EFFECT OF CONCENTRATION TIME ON THE QUALITY OF WOOD APPLE SYRUP (*LIMONIA ACIDISSIMA* L.)

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ABSTRACT:

Wood apple (*Limonia acidissima*), a characteristic fruit of Tra Vinh province, is rich in phenolic compounds, tannins, vitamin C, and other bioactive constituents. This study evaluates the effects of vacuum concentration time on the quality attributes of wood apple syrup. As concentration time increased from 10 to 25 minutes, water activity decreased (from 0.9078 to 0.8876) and vitamin C content declined (from 172.07 to 144.99 mg/100 mL), while total sugar (from 97.82 to 109.37 g/100 mL), total phenolic content (from 212.37 to 275.88 mg GAE/L), and tannin content (from 270.90 to 346.43 µg/mL) increased. Sensory evaluation indicated that the sample concentrated for 20 minutes achieved the highest overall acceptance, exhibiting desirable color, texture, aroma, and characteristic flavor. Under the examined conditions (70°C, 600 mmHg), a concentration time of 20 minutes yielded the most favorable balance of physicochemical and sensory qualities, suggesting an optimal processing parameter for wood apple syrup production.

Keywords: wood apple syrup, total phenolic content, Vitamin C, sensory evaluation

1. Introduction

Limonia acidissima L., commonly known as wood apple, is widely grown in Trà Vinh Province. The fruit is characterized by a hard outer shell and a soft brown pulp with a distinctive aroma and flavor. In addition, the fruit is known for its rich nutritional composition, containing carbohydrates and a wide range of bioactive compounds, including polyphenols, flavonoids, tannins, saponins, ascorbic acid, riboflavin, β-carotene, as well as essential vitamins and minerals (Pandey et al., 2014). Despite these advantages, the current utilization of wood apple remains limited. It is mainly consumed fresh or processed using simple traditional methods, which restrict its economic value and limit opportunities for wider market development. In recent years, there has been increasing interest in developing processed fruit products that are both convenient and shelf-stable. Among these, syrup is considered a practical option, as it is typically characterized by high soluble solids content and desirable physicochemical properties, which contribute to product stability during storage (Thi Le et al., 2021).

In syrup processing, the concentration step plays a

key role in determining final product quality. This process involves the removal of water to increase soluble solids and reduce water activity, thereby improving shelf life. However, processing conditions such as temperature, vacuum level, and concentration time can significantly influence both physicochemical and sensory properties. Excessive heating or prolonged processing may lead to the degradation of heat-sensitive compounds, particularly vitamin C, as well as undesirable changes in color and flavor (Shourove et al., 2020). In contrast, appropriate control of processing conditions, especially under vacuum, can help reduce thermal damage and better preserve product quality (Pham et al., 2024).

Studies on wood apple syrup remain limited, particularly regarding the combined effects of temperature and processing time. Therefore, this study aims to evaluate the influence of concentration time on the quality of wood apple syrup.

2. Materials and methods

2.1. Materials and equipment

Wood apples were obtained from local farmers in Vinh Long Province, Vietnam. Fruits were selected based on uniform weight (approximately 500-600 g), maturity stage, light-colored peel, and a characteristic mild aroma. After selection, the fruits were kept at room temperature for 2–3 days to reach full ripeness before processing.

The equipment used in this study included a four-digit analytical balance, blender, UV–Vis spectrophotometer (Genesys 20, Thermo Fisher Scientific), refractometer, pH meter, Brookfield viscometer (DV-E).

2.2. Syrup preparation

Ripe wood apples were washed thoroughly, and the pulp was separated from the shell. The pulp was mixed with water at a ratio of 1:1 (w/v), followed by enzymatic hydrolysis using a pectinase-cellulase mixture (1:1) at 0.4% (w/w). The mixture was incubated at 45°C for 1 h. After hydrolysis, the mixture was heated at 85°C for 10 min to inactivate the enzymes and then filtered to obtain the extract. The filtrate was formulated with 55% sugar, 0.6% citric acid, and 0.4% CMC prior to vacuum concentration.

2.3. Experimental design

The study evaluated the effect of concentration time on the quality of wood apple syrup under vacuum conditions. The experiment was conducted using a completely randomized design with four concentration times (10, 15, 20, and 25 min), each in triplicate, with a fixed sample volume of 500 mL. Concentration was carried out at 600 mmHg and approximately 70°C. Product quality was assessed based on physicochemical properties (total sugar, total phenolic content, tannin content, water activity, and vitamin C) and sensory attributes (color, aroma, taste, and texture).

