological properties of pickled mango peel determination

Different physical, chemical, and microbiological properties were examined. The physical properties underwent assessment for color parameters such as lightness (L), redness (a*), and yellowness(b*) using the Color meter ZE 2000 from Japan. For chemical properties, chemical composition such as moister content, protein content, lipid content, ash content, fiber content, and carbohydrate were determined following the method of AOAC (2005). Total soluble solids and pH were investigated using a hand refractometer (Atago, Japan) and pH meter (Subtex, Taiwan), respectively. The method of Iqbal *et al.* (2005) was used to examine the total phenolic compound content. In summary, a 3 ml solution was extracted with 30 ml of 80% ethanol and shaken for 24 hours. The resulting solution was filtered using Whatman No. 1 filter paper. Then, 50 ul of the filtrate was mixed with 950 ul of distilled water, 2 ml of folin-ciocalteu phenol reagent and 1.60 ml of 7.50% Na_2CO_3. The mixture was left to incubate for 2 hours at a temperature of 37 °C. Absorbance was assessed at 760 nm, followed by the calculation of phenolic compound concentration using gallic acid standard curve. For the determination of preservatives, the concentrations of sodium benzoate and developed vinegar were analyzed by the Institute of Food Research and Product Development at Kasetsart University, Thailand.

Microbiological properties analysis was conducted to determine the total viable count and yeast and mold count using PCA (plate count agar) medium and potato dextrose agar (PDA). The samples were cultured for 48 hours at 37ºC, following which the findings were reported as log CFU/ml.

Effect of the ratio between pickled mango peel and water on wine production

Five different ratios of pickled mango peel to water were prepared in 15-liter bottles, including 1:2, 1:3, 1:4, 1:5 and 1:6. The solutions were pasteurized at 60 °C for 30 minutes before adding 0.50 % w/v of active dry yeast. It was then mixed and incubated at a temperature of 37 °C for 9 days. Some chemical and microbiological properties were assessed every 3 days up to the 9^{th} day, including analyses of viable cell count, pH levels, total soluble solids, and phenolic compounds as previously outlined. The ethyl alcohol content was analysed using an Ebulliometer (Dujardin-Salleron, France).

Effect of the acetic acid starter concentration on vinegar production

The most effective method for maximizing ethyl alcohol production was selected for assessment in this section. All samples underwent pasteurization at 60 °C for 30 minutes. *A. pasteurianus* TISTR 102 was used at three distinct concentrations (5,10 and 15 % v/v), followed by an incubation period at 37 °C for 12 days. Monitoring of different chemical and microbiological properties was conducted every 3 days throughout the entire 12-day period. Viable cell count, pH, total soluble solid, and phenolic compounds were analysed as previously outlined. The total acidity of the samples throughout the fermentation process, measured in terms of acetic acid percentage, was determined through titration using 0.02 N NaOH until reaching a pH of 8.2. (AOAC, 2005).

Sensory evaluation

The best treatment was selected based on the significantly highest acetic acid fermentation. The vinegar solution underwent sedimentation with 0.5 % w/v bentonite for a duration of 9 days at a temperature of 37 °C. The pickled mango peel vinegar was then prepared for consumption by mixing honey and water in a ratio of 200:150:150 (vinegar: honey: water) (Boonsupa *et al*., 2017). The resulting vinegar as well as commercial apple cider vinegar (Heinz), were evaluated for sensory attributes (color, aroma, taste, texture, and overall liking) using a 9-point hedonic scale with 30 untrained panelists from the staff and students of the Department of Food Innovation and Business (Faculty of Agro-industrial Technology, Rajamangala University of Technology Tawan-Ok, Chanthaburi Campus, Chanthaburi, Thailand).

Statistical analysis

All experiments were performed in triplicate using different lots of samples. Analysis of variance (ANOVA) ($p \leq 0.05$) proceeded with the data. Following this, Duncan's multiple range test (DMRT) was utilized to distinguish significant differences among means within each experiment at a significance level of $\alpha = 0.05$, with the assistance of computer software (Helge, 2009).

