Optimization of Acidulant Type and Concentration on the Physicochemical and Bioactive Characteristics of Purple Sweet Potato Sauce

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Abstract. Purple sweet potato is a promising raw material for functional food development due to its high anthocyanin content; however, its low natural acidity limits its suitability for sauce production. Optimization of acidulant type and concentration is therefore required to enhance physicochemical stability, bioactive retention, and sensory quality. This study aimed to optimize the effects of acidulant type and concentration on the physicochemical and bioactive of purple sweet potato sauce. This study used a nested research design with two types of acidifiers (lime and apple cider vinegar) at various concentrations (10%, 15%, 20%, and 25%) as research variables. The parameters observed were pH, water content, total titratable acid, total dissolved solids, dispersion, antioxidant activity, and anthocyanin.. The results showed that differences in the type and concentration of acidulant affected the physicochemical and functional properties of the sauce. Lime produced a lower pH value, while apple cider vinegar produced higher water content, total titratable acidity, total soluble solids, antioxidant activity, and anthocyanin content. The higher concentration of acidulant can lower pH and increase total acidity, increase the value of antioxidant activity, and anthocyanin stability. The highest antioxidant activity (88.33%) and anthocyanin content (123.89 mg/L) were observed in the apple cider vinegar treatment with a concentration of 25%.. Apple cider vinegar demonstrated greater potential than lime juice as an acidulant in purple sweet potato sauce formulation, particularly in improving functional properties. Appropriate selection of acidulant type and concentration is essential to obtain purple sweet potato sauce with optimal physicochemical quality and functional value.

Keywords: anthocyanin, antioxidant activity, acidifier, purple sweet potato sauce

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INTRODUCTION

Purple sweet potato (Ipomoea batatas L.) has gained considerable attention as a functional food ingredient due to its high anthocyanin content, which exhibits strong antioxidant activity and potential health-promoting effects, including anti-inflammatory, antidiabetic, and cardioprotective properties. Purple sweet potatoes have a purple pigment that gives them a selling point. Diversification of purple sweet potato derivative products, such as semi-solid sauces, is still limited. Purple sweet potato has a high total phenol content and high antioxidant activity(Rahmah et al., 2023). Anthocyanins are intriguing natural pigments with beneficial bioactivities and their colour is extremely susceptible to acidity variation (Liu et al., 2014)

Sauces are semi-solid food products generally derived from fruit, sugar, pectin, and acid. The acidity of a sauce plays a crucial role in determining gel formation, physicochemical stability, microbiological safety, color retention, and sensory quality (Gim, Sgroppo, and Sosa 2022). An appropriate acidity level can increase the formation of pectin networks and is able to stabilize anthocyanins, where anthocyanins are very sensitive to pH variations. Inappropriate acidity levels will result in a weak gel structure, color degradation, and decreased product acceptability. Therefore, raw materials with low natural acid content require the addition of acidifiers to achieve good product quality (Sohany et al. 2021). Purple sweet potatoes contain relatively low levels of organic acids compared to fruits which are generally used in sauce production. Previous studies on purple sweet potatoes have focused primarily on their antioxidant content, anthocyanin profile, and their application in bakery products, beverages, or snacks, while research related to their use as sauces is still relatively limited. So far, research on fruit-based sauces has focused on test parameters focused on physicochemical quality or sensory evaluation separately. Research related to bioactive compounds in sauces has not been widely observed, especially on the stability of these bioactive compounds (Rahman et al. 2024).

Furthermore, although acidulant addition is widely recognized as an effective strategy to control acidity and texture, limited information is available regarding the comparative effects of different natural acidulants and their concentration levels on the physicochemical behavior, bioactive retention, and sensory acceptability of purple sweet potato-based sauces (Eduardo et al., 2015). The interaction between acid type, dosage, anthocyanin stability, antioxidant activity, and consumer perception has not been systematically investigated. The lack of research related to the stability of bioactive compounds in sweet potato-based sauce products led to this study being conducted with the aim of optimizing the type and concentration of acidifiers to improve the physicochemical, and bioactive of purple sweet potato sauce. This study is expected to produce sauce products with functional bioactive compounds and optimization with the formulation of purple sweet potato sauce.

