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Comparative Study on the Acid-Base Indicator Properties of Natural Dye, Turmeric Rhizome (*Curcuma longa*) and Synthetic Dyes

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Abstract

Acid-Base Indicator, Turmeric Rhizome (*Curcuma longa*) was extracted from the root of a turmeric plant. The turmeric was peeled, washed and dried in an oven at 60˚C. It was ground into powder and soaked in hot and cold ethanol for the extraction. The extract was filtered and part of it was concentrated to yield a reasonable quantity of turmeric indicator. On standardization of acid with a base, 0.05 M base respectively of Sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3) and Disodium borate ($B_4Na_2O_7$) were used. Hot and cold extracts of turmeric were used as indicators and were compared with methyl orange and phenolphthalein. On the preliminary test carried out, hot and cold turmeric indicator showed yellow colour in acid medium and orange colour in the base. Methyl orange showed red colour in acid but yellow in the base, phenolphthalein was colourless in acid but pink in the base. During titration there were colour changes at the end points in the entire test carried out. The average volumes at ends points were calculated, the molar concentrations and mass concentrations of the acids used were also determined. The results showed that there was no difference between the natural indicators used and the existing synthetic indicators which are toxic to our environment.

Keywords

Turmeric Rhizome, Extraction, Acid-Base Indicator, Methyl Orange, Phenolphthalein

1. Introduction

Despite the use of mineral or synthetic indicators in determining acids and bases, the use of natural dyes (Indicators) has gained ground due to their envi-

ronmental friendliness, availability, easy extraction and less toxicity. An indicator is a colourant from organic substance that exhibits different colours in acid and alkaline solution. Indicators can be of natural origin examples, archil, litmus, logwood, turnsole or synthetic examples, phenolphthalein, methyl orange and dinitrophenol, methyl red, thymol blue, and bromophenol.

Indicators can be classified based on their chemical structures such as azo, anthraquinone, indigo, phthalocyanine, nitroso, sulphur nitro dyes. It can equally be classified based on their methods of application such as acid, basic, reactive, dispense, direct and vat dyes. A substance that changes colour with the pH of the environment can be an indicator. Indicators change colour during titration indicating the end point (equivalence). The point at which the equivalent quantities of acid and base have chemically reacted together, indicators can cause changes in physical properties for instance olfactory indicator that indicates change in odor. An acid-base indicator is either a weak acid or weak base that exhibits a colour change as the acidic conditions, concentration of hydrogen (H^+) or alkaline condition, hydroxide (OH^-) ions change in an aqueous solution [1]. Higher indicators used nowadays are synthetic such as litmus paper, phenolphthalein and methyl orange [2]. Several solvents can be used in extraction of indicators from plants, fruits or leaves such as ethanol, methanol, water or their combinations.

So many works have been done on the extraction and use of natural indicators in acid-base titration. Most plant natural indicators contain anthocyanin (a secondary metabolite) a subgroup of flavonoids which is responsible for the purple, blue or red colours on fruits, leaves or flowers. Anthocyanin shows colour changes when reacted with acids or bases due to change in the molecular level [3]. Natural indicators have been extracted from butterfly pea [4], sweet potatoes [5], kolanut [6], *Bougainvillea spectabills*, wild flower and wild flower bracts [7], Moringa oleiferartic [8], *Nerium indicum* flower [8], *Allamanda cathartica* [9], golden beet root [10], corolla of roselle [11], betavulgaris [12], *Dahlia pinnata* flower [13], *Butea monosperma* [14], *Aspilia africana* [15], *Cassia aungostifolia* linn., the vetia peruviana, schum and thevetia thvetrodes [16].

The objective of this research work is to extract local indicator from turmeric rhizome, determine the molar concentration and the mass concentration of the acid and to compare its effectiveness with existing synthetic indicator (methyl orange, and phenolphthalein).