Results

Physical, chemical, and microbiological properties determination

Initially, an assessment was conducted on the properties of the mango pickle peel waste. For color parameters, lightness (L), redness (a*), and yellowness (b*) were 60.44±0.36, 0.72±0.35, and 20.68±0.39, respectively. The chemical composition, moister content, protein content, lipid content, ash content, fiber content, and carbohydrate were 80.53±0.21, 3.11±0.05, 0.00±0.00, 3.75±0.09, 8.46±0.25, and 4.16±0.25%, respectively. Total soluble solid, pH, and phenolic compound were 20.00±0.00 °Brix, 3.23±0.02, and 6.89±0.20 mg/ml. respectively. For the microbiological properties, total viable count and yeast and mold count were 2.04±0.06 LogCFU/g and 0.36±0.23 LogCFU/g. Finally, the raw material did not contain detectable levels of sodium benzoate in the preservative determination.

Effect of the ratio between pickled mango peel and water on the wine production

The changes in viable cell count, pH, total soluble solid and ethyl alcohol content of the pickled mango peel wine samples as they undergo fermentation are illustrated in Figures 1 and 2, respectively.

The viable cell counts of six different ratios of pickled mango peel to water showed a significant increase (p≤ 0.05) at 3 days of fermentation, followed by a sharp decrease at the end of fermentation. Conversely, the pH level of all treatments continued to decline at the end of fermentation, following the same as all samples. The ratio of 1:6 had the highest significant viable yeast cell count. However, the pH levels of all treatments exhibited similar data (Figure 1).

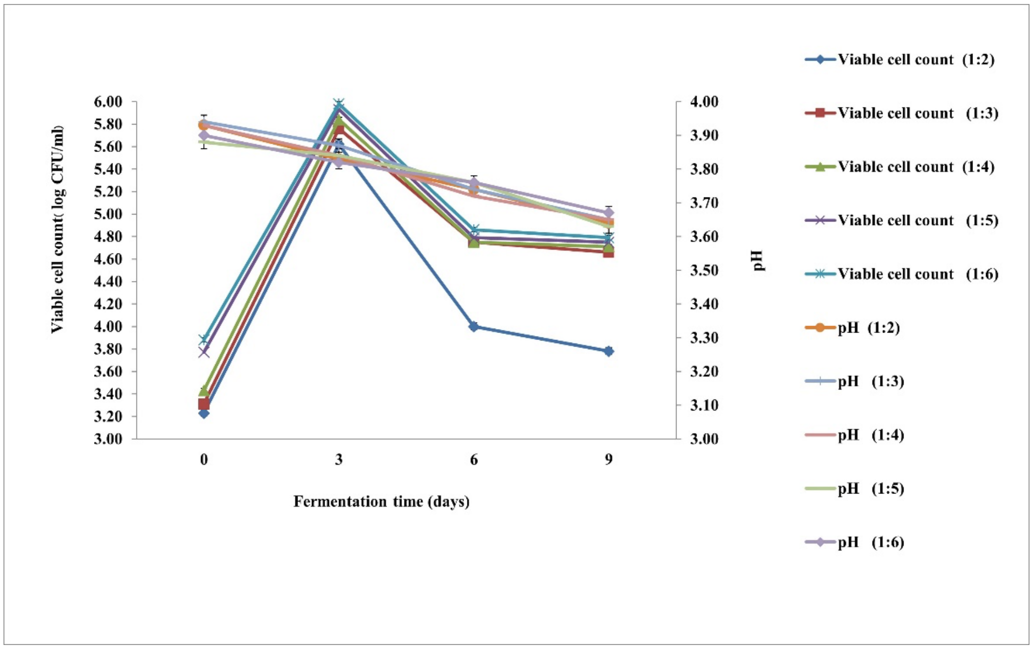

Figure 1. Changes in the viable cell count and pH level in pickled mango peel wine with fermentation by *S. cerevisiae* at different time intervals

For the total soluble solids and ethyl alcohol content, the reduction of total soluble solids of all treatments were detected when the fermentation time was longer (p≤ 0.05), whereas, the ethyl alcohol content increased in all treatments. The initial total soluble solids of 20 °Brix in all treatments decreased to approximately 5.00 °Brix by the end of fermentation. However, in the treatment with a 1:4 ratio, the ethyl alcohol content reached the highest level, showing significance (ρ≤ 0.05) at 10.78± 0.10 % (Figure 2).

