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Original Research Article

Performance of *Ipomoea batatas* L. Pigment as a pH Strip and Acid–Base Titration Indicator

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ABSTRACT

Purple sweet potato tubers (PSPT) are rich in anthocyanins, pigments that exhibit visible colour changes across varying pH levels. This study aims to evaluate the performance of PSPT pigment (PSPTP) as both a pH strip and a titration indicator for strong acid–strong base (SASB), strong acid–weak base (SAWB), weak acid–strong base (WASB), and weak acid–weak base (WAWB) titrations. PSPTP was extracted from dried tubers using medical-grade (MG) and analytical-grade (AG) ethanol, resulting in PSPTP-MG and PSPTP-AG, respectively. Strips were fabricated by immobilizing the extracts on cellulose paper, producing PSPTPIP-MG and PSPTPIP-AG. The strips were unchanged at pH 1–7, pale blue at pH 8–9, green at pH 10–12, and yellow at pH 13–14. PSPTPIP-MG was stable for 14 days, while PSPTPIP-AG lasted 21 days; both gradually faded but retained acceptable stability for up to 180 days. They demonstrated excellent sensitivity and produced clear results when applied to household chemicals. As titration indicators, PSPTP-MG and PSPTP-AG showed good precision (CV 0.09%–1.17%) across all titration types but were accurate only for SASB and SAWB titrations (recovery 102.4%–102.5%). In the analysis of pharmaceutical samples, SASB and SAWB titrations yielded acid concentrations of 0.042 M for PSPTP-MG and PSPTP-AG, and 0.041 M for phenolphthalein (PP) in unspiked samples, while spiked samples yielded 0.165 M with all three indicators. Overall, this study demonstrates that PSPTP performs effective as both a pH strip and a titration indicator, particularly for SASB and SAWB titrations.

Keywords: Pigment, pH Strip, Anthocyanin, Indicator, Acid-Base titration.

Introduction

Purple sweet potato (*Ipomea batatas L.)* tubers (PSPT) are nutrient-rich[1] and contain high levels of anthocyanins.[2–4] Anthocyanins *are widely used as natural food colorants*[5,6] and possess antioxidant, anti-inflammatory, antidiabetic, and anticancer activities.[7–9] They are soluble in water, methanol, and ethanol,[9–12] remain stable under acidic conditions,[11,13,14] and exhibit distinct colour changes in response to pH variations.[15] Therefore, anthocyanins from PSPT can be utilized as inexpensive, safe, and environmentally friendly pH indicators.[16–18] Under strongly acidic conditions, the pigments appear red and gradually change to pink, purple, blue, green, and yellow with increasing pH.[19,20] Several studies have reported the potential applications of purple sweet potato tuber pigment (PSPTP) in smart food packaging systems,[21–23] as pH indicators,[19] and as titration indicators.[6,20,24,25] pH indicator films consist of pH-sensitive pigments embedded in solid matrices,[26] such as sol–gel matrices, glass beads, and membranes,[18] which serve to immobilize the pigment.[26] Similarly, pH strips contain pH-sensitive pigments supported on solid matrices, including cellulose[27] or plain white computer paper,[28] and are likewise designed to immobilize the pigment.[26] pH indicator films based on natural pigments have been widely reported for smart food packaging systems; however, their application on paper-based strips has not been extensively investigated. In Indonesian junior and senior high schools, pH strips or indicator papers are commonly used in chemistry experiments. Therefore, these materials must be widely available, easily accessible, and inexpensive. The application of PSPTP as an acid–base indicator has been studied.[19] In the study, fresh PSPTP extracted using medical-grade ethanol was immobilized onto filter paper, and its sensitivity, stability, and applicability to real samples were evaluated. The authors reported that the resulting pH indicator paper exhibited good sensitivity but limited stability.[19] Therefore, improving its stability is necessary. The stability of PSPTP-based pH indicator paper (pH strips) can be enhanced in two ways: by employing analytical-grade ethanol as the extraction solvent and by using dried PSPTP. Beyond its application in the fabrication of pH strips, PSPTP has also been employed as a titration indicator.[6,25] Although its use as a titration indicator has been reported,[29] it has thus far been limited to the quantification of hydrochloric acid, leaving its broader applicability unexplored.

In this study, anthocyanin pigment was extracted from dried PSPT using medical-grade ethanol (PSPTP-MG) and analytical-grade ethanol (PSPTP-AG). The novelty of this work lies in the immobilization of PSPTP-MG and PSPTP-AG onto cellulose paper to fabricate pH strips. In addition, both extracts were employed as titration indicators for strong acid – strong base (SASB), strong acid – weak base (SAWB),

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weak acid – strong base (WASB), and weak acid – weak base (WAWB) systems. The objective of this study was to evaluate the performance of PSPTP as both a pH indicator strip and a titration indicator across these acid–base titration types.