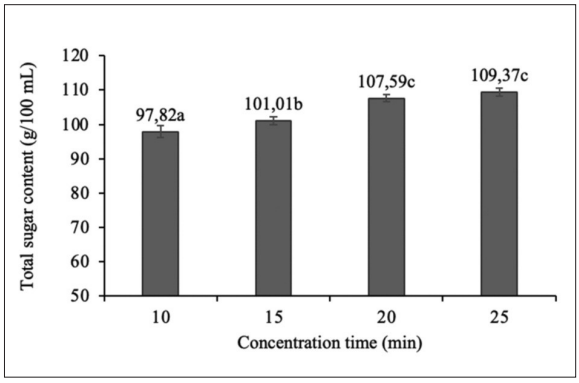
The data were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's test to determine significant differences between treatments at $p < 0.05$.

3. Results and discussion

3.1. Effect of concentration time on the total sugar content of wood apple syrup

Total sugar content is a key parameter in evaluating the quality of wood apple syrup, as it influences both nutritional value and sweetness, which affects consumer acceptance. During concentration, water evaporation increases the level of soluble solids, including sugars. Therefore, monitoring total sugar content is necessary to determine suitable processing conditions and the optimal concentration endpoint (Thi Le et al., 2021).

Figure 1. Effect of concentration time on the total sugar content of wood apple syrup



Values are mean ± SD (n = 3). Different letters indicate significant differences (p < 0.05).

The results show that the total sugar content of wood apple syrup increased progressively with concentration time. At 10 min, the total sugar content was 97.82±0.24 g/100mL; this value increased to 101.01±0.31 g/100mL at 15 min. A further increase was observed at 20 min (107.59±0.28 g/100mL), reaching the highest value of 109.37±0.27 g/100mL after 25 min of concentration. This trend is primarily attributed to water evaporation during heating, which reduces the system volume and consequently increases the concentration of soluble solids in the syrup. In addition to this concentration effect, the increase in total sugar content may also be associated with partial sucrose hydrolysis under thermal conditions, where sucrose is converted into glucose and fructose, contributing to higher measured sugar levels. A noticeable increase was observed between 10 and 20 min, indicating effective water removal without significant sugar degradation such as caramelization.

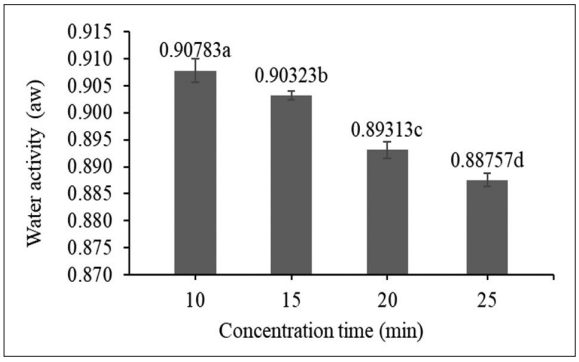
Similar behavior has been reported in fruit syrup systems. For example, an increase in total and reducing sugars due to sucrose hydrolysis has been observed in karonda syrup (Sabale et al., 2024), while gradual sucrose hydrolysis has also been reported in strawberry syrup during processing and storage (Singh et al., 2021). In addition, increased total soluble solids during heating have been reported in wild berry syrup (Minh Thuy, 2010), and higher soluble solids content has been associated with improved sensory quality in mulberry syrup (Tan Thanh, et al., 2022).

3.2. Effect of concentration time on water activity (aw) of wood apple syrup

Water activity (aw) is an important parameter used to describe the availability of free water for biochemical and microbial activities in food systems. It is widely applied to evaluate microbial stability, shelf life, and overall product quality. Controlling aw helps ensure that the product not only maintains desirable sensory characteristics but also remains microbiologically safe during storage (Santos et al., 2020).

Figure 2 illustrates the variation in water activity of the product as a function of concentration time (10, 15, 20, and 25 min). The results show a gradual decrease in aw with increasing concentration time, which can be attributed to continuous water evaporation during heating. At 10 min, the product exhibited the highest average aw = 0.9078± 0.0023a, which decreased slightly to 0.9032±0.0008b at 15 min. A more noticeable decrease was observed at 20 min (0.8931± 0.0015c), and the lowest value was observed at 25 min (aw = 0.8876±0.0012d). This reduction in aw is associated with the removal of free water and the simultaneous increase in soluble solids (°Brix) during concentration. Similar behavior has been reported in fruit syrup systems, where higher °Brix corresponds to lower water activity due to limited water mobility in concentrated sugar matrices (Santos et al., 2020; Thi Le et al., 2021). As the process continues, the product becomes more concentrated, leading to higher viscosity and improved physical stability. From a preservation standpoint, the decrease in aw is particularly important.