METHOD

MATERIALS

Purple sweet potatoes (*Ipomoea batatas* L.) were obtained from a local market in Malang and selected based on uniform size, maturity, and absence of physical damage or microbial spoilage. Lime fruit (Citrus aurantiifolia) comes from the local market in Malang and is used to make fresh lime juice, while apple cider vinegar is used as a second acidifier.. Granulated sugar, distilled water, Phenolphthalein, NaOH, distilled water, DPPH, KCl, HCl, Na-acetate, H2SO4 and K2SO4 indicators and other analytical-grade chemicals were used throughout the experiment.

RESEARCH DESIGN

This study used a nested design with two research variables, namely the type of acidulant and the amount of added concentration. The first variable is the type of acidulant lime (A1) and apple cider vinegar (A2). The second variable is the concentration of acidulant with four levels: 10% (K1), 15% (K2), 20% (K3), and 25% (K4) (v/w), resulting in 8 treatment combinations repeated 3 times.

RESEARCH PROCEDURS

Preparation of Purple Sweet Potato Sauce

Purple sweet potatoes were washed, peeled, sliced, and steamed for approximately 20 min until softened. The cooked samples were homogenized into puree using a blender. Sugar was added to achieve approximately 30 °Brix. The acidulants were then incorporated according to the experimental design. The mixture was heated at 90 ± 2 °C with continuous stirring until a semi-solid consistency was achieved. The sauce was cooled to room temperature.

Physicochemical Analysis

The physicochemical properties of purple sweet potato sauce were evaluated by measuring pH, moisture content, total titratable acidity (TTA), total soluble solids (TSS), and spreadability. The pH of each sample was measured at room temperature using a calibrated digital pH meter following standard AOAC procedures (AOAC, 2016). Water content testing using the oven drying method at a temperature of 105 °C until a constant weight is obtained (AOAC, 2016). Total titratable acidity was quantified by titration with 0.1 N NaOH and expressed as percentage of citric acid equivalent

(AOAC, 2016). Total soluble solids were measured using a digital refractometer and reported as °Brix (Ranganna, 2014). Spreadability was evaluated using the glass plate method by measuring the diameter of sample spreading under standardized load conditions, as described by Bourne (2002).

Bioactive Analysis
Antioxidant activity was evaluated using DPPH assay (Kim et al., 2025). Total anthocyanin content was measured by the pH differential method (Extracts, 2019).

Statistical Analysis
Statistical analysis was performed using analysis of variance (ANOVA) to determine the significance of differences among treatments. When significant effects were observed, mean comparisons were conducted using Tukey's honestly significant difference (HSD) test at a 95% confidence level ($p < 0.05$), following standard experimental data analysis procedures.

RESULTS AND DISCUSSION

The physicochemical and functional characteristics of purple sweet potato sauce formulated with different types and concentrations of acidulants were evaluated to determine their effects on product quality. The results of physicochemical analysis are summarized in Table 1, while functional properties are presented in Table 2.

Table 1. Physics Analysis

Sample	pH	Moisture Content (%)	Total Titratable Acidity (%)	Total Soluble Solids (Brix)
A1K1(lime juice 10%)	3,71±0,13$_{d}$	43,26±0,07$_{a}$	0,54±0,10$_{d}$	15,01±0,40$_{d}$
A1K2(lime juice 15%)	3,70±0,06$_{d}$	45,40±0,23$_{a}$	0,56±0.21$_{d}$	16,27±0,29$_{d}$
A1K3(lime juice 20%)	3,62±0,03$_{d}$	46,21±0,06$_{a}$	1,05±0,06$_{c}$	13,04±0,48$_{e}$
A1K4(lime juice 25%)	3,37±0,02$_{e}$	48,65±0,11$_{a}$	1,23±0,11$_{bc}$	18,24±0,70$_{c}$
A2K1(apple vinegar 10%)	4,83±0,05$_{a}$	49,41±0,11$_{a}$	1,38±0,15$_{abc}$	21,18±0,62$_{b}$
A2K2(apple vinegar 15%)	4,61±0,06$_{bc}$	52,80±10,38$_{a}$	1,56±0,29$_{ab}$	22,27±0,46$_{b}$
A2K3(apple vinegar 20%)	4,66±0,03$_{ab}$	47,78±0,09$_{a}$	1,31±0,01$_{b}$	24,31±0,21$_{a}$
A2K4(apple vinegar 25%)	4,48±0,03$_{c}$	49,47±0,13$_{a}$	1,68±0,03$_{a}$	22,01±0.68$_{b}$