Materials and Methods

Chemicals and equipment
The chemicals used in this study included analytical-grade ethanol (96%, Merck, Indonesia), medical-grade ethanol (95%, One Med, Indonesia), distilled water, hydrochloric acid (HCl, 37%, Merck, Indonesia), sodium hydroxide (NaOH, 99%, Merck, Indonesia), ammonia solution (NH_3, 25%, Merck, Indonesia), oxalic acid dihydrate (99.5%, Merck, Indonesia), cellulose-based filter paper (fine pores, Indonesia), red litmus paper, and blue litmus paper. Standard glassware (Pyrex, Indonesia), rotary evaporator (Buchi Rotavapor R-210), and a pH meter (Mediatech P-2Z–B1900126, Indonesia) were used as the equipment in this study.

Collection of purple sweet potato tubers (PSPT)
PSPT were purchased in May 2024 from Oesapa, a local market in Kupang City, Timor, East Nusa Tenggara-Indonesia (10°08'34.8"S 123°39'12.7"E).

Preparation of purple sweet potato tuber for extraction
PSPT was prepared following previously reported procedure.[20,29] Fresh PSPT was thoroughly washed, cleaned, thinly sliced, dried, and blended.[20]

Pigment extraction from purple sweet potato tubers
A total of 200 g of finely ground samples was macerated in 600 mL of analytical-grade ethanol under acidic conditions (with the addition of 1 M HCl) for 24 hours.[20] The extracts were then concentrated to 250 mL using a rotary evaporator at reduced pressure. The same procedure was repeated using medical-grade ethanol. The extract obtained with medical-grade ethanol was referred to as PSPTP-MG, whereas the extract obtained with analytical-grade ethanol was referred to as PSPTP-AG. PSPTP-MG and PSPTP-AG were subsequently used to produce pH indicator strips and were also applied as titration indicators for SASB, SAWB, WASB, and WAWB titrations.

Manufacture of PSPTP indicator paper (PSPTPIP)
PSPTP-MG was placed in a glass container, and filter paper strips (1 × 4 cm) were soaked in it for 24 hours, then removed and air-dried.[27] The same procedure was applied to PSPTP-AG. The resulting pH indicator papers were referred to as PSPTP-MG indicator paper (PSPTPIP-MG) and PSPTP-AG indicator paper (PSPTPIP-AG). PSPTPIP-MG and PSPTPIP-AG were subsequently used in the following tests.

Performance evaluation of PSPTPIP
PSPTPIP characteristic test
Solutions with pH 1 - 6 were prepared by diluting 1 M HCl with distilled water. Solution with pH 7 was prepared using distilled water. Solutions with pH 8 - 14 were prepared by diluting 0.1 M NaOH with distilled water. A volume of 1 mL each of the solutions with pH values ranging from 1 to 14 was placed on a drip plate. A sheet of PSPTPIP-MG was then immersed in each solution, and the resulting colour change was recorded.[28] The colour characteristics of PSPTPIP-AG were evaluated using the same procedure.

PSPTPIP stability and sensitivity test
The colour stability of PSPTPIP-MG and PSPTPIP-AG was evaluated by storing the pH strips in a polymer-based container and kept in a dark room at 25 - 30°C. Observations were made at intervals of 0, 3, 7, 14, 21, 30, 60, 90, 120, 150, and 180 days. Following the colour stability test, a sensitivity test was conducted across a pH range of 1–14, using the same procedure as described above.[30]

Application of PSPTPIP in determination of acid-base properties
After 180 days of storage, PSPTPIP-MG and PSPTPIP-AG were employed to determine the acid–base properties of household chemicals, including lime, vinegar, sprite, bath soap, baking soda, detergent, and lime betel.[28]

Comparison of PSPTPIP with standard indicators
PSPTPIP-MG and PSPTPIP-AG were tested for their colour characteristics across a pH range of 1 to 14. The same procedure was used for red and blue litmus paper indicators.[30]

Standard solution preparation for titration
The preparation of standard solutions for titration followed the previously reported procedure.[20]

Sample preparation for titration
The strong acid sample used was a pharmaceutical dosage form (Pharm DF), and the weak acid sample was table vinegar (VNG). Each sample was prepared in two ways: as an unspiked sample (without spike) and as a spiked sample. An unspiked sample is the original sample to which no standard analyte has been added. A spiked sample is prepared by adding a known amount of standard analyte at a specified concentration to the original sample.
Pharm DF without spike (Pharm DF-WS): One tablet of Pharm DF was smashed, dissolved, filtered, and diluted to 100 mL with distilled water in a volumetric flask.[29]
Pharm DF spiked (Pharm DF-S): One tablet of Pharm DF was smashed, dissolved, filtered, and transferred to a 100 mL volumetric flask, then 1 mL of concentrated HCl was added and diluted to 100 mL with distilled water.[29] This resulted in a 0.1206 M solution of Pharm DF-S.[20]
VNG without spike (VNG-WS): Exactly 1 mL of VNG was placed in a 100 mL volumetric flask, diluted to a volume of 100 mL with distilled water.[20]
VNG spiked (VNG-S): Exactly 1 mL VNG was placed in a 100 mL volumetric flask, then 1 mL of concentrated acetic acid (CH_3COOH) was added, and diluted to a volume of 100 mL with distilled water. This resulted in a 0.1745 M solution of VNG-S.[20]