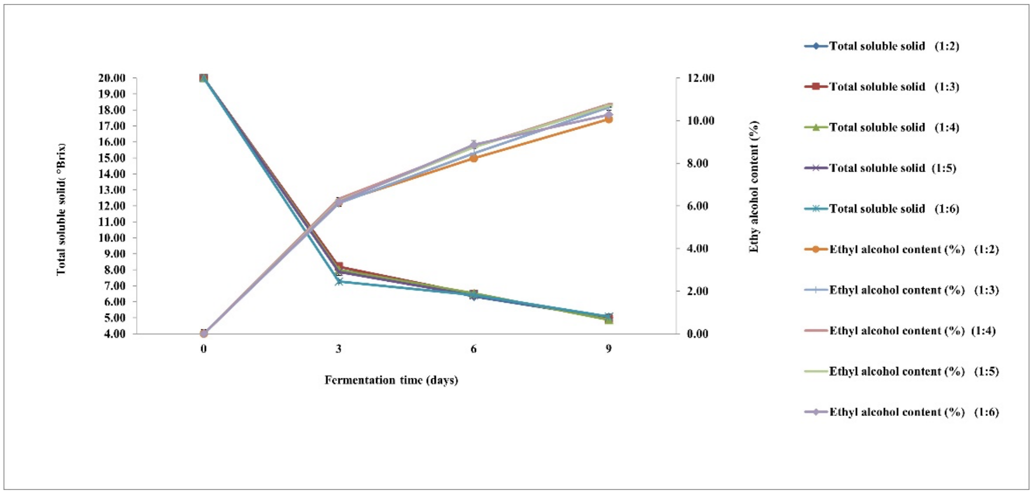

Figure 2. Changes in total soluble solid and ethyl alcohol content in pickled mango peel wine with fermentation by *S. cerevisiae* at different time intervals

Effect of the acetic acid starter concentration on vinegar production

Based on the ethyl alcohol content, the ratio of pickled mango peel to water was determined as 1:4 for further investigation into the effect of acetic acid culture concentration on vinegar production. Three concentrations of acetic acid culture including 5,10, and 15 %(v/v) were prepared and then fermented at 37 °C for 12 days to produce vinegar. Following this process, various chemical and biological properties were assessed as previously indicated. The results indicated that the number of viable cell counts increased after 6 days of fermentation and then decreased towards the end. On the other hand, the levels of pH of all treatments trend to reduce and significantly lowest at the end of fermentation. The 15 %(v/v) starter culture exhibited significantly ($\rho \leq 0.05$) the highest viable cell count but the lowest pH throughout the fermentation process, as shown in Figure 3.

The total soluble solids in all treatments decreased as the fermentation time increased ($p \leq 0.05$). Conversely, the acetic acid content significantly rose towards the end of the fermentation process. Moreover, the 15 % (v/v) starter culture exhibited significantly ($p \leq 0.05$) the highest acetic acid content at 9 days of fermentation, with a recorded value of 3.87± 0.03 % as presented in Figure 4.

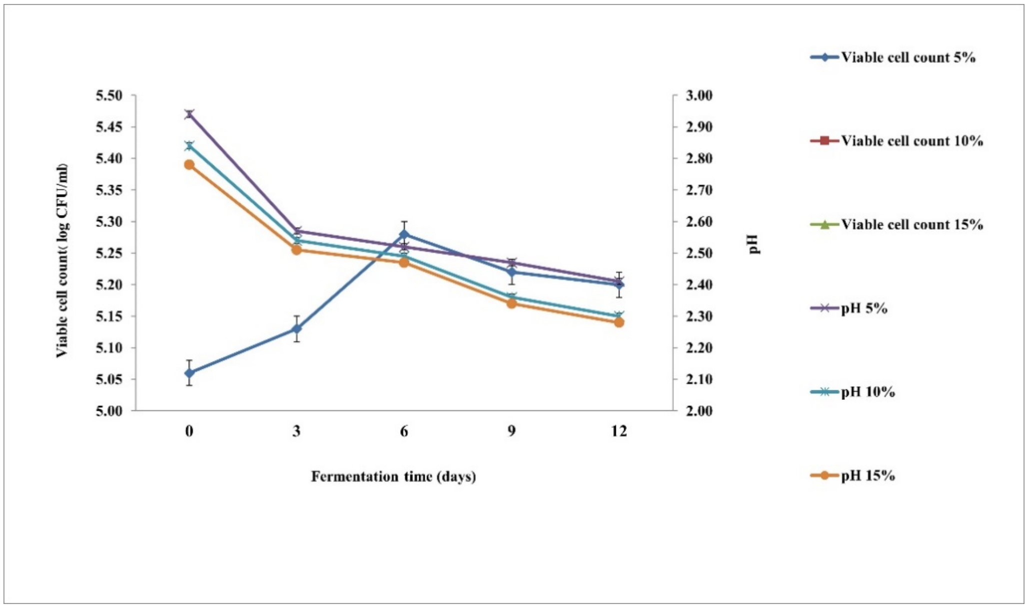

Figure 3. Changes in viable cell count and pH in pickled mango peel vinegar with fermentation by *A. pasteurianus* TISTR 102 at different time intervals