Figure 2. Effect of concentration time on the water activity of wood apple syrup



Values are mean ± SD (n = 3). Different letters indicate significant differences (p < 0.05).

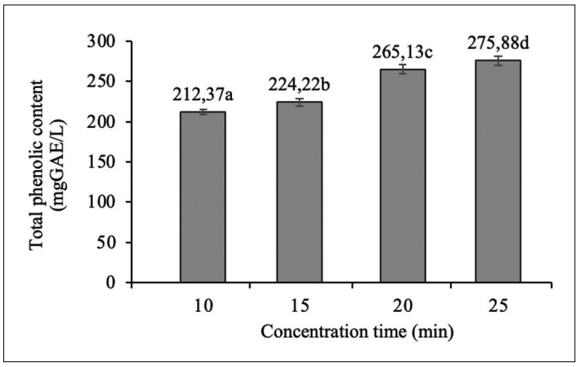
In this study, aw values dropped below 0.90 after 20 min, a level at which the growth of many spoilage microorganisms is significantly restricted (Santos et al., 2020). However, it should be noted that low aw does not completely prevent microbial survival, as some heat-resistant microorganisms may still persist under high-sugar conditions (Santos et al., 2020). Overall, these results demonstrate a strong dependence of water activity on total soluble solids,

indicating that concentration time simultaneously influences both compositional changes and microbial stability of the syrup.

3.3. Effect of concentration time on the total phenolic content of wood apple syrup

Total phenolic content in wood apple syrup increased progressively with concentration time, reflecting both the concentration of soluble solids and the possible release of phenolic compounds under thermal conditions (Tran et al., 2024). At 10 min, the phenolic content was 212.37±0.47 mgGAE/L, increasing to 224.22± 0.53 mgGAE/L at 15 min and 265.13±0.62mgGAE/L at 20 min. The highest value was observed at 25 min (275.88±0.58 mgGAE/L), corresponding to an increase of approximately 30% compared to the initial stage. This increasing trend is consistent with previous studies. For example, Tran et al. reported that phenolic content in red dragon fruit extract increased significantly during the early stages of vacuum concentration due to rapid water removal (Tran et al., 2024).

Figure 3. Effect of concentration time on the total phenolic content



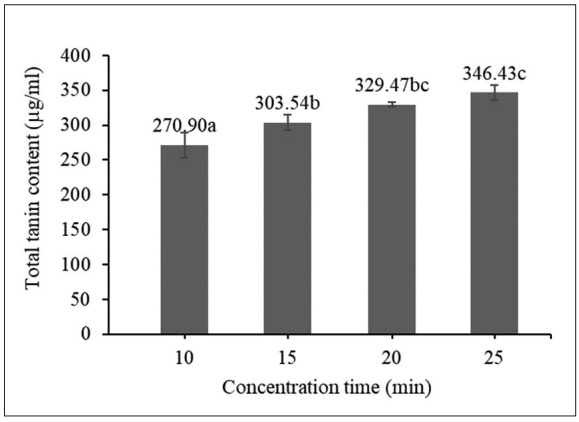
Values are mean ± SD (n = 3). Different letters indicate significant differences (p < 0.05).

Similarly, studies on fruit syrup systems such as strawberry syrup and other fruit-based syrups have shown that polyphenol content increases during concentration up to a certain level, particularly when water is reduced while phenolic compounds remain relatively stable (Sabale et al., 2024; Minh Thuy et al., 2014). These findings suggest that moderate thermal processing may enhance the extractability of phenolic compounds in pectin-rich systems, possibly by facilitating their release into the liquid phase.

3.4. Effect of concentration time on the total tanin content of wood apple syrup

Tannin content is an important indicator of the functional quality of wood apple syrup, as tannins are polyphenolic compounds associated with antioxidant and antimicrobial activities (Pandey et al., 2014). During thermal processing such as concentration, tannins may be affected by oxidation or precipitation, leading to a reduction in their content. Therefore, monitoring tannin levels is necessary to evaluate the retention of bioactive compounds in the final product.