Acid-base titration
Strong acid-strong base (SASB) titration: In this titration, a sample containing a strong acid (HCl) was titrated with a strong base solution (0.1030 M NaOH). Pharm DF-WS (10 mL) was placed in a titration flask, 3 drops of PSPTP-MG were added, and titrated with standard NaOH. Titration was carried out until the PSPTP-MG changes from pink to blue. The same procedure was carried out using PSPTP-AG and phenolphthalein (PP). The same method was carried out for Pharm DF-S.[29]
Strong acid-weak base (SAWB) titration: In this titration, a sample containing a strong acid (HCl) was titrated with a weak base solution (0.1029 M NH_4OH). Pharm DF-WS (10 mL) was placed in a titration flask, 3 drops of PSPTP-MG were added, and titrated with standard NH_4OH. The titration procedure was carried out as in SASB titration.[20]
Weak acid-strong base (WASB) titration: In this titration, a sample containing a weak acid (CH_3COOH) was titrated with a strong base solution (0.1030 M NaOH). VNG-WS (10 mL) was placed in a titration flask, 3 drops of PSPTP-MG were added, and titrated with standard NaOH. The titration procedure was carried out as in SASB titration.[20]
Weak acid-weak base (WAWB) titration: In this titration, a sample containing a weak acid (CH_3COOH) was titrated with a weak base solution (0.1029 M NH_4OH). VNG-WS (10 mL) was placed in a titration flask, 3 drops of PSPTP-MG were added, and titrated with standard NH_4OH. The titration procedure was carried out as in SASB titration. All titrations were performed seven times to evaluate the precision and accuracy of PSPTP-MG and PSPTP-AG as indicators for SASB, SAWB, WASB, and WAWB titrations, and to determine the acid concentration in the samples.

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Statistical analysis
All data were expressed as mean ± standard deviation (SD). Coefficient of variation (CV), and recovery (R) were determined using Microsoft Excel 2016. Precision was analyzed using the formula of coefficient of variation, CV (%), and accuracy was analyzed using the formula of recovery (%).[20,29]

Results and Discussion

Indicator paper of PSPTPIP
This indicator was prepared by immobilizing PSPTP-MG and PSPTP-AG on cellulose paper via adsorption,[27] resulting in PSPTPIP-MG and PSPTPIP-AG. Both indicator papers were pink (Figure 1).

Characteristic of PSPTPIP
The colour change patterns of PSPTPIP-MG and PSPTPIP-AG (in the paper form) in solutions with pH 1–14 is shown in Figure 2. Both PSPTPIP materials exhibited the same behaviour: they remained pink at pH 1–7, turned pale blue at pH 8–9, pale green at pH 10–11, deep green at pH 12, and yellow at pH 13–14, which is attributed to the immobilized anthocyanins that respond to changes in environmental pH. In comparison, the colour change patterns of PSPTP-MG and PSPTP-AG (in pigment form) in solution over the same pH range differed slightly: they were red at pH 1–2, pink at pH 3–6, purple at pH 7, blue at pH 8–9, green at pH 10–11, and yellow at pH 12–14 (Figure 3).[20] When comparing PSPTP and PSPTPIP in this study, PSPTP exhibited a clearer response than PSPTPIP. For example, at pH 7, PSPTPIP-MG and PSPTPIP-AG showed no colour change, whereas PSPTP-MG and PSPTP-AG showed a purple colour.[20] The colour change from pink to purple in PSPTPIP could not be observed in this study, which may be due to the suboptimal deprotonation of the immobilized anthocyanins (flavylium cation species, AH^+, to quinoidal base species, A) on cellulose paper.[31] However, this observation differs slightly from previous reports suggesting that immobilizing plant pigments on cellulose results in a clearer colour change.[27,32]

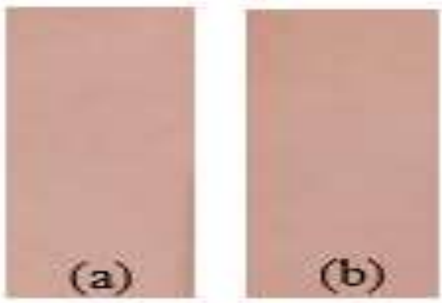

Figure 1: Purple sweet potato tuber pigment indicator paper (PSPTPIP). (a) PSPTPIP-MG (b) PSPTPIP-AG