Description: The same number followed by the same letter in the same column indicates an insignificant difference according to the Tukey α 5% test and ± is standart deviation.

The results showed that differences in the type and concentration of acidifier significantly affected the pH value of purple sweet potato sauce (as presented in Table 1). The addition of lime juice produced the lowest pH value, namely 3.37 in the A1K4 treatment (25% lime juice) to 3.71 in the A1K1 treatment (10% lime juice), while apple vinegar produced a higher pH value of 4.48–4.83. The lowest pH value was found in the A1K4 treatment (25% lime juice), and the highest pH value was found in the A2K1 treatment (10% apple vinegar).

This difference is associated with the characteristics of the organic acids present in each acidulant, where lime juice contains citric acid with stronger acid dissociation compared to acetic acid, which is dominant in apple cider vinegar. Increasing acidulant concentration tended to decrease the pH value, indicating an increase in product acidity. All pH values obtained were still within or close to the quality standard for sauce according to SNI 01-3546-1994 (pH 3–4), indicating acceptable acidity characteristics of the product.

As presented in Table 1, the type of acidulant did not show a statistically significant effect on moisture content; however, a clear increasing trend was observed with increasing acidulant concentration. The moisture content of sauces with lime juice ranged from 43.26–48.65%, while those with apple cider vinegar ranged from 47.78–52.80%. The highest moisture content was observed in treatment A2K2 (apple vinegar 15%).

The relatively higher moisture content in apple cider vinegar treatments is presumably related to the stability of acetic acid during heating and its ability to retain water within the sauce matrix. Increasing the acidifier concentration increases the water content of the acid. In sauce production, water plays a crucial role in determining the texture and gel structure, which are influenced by acid-pectin interactions.

Total titratable acidity (TTA) values increased significantly with increasing acidifier concentration, as shown in Table 1. The lime juice treatment showed TTA values ranging from 0.54–1.23%, while the apple cider vinegar treatment showed higher values ranging from 1.38–1.68%.The highest TTA value was observed in treatment A2K4 (apple vinegar 25%).

The addition of apple cider vinegar resulted in a higher total titratable acid value due to the acetic acid formed during fermentation, which contributes to greater and more stable acidity. The inverse relationship between total titratable acid and pH was clearly evident in this study, confirming that an increase in total acidity is associated with a decrease in pH. The pH of the sauces increased while the acidity decreased and Total acidity is an essential parameter for the preservation and acceptance of food products, similar to pH (Nemati & Ali, 2024).

The total soluble solids (TSS) values of purple sweet potato sauce are shown in Table 1. The sauce with lime added had a TSS value of 13.04 °Brix in the A1K3 treatment (20% lime juice) to 18.24 °Brix in the A1K4 treatment (25% lime juice), while the apple cider vinegar treatment produced a higher TSS value of 21.18–24.31 °Brix. The highest TSS value was found in the A2K3 treatment (20% apple cider vinegar).

According to SNI 01-3546-1994, the standard total dissolved solids for sauce is 25–40 °Brix. The use of apple cider vinegar resulted in a TSS value closer to the standard, while the other treatments did not meet the standard.Differences in TSS values are influenced by raw material composition, acidulant type, and the presence of sugars and other soluble components during processing. Total dissolved solids increase due to the presence of carbohydrates and proteins that break down into compounds. If total dissolved solids are low, this is due to the low carbohydrate and protein content in the sauce (Fisik et al., 2006).