Figure 4. Effect of concentration time on the total tanin content of wood apple syrup



Values are mean ± SD (n = 3). Different letters indicate significant differences (p < 0.05).

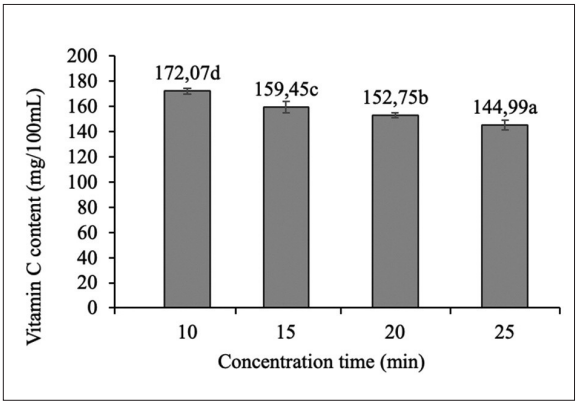
Figure 4 shows that tannin content increased significantly ($p < 0.05$) with increasing concentration time, from 270.90 ± 17.71 µg/mL at 10 min (a) to 346.43 ± 11.14 µg/mL at 25 min (c). A clear rise was observed from 10 to 15 min, where tannin content reached 303.54 ± 10.99 µg/mL (b). Further increases were recorded at 20 min (329.47 ± 2.95 µg/mL, bc) and 25 min (346.43 ± 11.14 µg/mL, c); however, the difference between these treatments was not statistically significant ($p > 0.05$). This trend is mainly attributed to the concentration effect during water evaporation, which leads to the accumulation of soluble compounds such as tannins. Similar behavior has been reported in fruit syrup systems, where processing conditions influence the retention

of bioactive compounds (Pham et al., 2024). In addition, thermal processing may affect polyphenolic compounds, resulting in changes in their measurable content depending on processing conditions (Shourove et al., 2020). Overall, the increase in tannin content appears to be primarily driven by concentration, while thermal conditions may also influence the stability of these compounds. This observation is consistent with the increase in total phenolic content, suggesting that concentration enhances the accumulation of polyphenolic constituents in the syrup.

3.5. Effect of concentration time on vitamin C of wood apple syrup

Vitamin C is highly sensitive to heat and oxygen and can be easily degraded during prolonged thermal processing. Therefore, monitoring vitamin C content throughout the concentration process is essential to evaluate nutrient losses, identify suitable processing conditions, and ensure that the syrup retains the characteristic biological value of the raw material (Shourove et al., 2020).

Figure 5. Effect of concentration time on Vitamin C of product quality



Values are mean ± SD (n = 3). Different letters indicate significant differences ($p < 0.05$).

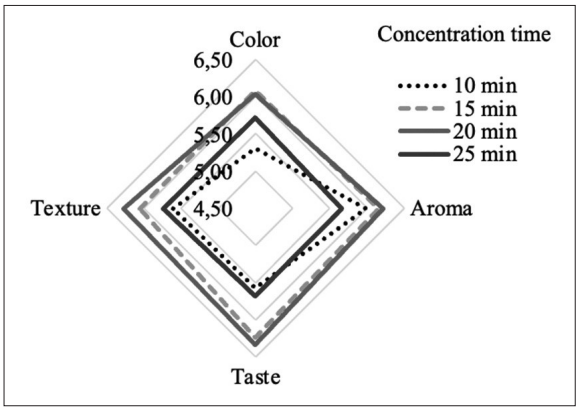
The vitamin C content of wood apple syrup decreased progressively with increasing concentration time. At 10 min, the vitamin C content was approximately 172.07 mg/100 mL, decreasing to 159.45 ± 0.56 mg/100 mL at 15 min and 152.75 ± 0.38 mg/100 mL at 20 min. After 25 min of concentration, the value further declined to 144.99 ± 0.41 mg/100 mL, corresponding to an overall reduction of about 16% compared to the initial stage. This decrease is mainly attributed to the sensitivity of vitamin C to heat and oxidation during thermal processing. Similar observations have been reported in previous studies. For example, Singh et al. reported a significant reduction in vitamin C content in strawberry syrup as heating time increased (Singh et al., 2021).