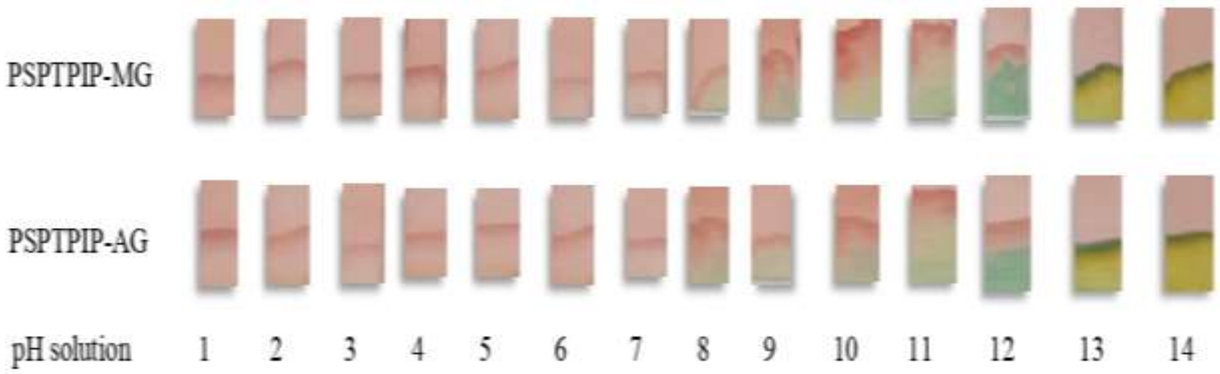

Figure 2: Colour characteristics of purple sweet potato tuber pigment indicator paper (PSPTPIP): PSPTPIP-MG and PSPTPIP-AG

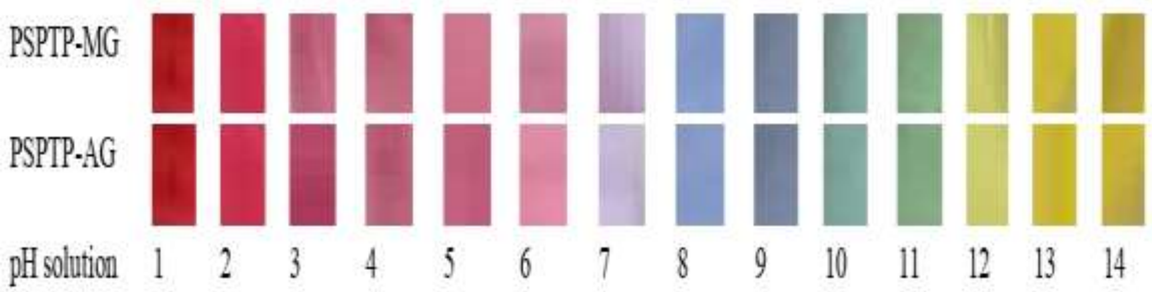

Figure 3: Colour characteristics of purple sweet potato tuber pigment (PSPT): PSPTP-MG and PSPTP-AG ([20])

Stability of PSPTPIP
The stability of PSPTPIP-MG and PSPTPIP-AG was evaluated based on colour stability during storage (Table 1). PSPTPIP-MG remained stable for 14 days before fading, whereas PSPTPIP-AG remained stable for 21 days, indicating that PSPTPIP-AG has higher stability. Previous studies on indicator paper produced from the immobilization of fresh PSPTP-MG reported stability for only 3 days.[19] Therefore, the improved stability observed in this study is likely due to the use of dry samples. These results also highlight the influence of ethanol grade as an extraction solvent on the stability of PSPTPIP.

Sensitivity of PSPTPIP
The sensitivity of PSPTPIP-MG and PSPTPIP-AG was evaluated based on their colour response in solutions with pH 1–14, as presented in Table 2. Both PSPTPIP-MG and PSPTPIP-AG showed good sensitivity, producing clear colour changes. Although, PSPTPIP-MG had lower colour stability than PSPTPIP-AG (Table 1), it still produced a clear colour change comparable to PSPTPIP-AG. Figure 4 shows the colour changes of the indicators across several pH ranges after specific storage periods. These findings demonstrated that PSPTPIP exhibits higher sensitivity than previously reported.[19]

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Table 1: Colour stability of purple sweet potato tuber pigment indicator paper (PSPTPIP)

Storage time (day)	Colour Stability of PSPTPIP-MG	Picture	Colour Stability of PSPTPIP-AG	Picture
1	Pink		Pink	
3	Pink *		Pink *	
7	Pink *		Pink *	
14	Pink *		Pink *	
21	Faded pink		Pink *	
30	Faded pink *		Faded pink	
60	Very faded pink *		Faded pink *	
90	Very faded pink		Faded pink *	
120	Very faded pink*		Faded pink *	
150	Very faded pink*		Faded pink *	
180	Very faded pink*		Faded pink *	

