RESEARCH ARTICLE

CRAFTING COLORS: FROM PIGMENTS TO HUES

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Abstract:

This study explores *Clitoria ternatea*, purple cabbage, and beetroot as natural sources of anthocyanins and betalains for making sustainable powder colorants, dyes, and inks. Clear pH-dependent color alterations, acceptable textile retention, and significant antioxidant qualities were found after aqueous extraction, tissue paper experiments, and phytochemical studies. These pigments demonstrated their worth as sustainable alternative for synthetic dyes and the need for better stabilization techniques despite certain stability issues. They also showed to be safe, biodegradable, and effective.

Keywords: Beetroot, Betalains, Cabbage, Cyanidin, Clitoria, Delphinidin.

Introduction:

The food, cosmetic, textile, and pharmaceutical industries have seen a significant rise in interest in natural colorants as sustainable substitutes for synthetic dyes. The development of natural colors from plant sources, such as inks, dyes, and powders, is an example of how traditional knowledge and innovative technological advancements have combined to meet the present demand for safer, environmentally friendly, and bioactive substances.[1] [2]

Pigment Production:

Betalains and anthocyanins are the pigments that give these plants their unique hues. Beetroot contains nitrogen-containing chemicals called betalains, which give plants their yellow to red hues. On the other hand, a wider variety of hues, from orange red to violet blue, are caused by anthocyanins, a class of flavonoids present in purple cabbage and butterfly pea. Several techniques have been devised to optimize the extraction process from the plant source used in the creation of these natural hues.[3]

1. Beetroot (*Beta vulgaris*)

Beetroot's rich red color is caused by a group of pigments known as betalains, particularly betacyanin. The plant's vacuoles are where these water-soluble pigments are kept. In certain applications, betalains are a more stable natural colorant than anthocyanins because their color is less pH dependent. A popular source of natural food colouring is red beet. Unlike the biosynthesis of anthocyanins, the biosynthesis of betalains is a complicated process. The final pigment is created via a number of enzymatic and spontaneous chemical processes. [3]

2. Purple Cabbage (*Brassica oleracea*)

Purple cabbage is a significant source of anthocyanins, especially cyanidin acyl glucosides, which are water-soluble colors. The color of anthocyanins is highly sensitive to pH, which allows for a range of colors to be created from a single extract. Purple cabbage extract appears red in acidic environments (pH < 7), turns purple and then blue in neutral to alkaline environments (pH 7–11), and eventually turns colorless at extremely high pH values.[3] [4]

3. *Clitoria ternatea* (Butterfly Pea)

The polyacylated delphinidin-based anthocyanins known as ternatins give the Clitoria flower petal its vivid blue appearance. Through a process known as intramolecular co-pigmentation, ternatins' many aromatic acyl groups contribute to their exceptional stability and vivid blue hue. This is when the color-bearing portion, remains protected from degradation by portions of the pigment molecule folding over it.[5] Glycosylation and acylation are two of the enzyme processes involved in the manufacture of ternatins, which give these pigments their intricate structure. Mordants like alum can be used in the dyeing process to adhere butterfly pea dye to textiles.[6]

Natural and Synthetic Bio colours

Table 1: Comparison between natural and synthetic products. [7]

Factors	***Natural Products***	***Synthetic Products***
Source	Beetroot – **Betalains** Purple Cabbage – **Cynidine** Clitoria – **Delphinidin** (Natural Pigments)	Chemicals, Hazardous Compounds, Toxins, Heavy Metals, etc
Process	Easy and simple way of production	Complex procedure requiring various chemical reactions
Cost	Cheap	Expensive
Availability	Always Available as the materials are from nature	Availability in Long Term is affected due to metals and chemical shortages
Stability	More Stable	Highly Unstable
Efficiency	Lower Efficiency	High Efficiency
Effects	Less or no impact on environment as its originating from nature	Adverse effects on environment due to its hazardous properties

Extraction Methodologies

Natural pigment extraction from various plant sources has undergone significant evolution, moving from traditional aqueous extraction techniques to advanced green technologies.

Table 2: Comparison between Traditional and Modern Extraction Technologies. [8]

Traditional Technology	Emerging Technology
A mild extraction protocol involves • Cutting the vegetable into pieces • Soaking in deionized water for time period. • Multiple filtration steps • Purification with organic solvents to remove unwanted plant materials such as chlorophylls, carotenes, and polyphenols. • The final pH after extraction typically ranges from 3.7 to 4.4, which is optimal for anthocyanin stability.	Offer more efficient and sustainable alternatives to conventional methods. These include • Ultrasound-assisted extraction (UAE), which uses cavitation to disrupt plant cells • Microwave-assisted extraction (MAE) that accelerates the process with heat and pressure • Supercritical fluid extraction (SFE) with CO_2 for high yields and stability • Pressurized liquid extraction (PLE) for fast, high recovery of bioactive compounds.