In addition, studies on red dragon fruit syrup under vacuum concentration have also shown a gradual decrease in vitamin C due to thermal exposure, although the rate of degradation may be lower compared to conventional heating (Pham et al., 2024). Despite this reduction, a considerable amount of vitamin C was retained after processing, indicating that the applied conditions limited excessive degradation. In contrast to the increasing trends observed for phenolic and tannin contents, vitamin C exhibited a decreasing pattern, reflecting the different thermal stability of bioactive compounds during concentration.

3.6. Effect of concentration time on sensory evaluation of wood apple syrup

Sensory attributes were monitored to observe changes in color, aroma, taste, and texture during processing, in relation to variations in product composition and structure. Evaluation at different concentration stages helps identify suitable conditions that preserve the characteristic properties of the raw material while maintaining consumer acceptability.

Figure 6. Effect of concentration time on the sensory evaluation of wood apple syrup



The sensory evaluation results showed that color, aroma, taste, and texture of wood apple syrup varied with concentration time. At 10 min, the syrup was characterized by a relatively light color (5.30 ± 0.12), a mild aroma (5.98 ± 0.15), an unbalanced taste (5.56 ± 0.11), and a thin consistency (5.60 ± 0.14). At 15 min, slight improvements were observed in all attributes, indicating progressive development of product quality. At 20 min, the product reached higher scores for all attributes, including color (6.15 ± 0.21), aroma (6.21 ± 0.18), taste (6.23 ± 0.19), and texture (6.05 ± 0.26), reflecting a more desirable combination of appearance, flavor, and consistency.

However, at 25 min, the sensory scores slightly decreased (color: 5.71 ± 0.17; aroma: 5.65 ± 0.15; taste: 5.68 ± 0.16; texture: 5.73 ± 0.18). This decline may be related to the loss of volatile aroma compounds and excessive concentration of sugars, which reduced the overall balance of the product. A similar trend has been reported in fruit syrup systems under prolonged heating conditions [12]. Overall, a concentration time of 20 min can be considered optimal, as it provides a balance between physicochemical properties (higher soluble solids and lower water activity), retention of bioactive compounds (phenolics and tannins), and acceptable loss of heat-sensitive nutrients such as vitamin C, resulting in the highest sensory acceptability.

4. Conclusions

Concentration time significantly affected both physicochemical and sensory properties of wood apple syrup. Increasing time led to higher total sugar (109.37±0.27 g/100mL), phenolic (275.88±0.58 mgGAE/L), and tannin contents (346.43 ± 11.14 µg/ml), while water activity (aw = 0.8876d ± 0.0012) and vitamin C decreased. Sensory quality improved up to 20 min but declined slightly at 25 min. Overall, a concentration time of 20 min provided the most suitable balance among physicochemical properties, stability, and sensory quality ■

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ẢNH HƯỞNG CỦA THỜI GIAN CÔ ĐẶC CHÂN KHÔNG ĐẾN CÁC ĐẶC TÍNH CHẤT LƯỢNG CỦA SIRO QUÁCH (*LIMONIA ACIDISSIMA*)

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TÓM TẮT:

Quách (*Limonia acidissima*), một loại trái cây đặc trưng của tỉnh Trà Vinh, giàu các hợp chất phenolic, tannin, vitamin C và nhiều hợp chất hoạt tính sinh học khác. Nghiên cứu này đánh giá ảnh hưởng của thời gian cô đặc chân không đến các đặc tính chất lượng của siro quách. Khi thời gian cô đặc tăng từ 10 đến 25 phút, hoạt độ nước giảm (từ 0,9078 xuống 0,8876) và hàm lượng vitamin C giảm (từ 172,07 xuống 144,99 mg/100 mL), trong khi tổng lượng đường (từ 97,82 lên 109,37 g/100 mL), tổng hàm lượng phenolic (từ 212,37 lên 275,88 mg GAE/L) và hàm lượng tannin (từ 270,90 lên 346,43 µg/mL) tăng. Kết quả đánh giá cảm quan cho thấy mẫu được cô đặc trong 20 phút đạt mức chấp nhận tổng thể cao nhất, với màu sắc, cấu trúc, hương và vị đặc trưng mong muốn. Trong điều kiện nghiên cứu (70°C, 600 mmHg), thời gian cô đặc 20 phút tạo ra sự cân bằng tối ưu giữa các đặc tính hóa lý và cảm quan, cho thấy đây là thông số phù hợp cho quá trình sản xuất siro quách.

Từ khóa: siro quách, polyphenol tổng số, Vitamin C, cảm quan.