Remarks: * colour does not change

Table 2: Colour response of purple sweet potato tuber pigment indicator paper (PSPTPIP)

Storage time (day)	Sensitivity of PSPTPIP-MG and PSPTPIP-AG				
	pH 1-7	pH 8-9	pH 10 -11	pH 12	pH 13-14
1	Pink	Pale blue	Pale green	Deep green	Yellow
3	Pink	Pale blue	Pale green	Deep green	Yellow
7	Pink	Pale blue	Pale green	Deep green	Yellow
14	Pink	Pale blue	Pale green	Deep green	Yellow
21	Pink	Pale blue	Pale green	Deep green	Yellow
30	Pink	Pale blue	Pale green	Deep green	Yellow
60	Pink	Pale blue	Pale green	Deep green	Yellow
90	Pink	Very pale blue	Very pale green	Deep green	Yellow
120	Pink	Very pale blue	Very pale green	Deep green	Yellow
150	Pink	Very pale blue	Very pale green	Deep green	Yellow
180	Pink	Very pale blue	Very pale green	Deep green	Yellow

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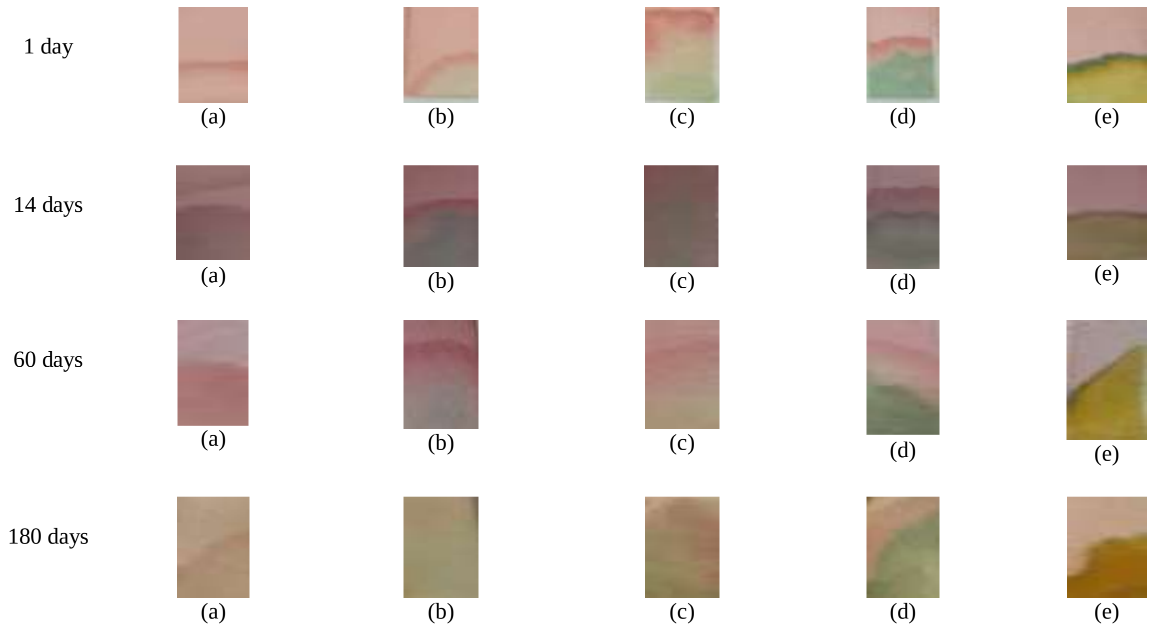

Figure 4: Colour response of purple sweet potato tuber pigment indicator paper (PSPTPIP): PSPTPIP-MG and PSPTPIP-AG based on storage time in solutions (a) pH 1-7, (b) pH 8-9, (c) pH 10-11, (d) pH 12 and (e) pH 13-14

In this study, PSPTPIP retained a clear response for up to 180 days of storage, whereas earlier reports demonstrated stability for less than 30 days.[19]

Comparison of PSPTPIP with standard indicator paper

The comparison of PSPTPIP-MG and PSPTPIP-AG with red and blue litmus papers was evaluated based on their colour response in solutions with pH 1–14 (Table 3). PSPTPIP-MG and PSPTPIP-AG exhibited broader colour changes than litmus papers. Red litmus paper changes colour from red to blue only in solutions with pH 8–14, while blue litmus paper changes from blue to red only in solutions with pH 1–4, which is different from PSPTPIP-MG and PSPTPIP-AG. The immobilized anthocyanins enabled broader colour changes over a wider pH range. Therefore, PSPTPIP-MG and PSPTPIP-AG can serve as effective pH indicators, potentially replacing litmus paper.