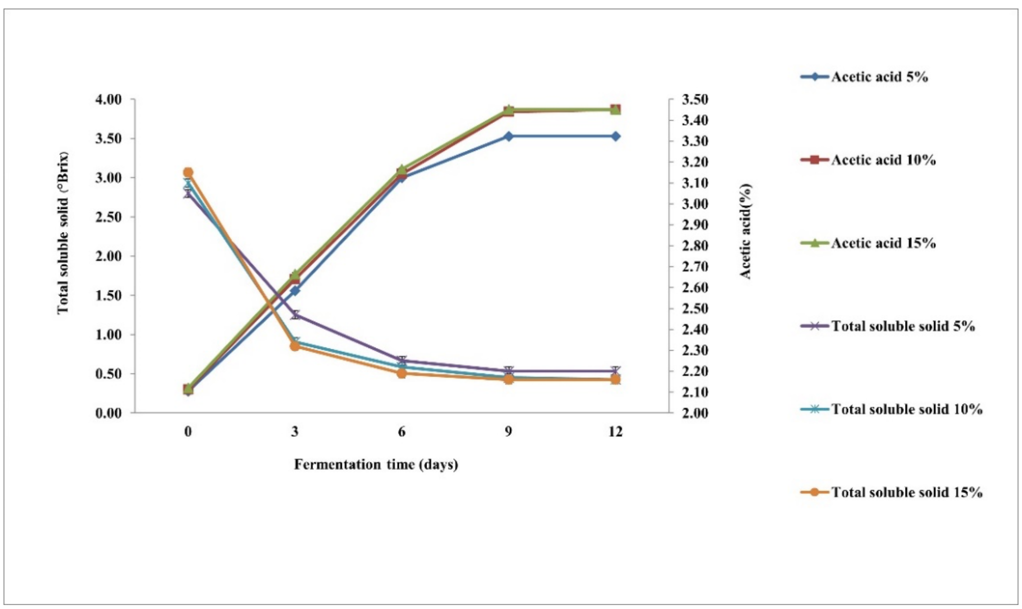

Figure 4. Changes in total soluble solid and acetic acid in pickled mango peel vinegar with fermentation by *A. pasteurianus* TISTR 102 at different time intervals

In terms of significantly high acetic acid content, the 15 %(v/v) acetic acid cultures demonstrated significance, leading to the selection of this treatment for vinegar production. The resulting vinegar underwent sedimentation with 0.50 % (w/v) bentonite at 37 °C for a duration of 9 days. The unique vinegar displayed a distinct green-yellow color, as illustrated in Figure 5.

Figure 5. The pickled mango peel vinegar produced in this study

The properties of produced pickled mango peel vinegar included lightness (L*), redness (a*), yellowness (b*), pH level, DPPH antioxidant activity (%), acetic acid content, total soluble solids, viable cell count as well as yeast and mold count were measured at 36.33±0.20, 2.65±0.02, -0.15±0.03, 2.76±0.01, 4.22±0.16%, 3.77±0.00, 3.00±0.00 °Brix, <10 CFU/ml, and <10 CFU/ml, respectively. Additionally, the developed that was produced did not identify the presence of sodium benzoate preservatives. In terms of sensory evaluation, the sensory attributes of the produced vinegar are shown in Figure 6. There was no significant difference ($p \leq 0.05$) found in color and texture when compared to the commercial vinegar. A significant difference ($p \leq 0.05$) was observed in the attributes of aroma, taste, and overall liking surpassing that of the commercially available product. The results indicated that the produced vinegar exhibited the highest aroma, taste, and overall liking scoring 6.73±0.74, 6.90±0.71, and 6.87±0.57(moderately liked), respectively.