Table 2. Functional Analysis

Sample	Antioxidant (%)	Anthocyanin (mg/L)
A1K1(lime juice 10%)	83,57±1,,64$_{b}$	43,25±0,72$_{g}$
A1K2(lime juice 15%)	86,39±0,54$_{a}$	52,54±0,38$_{f}$
A1K3(lime juice 20%)	86,19±0,51$_{ab}$	70,81±0,95$_{e}$
A1K4(lime juice 25%)	87,51±0,44$_{a}$	87,95±0,21$_{b}$
A2K1(apple vinegar 10%)	86,83±1,91$_{a}$	67,51±0,35$_{e}$
A2K2(apple vinegar 15%)	87,48±0,60$_{a}$	74,90±0,09$_{d}$
A2K3(apple vinegar 20%)	87,39±0,29$_{a}$	83,68±1,30$_{c}$
A2K4(apple vinegar 25%)	88,33±0,29$_{a}$	125,90±0,3,38$_{a}$

Description: The same number followed by the same letter in the same column indicates an insignificant difference according to the Tukey α 5% test and ± is standart deviation.

The antioxidant activity of purple sweet potato sauce ranged from 83.57–88.33%, as presented in Table 2. The lowest antioxidant activity was observed in treatment A1K1 (lime juice 10%), while the highest activity occurred in treatment A2K4 (apple cider vinegar 25%). Fresh, deep purple sweet potatoes have an antioxidant activity of 59.25%, higher than the antioxidant activity of light purple sweet potatoes, which is 56.64% (Dan et al., 2013).

An increase in acidulant concentration tended to enhance antioxidant activity. Lower pH conditions resulting from higher acid addition promoted the stability of anthocyanins, which are the main antioxidant compounds in purple sweet potatoes. Consequently, treatments with higher acid concentrations exhibited greater antioxidant activity.

Anthocyanin content in purple sweet potato sauce was significantly affected by acidulant type and concentration (as presented in Table 2). Lime juice treatments resulted in anthocyanin content ranging from 43.25–87.95 mg/L, while apple cider vinegar treatments produced higher values ranging from 67.51–125.90 mg/L. The highest anthocyanin content was obtained in treatment A2K4 (apple vinegar 25%).

Anthocyanin stability is strongly influenced by product acidity. Lower pH conditions favor the stability of the flavylium cation responsible for red–purple coloration, whereas higher pH conditions may lead to pigment degradation. Therefore, the use of apple vinegar at higher concentrations was more effective in preserving anthocyanin content in purple sweet potato sauce. Anthocyanin stability and degradation can be influenced by various factors, such as light, pH, temperature, sulfite, ascorbic acid, and others (Pati et al., 2019). Increasing the concentration of acidulant can increase antioxidant activity. Anthocyanin stability can be affected by pH, but higher antioxidants in the apple cider vinegar treatment indicate that antioxidant retention is not only influenced by pH but also by the characteristics of the acidifier, including its organic acid composition and the natural phenolic constituents present.

CONCLUSION

The type and concentration of acidifier significantly affected the physicochemical characteristics and functional properties of purple sweet potato sauce. Lime juice resulted in a lower pH value, while apple cider vinegar resulted in higher pH, water content, total titratable acidity, total soluble solids, antioxidant activity, and anthocyanin content. Increasing the acidifier concentration can increase the product acidity, improve anthocyanin stability, and increase antioxidant activity. Apple cider vinegar treatment with a concentration of 25% (A2K4) showed the most optimal functional properties characterized by the highest total titratable acidity, antioxidant activity, and anthocyanin content. Overall, apple cider vinegar showed greater potential than lime juice as an acidifier for purple sweet potato sauce formulation, in terms of functionality. These findings indicate that selecting the right type and concentration of acidifier is crucial to produce purple sweet potato sauce with optimal quality attributes and functional potential.

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