Application of PSPTPIP in determining acid-base properties of household chemicals

After 180 days of storage, PSPTPIP-MG and PSPTPIP-AG were employed to assess the acid–base properties of several household chemicals, as presented in Table 4. The indicator papers remained pink (no colour change) in acidic samples with pH 2.4–3.6, and changed to blue, green, or yellow in basic samples with pH 8.0–12.4 (Table 4). These results confirmed that PSPTPIP-MG and PSPTPIP-AG can reliably indicate the acid–base characteristics of the tested samples, and are consistent with previous reports.[19]

Precision of PSPTP as indikator for SASB, SAWB, WASB, and WASB titrations

The precision of PSPTP-MG and PSPTP-AG as SASB, SAWB, WASB, and WASB titration indicator was expressed as a coefficient of variation, CV (%).[29] The CV of this titration was determined based on the NaOH volume for seven replicates and is presented in Figure 5 and Table 5. The results showed that the CV values obtained in all types of titrations using the three indicators did not exceed 2%, CV ranged from 0.09% to 1.17%. These findings indicate that PSPTP-MG and PSPTP-AG exhibit good precision as titration indicators. This finding aligns with previous reports, in which the CVs of PSPTP-MG and PSPTP-AG as indicators ranged from 0.16% to 1.17%.[20,29]

Table 3: Comparison of purple sweet potato tuber pigment indicator paper (PSPTPIP) with standard indicator paper

Solution pH	PSPPIP*	RL	BL	Solution pH	PSPPIP*	RL	BL
1	Pink	Red	Red	8	Pale blue	Faded Blue	Blue
2	Pink	Red	Red	9	Pale blue	Faded Blue	Blue
3	Pink	Red	Red	10	Pale green	Faded Blue	Blue
4	Pink	Red	Red	11	Pale green	Faded Blue	Blue
5	Pink	Red	Purplish blue	12	Deep green	Blue	Blue
6	Pink	Red	purplish blue	13	Yellow	Blue	Blue
7	Pink	Red	Blue	14	Yellow	Blue	Blue

PSPTPIP*: PSPTP-MG and PSPTP-AG, RL: Red litmus, BL: Blue litmus

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Table 4: Identification of household chemicals with purple sweet potato tuber pigment indicator paper (PSPTPIP)

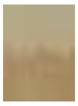
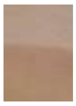
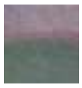
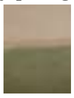
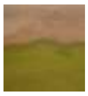
Sample solution	pH	PSPTPIP-MG	PSPTPIP-AG
Lime	2.4	 Pink	 Pink
Vinegar	2.7	 Pink	 Pink
Sprite	3.6	 Pink	 Pink
Bath soap	8.0	 Very pale blue	 Blue
Baking soda	9.0	 Very pale green	 Very pale green
Detergent	12.0	 Green	 Green
Lime betel	12.4	 Yellow	 Yellow

Table 5: The coefficient of variation (CV) of purple sweet potato tuber pigment (PSPTP) as a titration indicator

Types of titrations	Indicator	Unspiked sample			Spiked sample		
		$NaOH/NH_4OH$ (mL)[a]	SD	CV (%)	$NaOH/NH_4OH$ (mL)[a]	SD	CV (%)
SASB	PSPTP-MG	4.0271	0.0364	0.9035	16.0214	0.0393	0.2455
	PSPTP-AG	4.0271	0.0364	0.9035	16.0214	0.0393	0.2360
	PP	4.0143	0.0244	0.6078	16.0143	0.0244	0.1523
SAWB	PSPTP-MG	4.0286	0.0393	0.9765	16.0286	0.0488	0.3044
	PSPTP-AG	4.0286	0.0393	0.9035	16.0143	0.0378	0.2360
	PP	4.0183	0.0244	0.6078	16.0143	0.0244	0.1523
WASB	PSPTP-MG	2.0857	0.0244	1.1697	14.0043	0.0513	0.3661
	PSPTP-AG	2.0914	0.0186	0.8915	14.0057	0.0583	0.4160
	PP	2.0986	0.0038	0.1801	13.9857	0.0378	0.2703
WAWB	PSPTP-MG	6.0000	0.0577	0.9623	18.0543	0.0509	0.2822
	PSPTP-AG	6.0214	0.0393	0.6530	18.0557	0.0779	0.4312
	PP	7.0143	0.0244	0.3478	26.0143	0.0244	0.0938

[a]:Mean value of NaOH (for SASB and WASB) and NH_4OH (for SAWB and WAWB) (mL) from seven replication, SD: standard deviation, CV: coefficient of variation (%).