2. Materials and Methods

The turmeric rhizome used in this research work was purchased from Ihiagwa market, Owerri, Imo State, Nigeria. Turmeric has the chemical formular, $C_{12}H_{20}O_6$ (curcumin) and molecular weight of 368.38 g/mol [17]. The reagents used were purchased from Fin Lab. Owerri, Imo State. Phenolphtalein used was colourless, with the chemical formula, $C_{20}H_{14}O_4$, pH value of 8.3 and molecular weight, 368.38 g/mol. Methyl orange used has the pH value of 3.1 with the chemical

formular, $C_{14}H_{14}N_3NaOS$ and molecular weight of 327.36 g/mol. All other reagents; Oxalic acid ($H_2C_2O_4$), Sodium hydroxide (NaOH), Sodium carbonate (Na_2CO_3), Disodium borate ($B_4Na_2O_7$), and Hydrochloric acid (HCl) used were of analytical value.

The following apparatus were used in the research work; Pipette, burette, conical flask, automatic pipette, dropper, volumetric flask, distillation apparatus, auto digital pH metre, heating mantle, oven, laboratory metre, electronic weighing balance, retort stand with clamp, wash bottle, spatula, stirrer, soxhlet extractor, desiccator, mechanical blender.

2.1. Sample Preparation

Turmeric rhizomes were cut into small pieces and dried at 40˚C for 48 hrs in an open air and ground into powder. Then 1.5 kg of the turmeric was treated with 2 litres of 70% ethanol in a soxlet extractor. The extract was concentrated in vacuum at 50˚C and finally dried in a desiccator to remove residual water. A total of 230 g (18.67%) yield of the crude extract powder was obtained.

2.2. Extraction of Dye/Indicator from Turmeric Rhizome (*Curcuma longa*)

Hot and cold methods of extraction were employed in the extraction. For hot ethanol extraction, 40 g of the turmeric rhizome extract powder was weighed, and dissolved in 80 ml of ethanol and boiled for 30 mins, the extract was filtered and concentrated to produce acid-base indicator. For cold extraction, the turmeric rhizome extract powder was soaked in 60 ml of cold ethanol and left overnight. The extract was filtered and concentrated on a water bath to produce an indicator for acid-base titration.

2.3. Acid-Base Titration with the Indicators

In the titration experiment, strong acid (HCl) was used against strong base (0.05 M NaOH), weak acid ($H_2C_2O_4$) against strong base (0.05 M and 0.03 M NaOH respectively), and strong acid (HCl) against weak base (0.05 M $B_4Na_2O_7$ and 0.03 M Na_2CO_3 respectively). Each acid was filled in the burette and the level was adjusted to the zero mark. 20 cm^3 of the bases were pipetted into a conical flask and two drops of the indicators (phenolphthalein, methyl orange, turmeric extracted from cold and hot ethanol) were added respectively for each test. The flask was swirled all the time to mix the two solutions during each test period. The titration continued till the end point was reached (that is, when the colour of indicators changed). The volume of acid used to neutralize the base was recorded, after which more accurate titrations were carried out. Level of acid in the burette after titrations were recorded and the average volumes of the acids used were calculated.

2.4. Determination of the Molar Mass Concentration of the Acids

In calculating the molar mass concentrations of the Acids used in the experi-

ment, the equations of the reactions were balanced and the concentrations calculated using the formula:

$$\frac{C_A V_A}{C_B V_B} = \frac{n_b}{n_a} \quad (1)$$

where C_A = Concentration of acid, V_A = Volume of acids, C_B = Concentration of bases, V_B = Volume of bases.

n_a = number of moles of a, n_b = volume of moles of bases.

$$\text{Mass concentration}\left(\text{g}/\text{dm}^3\right) = \text{molar concentration} \times \text{molar mass} \quad (2)$$

3. Results and Discussions

The average volume of the acids used were determined, calculated and recorded in Tables 1-15. The acids titrated against the bases, indicators, number of moles of acids & bases, volume, calculated values of molar concentration and mass concentration of the acids used were recorded in Table 16.

