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Review

A Review on Herbal Indicators

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Abstract

Herbal indicators, derived from plant-based sources, offer a sustainable, cost-effective, and eco-friendly alternative to synthetic indicators in analytical chemistry. These natural compounds possess color-changing properties in response to pH variations, redox reactions, or other chemical changes, making them invaluable tools in titrations and other analytical procedures. This review explores the historical development, extraction methods, chemical properties, and applications of herbal indicators. It highlights their advantages over synthetic indicators, addresses challenges in their adoption, and identifies future research opportunities in this field.

Keywords: Herbal indicators, Natural pH indicators, Plant-based indicators, Chemical properties of herbal indicators.

INTRODUCTION

Fundamental chemistry laboratory technique used for the quantitative analysis of substances with unknown concentrations and using standard solutions with known concentrations is termed as titration. The substance with known concentration is termed as analyte while the standard solution is termed as the titrant[1]. The conventional varieties of titrations include acid-base titrations, redox, and complexometric titrations. Neutralization with an acid or base of known concentration is done to determine the unknown concentration of an acid or base in acid-base titration[1]. The most commonly used indicators in acid-base titrations are phenolphthalein, phenol red, bromocresol blue, methyl red, methyl orange, bromophenol blue, etc[1]. pH indicators are generally weak bases or weak acids indicate color change according to the pH of the solution to which the indicator is added. The range of pH over which the color change occurs varies with the indicator used[2]. The frequently and most commonly used acid-base indicator which has a broad range for the color change is “litmus”. It is therefore used for detecting acids and bases over a wide pH range, whereas, synthetic indicators such as methyl orange or phenolphthalein are used only when the solutions are highly acidic or basic respectively[1].

Most of the commercially available standard synthetic indicators are expensive. Additionally, they are toxic as well as flammable. Also, they show disadvantages such as availability, environmental pollution, and chemical pollution. Furthermore, the use of synthetic indicators for food applications is avoided or minimized to a greater extent due to their potentially deleterious effects on human beings[3]. To triumph over the disadvantages of synthetic indicators, researches are being carried out extensively by scientists in the field of natural products as they are less hazardous to humans, cost-effective, easy availability and eco-friendly nature[3].

Natural pigments or dyes in plants are rarely toxic, pollution-free and easy to prepare or extract. Various organic and inorganic compounds are responsible for the color property of plant parts such as anthocyanins. Anthocyanins exhibit different colors in different pH, and therefore, can be used as natural indicators[4].

Anthocyanins are vacuolar water-soluble pigments that may appear purple, red or blue according to pH. They belong to the parent class of molecules termed as flavonoids which are synthesized via the phenylpropanoid pathway. They occur in all tissues of the higher plants including stems, roots, leaves, fruits, and flowers. The difference in the chemical structure that arises due to the pH change is the reason for the often use of anthocyanins as a natural pH indicator, as they change from red in acid to blue in bases[5].

Historical perspective of herbal indicators

The concept of using natural substances as indicators dates back centuries. Early chemists utilized plant extracts like litmus, derived from lichens, to measure pH. Traditional practices in herbal medicine often relied on the color-changing properties of plant-based substances for diagnostic purposes.

The formal study of herbal indicators gained momentum in the 20th century as researchers began isolating plant pigments such as anthocyanins, flavonoids, and betalains. These compounds were found to exhibit color changes over a wide pH range, making them suitable for various analytical applications. Renewed interest in herbal indicators has emerged in recent years due to their potential to replace synthetic chemicals in environmentally sensitive processes.

Chemical basis of herbal indicators

The effectiveness of herbal indicators lies in their chemical composition. Key compounds responsible for color changes include:

Anthocyanins

It is a coloured water-soluble pigment belonging to the phenolic group. The pigments are in glycosylated forms. Anthocyanins responsible for the colours, red, and blue, are in fruits and vegetables. Red to purplish blue-coloured leafy vegetables, grains, roots, and tubers are the edible vegetables that contain a high level of anthocyanins. Among the anthocyanin pigments, cyanidin-3-glucoside is the major anthocyanin found in most of the plants [6]

Exhibit a wide range of colors depending on pH:

- Red in acidic conditions ($pH < 3$)
- Purple in neutral pH (around 7)
- Green to yellow in alkaline conditions ($pH > 8$).

Flavonoids

- Present in plants such as onion skins and citrus fruits.
- Respond to pH changes with subtle color variations.

Betalains

The term “betalains” was introduced by Mabry and Dreiding;[7] this was supported by structural and biogenetic considerations. In a strict sense, betalains do not belong to alkaloids because they are acidic in nature due to the presence of several carboxyl groups. Originally, betalains were called “caryophyllinenroth” and successively renamed “rübenroth” and “chromoalkaloids”[8,9]

- Extracted from beetroot (*Beta vulgaris*), producing intense red and yellow hues.
- Stable over a limited pH range and suitable for acidic to neutral solutions.

Tannins and Carotenoids

The presence of condensed tannins (CT) in alfalfa has supported a higher sheep productivity higher weight and wool production) than CT-free alfalfa. Recently, it was shown that cultivars with higher CT content could be obtained by molecular biology. It has been established that dfr is involved in CT biosynthesis, and some Lotus corniculatus plants transformed with the Antirrhinum majus dfr cDNA showed increased CT levels.[10]

- Found in tea leaves and carrots, respectively.
- Exhibit color changes through redox reactions rather than pH variations.

The structural changes in these compounds during protonation or deprotonation explain their ability to indicate pH.

In general, carotenoids are compounds comprised of eight isoprenoid units (ip) whose order is inverted at the molecule center. All carotenoids can be considered as lycopene (C40 H56) derivatives by reactions involving: (1) hydrogenation, (2) dehydrogenation, (3) cyclization, (4) oxygen insertion, (5) double bond migration, (6) methyl migration, (7) chain elongation, (8) chain shortening.[11]

Applications of herbal indicators

Natural herbal indicators are a good replacement for synthetic indicators used in many labs and research institutes due to their availability, ease of extraction, high performance, and accurate results. Herbal indicators find applications in various fields, ranging from routine laboratory titrations to environmental monitoring[12]

Advantages of herbal indicators

Eco-Friendly: Unlike synthetic indicators, herbal indicators are biodegradable and non-toxic.
Cost-Effective: Readily available plant materials reduce production costs.
Renewable: Derived from sustainable sources, ensuring long-term availability.
Non-Toxic: Safer for laboratory personnel and the environment.
Versatile: Wide pH response range makes them suitable for diverse analytical applications.

Challenges in using herbal indicators

Despite their advantages, herbal indicators face certain limitations:
Stability Issues: Susceptible to degradation due to light, heat, or microbial activity; Improved storage methods are required.

Batch-to-Batch Variability: Natural variations in plant composition can affect consistency.

Limited Commercial Availability: Most herbal indicators are prepared on a small scale, limiting their widespread adoption.

Sensitivity: Some herbal indicators lack the precision of synthetic counterparts in detecting subtle changes.

CONCLUSION

Herbal indicators represent a promising alternative to synthetic indicators, aligning with the principles of green chemistry. Their eco-friendliness, cost-effectiveness, and versatility make them suitable for various analytical applications. While challenges remain, continued research and development will enhance their viability, ensuring a sustainable future in analytical science.

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