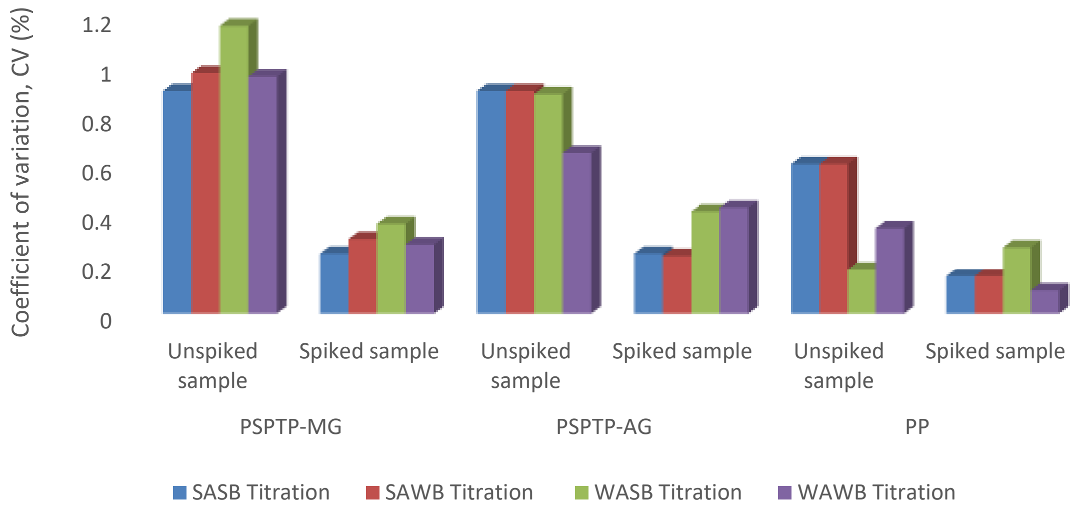


Figure 5: The coefficient of variation of purple sweet potato tuber pigment (PSPTP) as a titration indicator

Accuracy of PSPTP as indikator for SASB, SAWB, WASB, dan WASB titrations

The accuracy of PSPTP-MG and PSPTP-AG as indicators for SASB, SAWB, WASB, and WASB titrations was evaluated based on the recovery (%) of acid concentration. As shown in Figure 6 and Table 6, the results show that only SASB and SAWB titrations were accurate, with recoveries of 102.4%–102.5%, while WASB and WAWB titrations were not accurate since their recoveries fell outside the AOAC acceptance range (90%–108%).[29] The recoveries of WASB titration were 70.34% for PSPTP-MG and PSPTP-AG, and 70.18% for phenolphthalein (PP) indicator. For the WAWB titration, the recoveries were 71.14%, 71.04%, and 112.15% for PSPTP-MG, PSPTP-AG, and PP, respectively. These findings indicate that PSPTP-MG and PSPTP-AG are accurate indicators for SASB and SAWB titrations. This finding aligns with previous reports, in which HCl recovery using PSPTP-MG and PSPTP-AG as indicators was 102.4%.[29]

Table 6: The recovery of $[H^+]$ in titration using purple sweet potato tuber pigment (PSPTP) as an indicator

Types of titrations	Recovery of $[H^+]$ (%) ± SD		
	PSPTP-MG	PSPTP-AG	PP
SASB	102.4402 ± 0.1648	102.4402 ± 0.1649	102.4876 ± 0.2394
SAWB	102.4876 ± 0.2394	102.3691 ± 0.2023	102.5468 ± 0.1567
WASB	70.3397 ± 0.2166	70.3397 ± 0.3290	70.1842 ± 0.2212
WAWB	71.1420 ± 0.2919	71.0356 ± 0.3607	112.15 ± 0.1654

Figure 6: The recovery of $[H^+]$ in titration using purple sweet potato tuber pigment (PSPTP) as an indicator

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Concentration of acid in samples

The acid concentration in the sample is presented in Table 7. In the SASB and SAWB titrations, the acid concentration was 0.0415 M for PSPTP-MG and PSPTP-AG, and 0.0410 M for PP in the unspiked sample, whereas it was 0.1651 M for PSPTP-MG, 0.1649 M for PSPTP-AG, and 0.1650 M for PP in the spiked sample. In the WASB titration, the acid concentration was 0.0215 M for PSPTP-MG and PSPTP-AG, and 0.0216 M for PP in the unspiked sample, whereas it was 0.1442 M for PSPTP-MG, 0.1443 M for PSPTP-AG, and 0.1441 M for PP in the spiked sample. In the WAWB titration, the acid concentration was 0.0618 M for PSPTP-MG, 0.0620 M for PSPTP-AG, and 0.0722 M for PP in the unspiked sample, whereas it was 0.1859 M for PSPTP-MG, 0.1860 M for PSPTP-AG, and 0.2679 M for PP in the spiked sample. The results showed that the strong acid concentration in the SASB titration gives the same result as in the SAWB titration for all three indicators. This behaviour differed from that of the weak acid concentrations in the WASB and WAWB titrations. The weak acid concentration in the WAWB titration was approximately three times greater than that in the WASB titration. In the WAWB titration, ammonium hydroxide (NH_4OH) acts as a weak base, and only a small portion is ionized. Table vinegar contains acetic acid (CH_3COOH), which is also a weak acid. Therefore, the reactions do not proceed completely and the equivalence point is not sharply defined. Consequently, there is no sharp increase in pH around the equivalence point, making it difficult to detect using these three indicators. This limitation can lead to errors in determining the volume of titrant. Based on the recovery data shown in Figure 6, only the strong acid concentrations obtained from the SASB and SAWB titrations were considered accurate. This finding is consistent with previous studies that reported that PSPTP-MG and PSPTP-AG performed well in quantifying HCl in pharmaceutical samples. Moreover, PSPTP-MG and PSPTP-AG have also been shown to be accurate indicators for the titration of HCl with NaOH.[20,29]