Methyl orange was used for titrations involving strong acids while phenolphthalein was used for titrations involving weak acids. Tumeric extracts were used for both the strong and weak acids during the titration. The results in Table 16 show that turmeric indicators endpoints compared favorably with that of methyl orange and phenolphthalein which are standard indicators. Furthermore, the temperature difference of turmeric indicator extraction did not lead to any significant change in the titration results. Rather it led to noticeable differences at

Table 1. Titration of strong acid (HCl) versus strong base (0.05 M NaOH) using methyl orange.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	22.50	45.10	22.60
Initial reading	0.00	22.50	0.00
Volume of acid used	22.50	22.60	22.60

Average titre value = 22.57 cm^3.

Table 2. Titration of strong acid (HCl) versus strong base (0.05 M NaOH) using turmeric extracted from hot ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	22.20	44.30	22.20
Initial reading	0.00	22.20	0.00
Volume of acid used	22.20	22.10	22.20

Average titre value = 21.17 cm^3.

Table 3. Titration of strong acid (HCl) versus strong base (0.05 M NaOH) using turmeric extracted from cold ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	22.40	44.70	22.40
Initial reading	0.00	22.40	0.00
Volume of acid used	22.40	22.30	22.40

Average titre value = 22.36 cm^3.

Table 4. Titration of weak acid ($H_2C_2O_4$) versus strong base (0.05 M NaOH) using phenolphthalein.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	11.50	22.90	34.40
Initial reading	0.00	11.50	22.90
Volume of acid used	11.50	11.40	11.50

Average titre value = 11.47 cm^3.

Table 5. Titration of weak acid ($H_2C_2O_4$) versus Strong base (0.05 M NaOH) using turmeric extracted from hot ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	13.50	27.10	40.60
Initial reading	0.00	13.50	27.10
Volume of acid used	13.50	13.60	13.50

Average titre value = 13.53 cm^3.

Table 6. Titration of weak acid ($H_2C_2O_4$) versus Strong base (0.05 M NaOH) using turmeric extracted from cold ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	12.70	25.30	38.00
Initial reading	0.00	12.70	25.30
Volume of acid used	12.70	12.60	12.70

Average titre value = 12.67 cm^3.

Table 7. Titration of strong acid (HCl) versus weak base ($B_4Na_2O_7$) using methyl orange.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	23.00	46.10	23.00
Initial reading	0.00	23.00	0.00
Volume of acid used	23.00	23.10	23.00

Average titre value = 23.03 cm^3.

Table 8. Titration of strong acid (HCl) versus weak base $B_4Na_2O_7$ using turmeric extracted from hot ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	23.10	46.10	23.20
Initial reading	0.00	23.10	0.00
Volume of acid used	23.10	23.10	23.00

Average titre value = 23.07 cm^3.

Table 9. Titration of strong acid (HCl) versus weak base ($B_4Na_2O_7$) using turmeric extracted from cold ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	22.50	44.80	22.50
Initial reading	0.00	22.50	0.00
Volume of acid used	22.40	22.40	22..40

Average titre value = 22.40 cm^3.

Table 10. Titration of strong acid (HCl) versus weak base (0.03 M Na_2CO_3) using methyl orange.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	27.00	27.10	27.00
Initial reading	0.00	0.00	0.00
Volume of acid used	27.00	27.10	27.00

Average titre value = 27.03 cm^3.

Table 11. Titration of strong acid (HCl) versus weak base (0.03 M Na_2CO_3) using turmeric extracted from cold ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	26.10	26.20	26.10
Initial reading	0.00	0.00	0.00
Volume of acid used	26.10	26.20	26.10

Average titre value = 26.13 cm^3.

Table 12. Titration of strong acid (HCl) versus weak base (0.03 M Na_2CO_3) using turmeric extracted from hot ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	25.50	25.40	25.40
Initial reading	0.00	0.00	0.00
Volume of acid used	25.50	25.40	25.40

Average titre value = 25.43 cm^3.

Table 13. Titration of weak acid ($H_2C_2O_4$) strong base (0.03 M NaOH) using phenolphthalein.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	14.20	28.50	42.70
Initial reading	0.00	14.20	28.50
Volume of acid used	14.20	14.30	14.20

Average titre value = 14.23 cm^3.