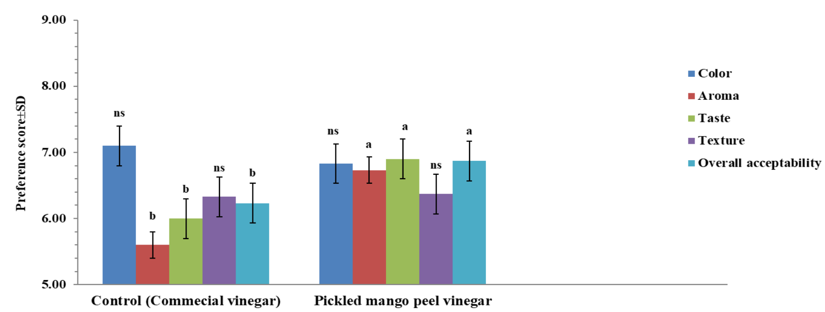

Figure 6. Sensory evaluation of pickled mango peel vinegar compared with the commercially available vinegar (Control)

Discussion

The properties of pickled mango peel waste included acidity, green-yellow color, and a high fiber content, with no lipid content detected. As mango peel is abundant in pectin and fiber, the highest fiber content was identified.

The effect of the ratio between pickled mango peel and water on wine production was investigated. The results revealed that the viable cell counts for six different ratios between pickled mango peel and water significantly increased ($p \leq 0.05$) after 3 days of fermentation, followed by a sharp decrease towards the end of fermentation. In contrast, the pH levels for all treatments continued to decline at the end of fermentation consistently. This observation suggests that *S. cerevisia*e utilized the sugar in pickled mango peel wine for cell synthesis and acid production without the need for additional nutrients or pH adjustments (Luzon-Quintana *et al*., 2021).

The decrease in total soluble solids across all treatments was observed with longer fermentation times ($p \leq 0.05$), while the ethyl alcohol content showed an increase in all treatments. The reason for this may be attributed to the ability of *S. cerevisiae* to convert glucose into ethyl alcohol, hence, the study sought to clarify the total soluble solids of ethyl alcohol content in both downward and upward directions. The results align with previous studies by Boonsupa *et al.* (2017) and Taweekasemsombut *et al*. (2021), which reported a decrease in glucose levels and an increase in ethyl alcohol content during the fermentation of cantaloupe vinegar and rice vinegar, respectively.

The ratio of pickled mango peel to water of 1:4 was selected for the investigation of the effect of acetic acid culture concentration on vinegar production. Three concentrations of acetic acid culture (5,10, and 15 % v/v) were prepared and then fermented at 37 °C for 12 days to produce vinegar. Following this process, various chemical and biological properties were analyzed. The results found that the number of viable cells counts increased after 6 days of fermentation in all of the treatments, followed by a decrease towards the end of the process. The pH levels decreased in all treatments and were significantly lowest at the end of fermentation. The total soluble solid decreased with longer fermentation periods ($p \leq 0.05$), whereas the level of acetic acid content exhibited a significant rise towards the end of fermentation. The rise in acetic acid content was attributed to the metabolism of acetic acid cultures, which utilized pickled mango peel vinegar for cell synthesis and acetic acid production. Therefore, the numbers of cells and acetic acid content increased, while the pH levels and total soluble solids decreased significantly. However, the decrease in cell numbers after 6 days of fermentation is a result of the toxicity of acetic acid and the lack of nutrients (Hailu *et al*, 2012).

The vinegar produced was subjected to sensory evaluation and compared with apple cider vinegar. The result showed a significant difference ($p \leq 0.05$) in the attributes of aroma, taste, and overall liking, which is higher than the commercially available vinegar. Nevertheless, there was no significant difference ($p \leq 0.05$) in the color and texture in comparison to the commercial vinegar. The improved sensory attributes observed in the study may be linked to the distinctive aroma and taste of pickled mango peel. Consequently, the analysis revealed a marked elevation in aroma, taste, and overall preference when compared with the commercially available vinegar.

Following the study outcomes, it is suggested that the ideal concentrations for pickled mango peel vinegar production are a ratio of 1:4 pickled mango peel to water and a 15 %(v/v) acetic acid culture. The pickled mango peel vinegar produced exhibits a distinct green-yellow color and retains the unique aroma of pickled mango peel. Interestingly, the produced vinegar possesses a stronger aroma, taste, and overall acceptability compared to the commercial apple vinegar, and no preservatives were detected. This study is provided valuable insight for the transformation of pickled mango peel waste into vinegar, contributing to waste reduction and environmental conservation.

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