Toward a PSPTP-based acid–base titration game

Based on the finding that PSPTP is effective as an acid–base titration indicator, an acid–base titration game using PSPTP is currently being developed. This game is designed to provide an interactive tool for learning acid–base titration concepts, allowing students to observe colour changes before and after titration, determine the titration endpoint, and practice titration procedures in a virtual environment. An illustration of the game is shown in Figure 7.

Table 7: The acid concentration in sample

Types of titrations	$[H^+]$ in unspiked sample ± SD			$[H^+]$ in spiked sample ± SD		
	PSPTP-MG	**PSPTP-AG**	**PP**	**PSPTP-MG**	**PSPTP-AG**	**PP**
SASB	0.0415±0.0004	0.0415±0.0004	0.0413±0.0002	0.1650±0.0004	0.1650±0.0004	0.1649±0.0002
SAWB	0.0415±0.0004	0.0415±0.0004	0.0413±0.0002	0.1651±0.0005	0.1649±0.0004	0.1650±0.0003
WASB	0.0215±0.0002	0.0215±0.0002	0.0216±0.0004	0.1442±0.0005	0.1443±0.0006	0.1441±0.0004
WAWB	0.0618±0.0006	0.0620±0.0004	0.0722±0.0002	0.1859±0.0005	0.1860±0.0008	0.2679±0.0002

$[H^+]$: Concentration of acid in molar (M)

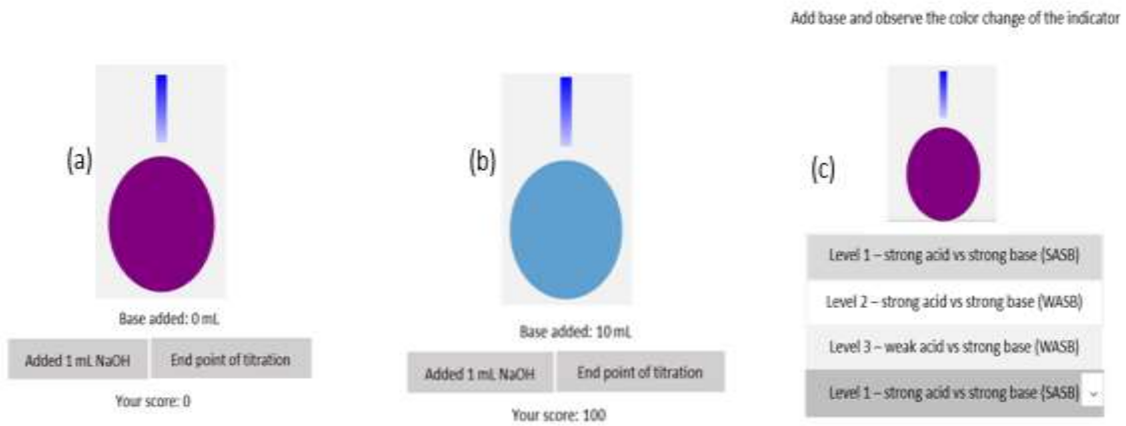

Figure 7: Illustration of the titration game using purple sweet potato tuber pigment (PSPTP) as an indicator: **(a)** before titration, **(b)** at the end point of titration, and **(c)** an example of a game menu

Conclusion

This study investigated the fabrication of pH indicator paper by immobilizing PSPTP (PSPTP-MG and PSPTP-AG) onto cellulose paper. The resulting pH indicator papers (PSPTPIP-MG and PSPTPIP-AG) were pink and exhibited good performance in terms of colour characteristics, stability, and sensitivity, with more varied colour changes than litmus paper. They also provided reliable responses when used to identify household chemical samples. The fabrication process is simple and cost-effective. In addition, PSPTP-MG and PSPTP-AG proved to be effective indicators for SASB and WAWB titrations. The use of these pigments as indicators is environmentally friendly and reduces reliance on synthetic alternatives. Moreover, they can be further developed into pH indicator films. Currently, an acid–base titration game using PSPTP as an indicator is under development.

Conflict of Interest

The author declares no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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