Table 14. Titration of weak acid ($H_2C_2O_4$) with strong base (0.03M NaOH) using turmeric extracted from hot ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	15.00	30.10	45.10
Initial reading	0.00	15.00	30.10
Volume of acid used	15.00	15.10	15.00

Average titre value = 15.03 cm^3.

Table 15. Titration of weak acid ($H_2C_2O_4$) with strong base (0.03 M NaOH) using turmeric extracted from cold ethanol.

Burette reading	First reading (cm^3)	Second reading (cm^3)	Third reading (cm^3)
Final reading	14.10	28.30	42.40
Initial reading	0.00	14.10	28.30
Volume of acid used	14.10	14.20	14.10

Average titre value = 14.13 cm^3.

Table 16. The acids titrated against the bases, indicators, number of moles of acids & bases, volumes, calculated values of molar concentration and mass concentration of the acids used.

Acids/Bases	Indicators	Mole of acids, (n_a)	Mole of Bases (n_b)	Volume of Acids, Va (dm^3)	Molar conc. of Acids (mol/dm^3)	Mass Conc. of Bases (g/dm^3)	Change in Colours
HCl/NaOH (0.05 M base)	Methyl orange	2	1	0.02257	0.0443	1.6172	Yellow to Orange
	Hot Turmeric	2	1	0.02117	0.0472	1.7228	Yellow to green
	Cold Turmeric Extract	2	1	0.02236	0.0447	1.6325	Light green to brown
$H_2C_2O_4$/2NaOH (0.05 M base)	phenolphthalein	1	2	0.01147	0.0436	2.7899	Pink to colourless
	Hot Turmeric Extract	1	2	0.01353	0.0369	2.3599	Orange to light green
	Cold Turmeric Extract	1	2	0.01267	0.0395	2.5296	Light green to yellow
2HCl/$B_4Na_2O_7$ (0.05 M Base)	Methyl Orange	2	1	0.02303	0.0868	6.3396	Yellow to orange
	Hot Turmeric Extract	2	1	0.02307	0.0867	6.3287	Light brown to colourless
	Cold Turmeric Extracted	2	1	0.02240	0.0893	6.5179	Light brown to colourless
2HCl/Na_2CO_3 (0.03 M Base)	Methyl orange	2	1	0.02703	0.0740	5.4014	Yellow to orange
	Hot Turmeric Extract	2	1	0.02543	0.0787	5.7413	Yellow to light green
	Cold Turmeric Extract	2	1	0.02613	0.0765	5.5874	Green to light yellow
$H_2C_2O_4$/2NaOH (0.03 M base)	Phenolpthalein	1	2	0.01423	0.0351	2.2490	Pink to colourless
	Hot Turmeric Extract	1	2	0.01503	0.0333	2.1291	Orange to light green
	Cold Turmeric Extract	1	2	0.01413	0.0354	2.2647	Light green to yellow

the end point colour change. Berhave *et al*., 2018 [18] attributed the sharp colour changes that occur at the end points of titration with natural indicators to the presence of flavonoids (anthocyanin's). The hot and cold extract of turmeric can therefore serve as adequate replacements for methyl orange and phenolphthalein in acid-base titration.

4. Conclusion

The use of turmeric rhizome dye extracts for acid–base titration has been studied and noticeable end point colour changes were observed. The colour change of hot and cold turmeric were found to differ at the end of titration under same condition except in the case of strong acid (HCl) and weak bases ($B_4Na_2O_7$) where the colour change of Light brown to colourless was observed for both. The Volume of acid, molar concentration of acid and mass concentration of base used for each titration test was calculated, with negligible differences observed between standard indicators and turmeric extract indicators. Synthetic indicators have been reported to cause some health challenges such as abdominal cramps, rashes and diarrhea and causes environmental pollution. Hence the use of a natural indicator like turmeric will be preferred to synthetic indicators due to their availability, easy to prepare, low cost and non-toxic properties.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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