Phytochemical Properties

Beyond their colouring capabilities, these plant extracts offer significant nutritional and functional benefits:

1. Among the natural plant pigments, purple cabbage had the highest total flavonoid level (95.5 μg/ml) and a significant polyphenol content. At its highest concentration of 2500 mg/L, DPPH radical scavenging activity ranges from 88.9%, indicating a strong antioxidant capacity. Additionally, the extract has broad-spectrum antibacterial action against bacteria that are both gram-positive and gram-negative. [1] [9]
2. In addition to its distinctive anthocyanins, butterfly pea flowers include a complex blend of phenolic chemicals such as cis resveratrol, naringenin, myricetin, catechin, kaempferol, and quercetin. Optimized aqueous extraction techniques can yield a total anthocyanin content of 7925.29 ± 36.07 mg/L.[9]
3. Under ideal extraction conditions (54°C, 94W, 32 minutes, solid-to-liquid ratio of 1:17 g/mL), beetroot yields betanin concentrations of 1.43 mg/g and betaxanthin at 5.37 mg/g. In biological systems, betanin exhibits gastrointestinal absorption and serves as a potent antioxidant. [2]

pH Dependent Colour Behaviour

The pH-dependent structural change of anthocyanins from purple cabbage and Clitoria is a unique feature that directly affects color manifestation. Although this characteristic poses difficulties for industrial uses, it also presents special chances for pH indicator applications. [10]

Anthocyanins are mostly found as the flavylium cation in acidic environments (pH 2-3), with maximal absorbance at 530 nm and vivid red colors. Blue-violet hues result from structural conversion to quinoidal bases as pH rises to neutral levels (pH 5-7). Additional pH rises cause colorless carbinol and chalcone to develop, producing pale yellow-brown tones. Because quinoidal and chalcone forms are present, purple cabbage extract is red at pH 2, light pink at pH 4-5, and brownish at neutral ph. [1] [10]

Stabilization

Maintaining stability during processing and storage is a crucial difficulty in the use of natural colorants. The presence of specific enzymes, pH, temperature, light, and oxygen can all cause anthocyanins to degrade. For 360 minutes, blue pea flower anthocyanins show good thermal stability at 60°C and 70°C between pH 3.6 and 5.4; degradation rate constants only significantly increase at 70°C.[11]

Comparative advantages and Challenges

A strategic potential to diversify pigment production, lessen dependency on synthetic dyes, and advance sustainable practices is presented by the synthesis of natural colors from beetroot, purple cabbage, and butterfly pea flower. These resources have clear benefits:

1. **Local availability and cultivation**: By cultivating all three species in a variety of climates, reliance on imports is lessened.
2. **Bioactivity**: In contrast to artificial colors, these natural pigments include antibacterial, anti-inflammatory, and antioxidant qualities.
3. **Sustainability**: The ecological impact of extraction can be reduced by adopting eco-friendly technologies and solvents.
4. **Multifunctionality**: The same extracts bring value beyond aesthetics by acting as colorants, antioxidants, and functional substances.
5. **Cultural significance**: Using traditional plant sources satisfies customer demands for identifiable, natural components.[12]

Table 3: Significance of natural colours in various aspects [12]

Aspect	***Description***
Cultural	Preserve traditional crafts and link to cultural identity through textiles, art, and festivals.
Spiritual	Carry symbolic significance in rituals, with specific colours representing purity, vitality, and auspiciousness.
Health	Non-toxic and hypoallergenic, making them safer for skin contact and the human body compared to synthetic dyes.
Environment	Biodegradable, made from renewable resources, and minimize water and environmental pollution.

Standardizing extraction techniques, enhancing pigment stability in a variety of industrial settings, and expanding results to satisfy market demands are still challenges. Future studies should concentrate on improving culture methods, creating hybrid stabilization techniques and extending applicability in advanced sectors including natural cosmetics and bioactive packaging. [2]

Applications

Beyond their vivid hues, many plants have a dual nature that makes them useful resources for industrial and agriculture as well as beneficial nutrients for human health. Nitrate-rich beetroot, which improves athletic performance, the anthocyanin - packed purple cabbage, which is beneficial to heart health, and the antioxidant-rich Clitoria, which is utilized in traditional medicine, are just few of the natural sources that offer a wide range of benefits:

Medical:

- **Beetroot** can be a valuable addition to a healthy diet. Its unique combination of nutrients, particularly nitrates, and antioxidants, offers potential benefits for cardiovascular health, exercise performance, cognitive functions, and inflammation. It's a good source of essential vitamins and minerals like Potassium, Folate, Vitamin C, and Fiber. In fact, it is considered a good source of several antioxidants offering various health benefits. [13]
- **Purple cabbage** has a high nutritional content and is a great source of important vitamins, minerals, and antioxidants. Powerful antioxidants that may help reduce inflammation and protect against chronic diseases. Additionally, purple cabbage contains vitamin A, vitamin B6, folate, manganese, and small amounts of other vitamins and minerals. [14]
- **Clitoria** has long been used in medical traditions to treat a wide range of ailments. The roots were used to heal skin problems, sore throats, and abdominal swelling, and they were also thought to be beneficial to children's brains. The leaves were commonly utilized to enhance cognitive function and memory. The plant was also used to treat more serious illnesses; its crushed seeds were used to treat joint pain and urinary problems, while its petals and juice were used to heal snake bites. [15]

Agro -Industrial:

- **Beetroot** pigments, particularly betanin, offer a colourful and natural alternative to synthetic dyes, with a wide range of applications across many industries. It is commonly utilized in the food industry as a safe, natural colorant in products such as yogurts, beverages, sweets, and certain savoury dishes. The cosmetic industry uses this reddish-pink hue to create lipsticks, blushes, and hair tints. Beyond consumer goods, beetroot pigments are an environmentally benign option for dyeing textiles, producing colours of red and pink with less longevity than synthetic counterparts. [7]
- **Purple cabbage** is a significant industrial crop that is grown around the world and valued for its contribution to the agricultural industries. Its economic worth arises from high consumer demand, which is supported by its recognized nutritional benefits. This demand spans new sectors and various processing industries. The plant's worth is directly related to its high concentration of medicinal nutrients, particularly anthocyanins. [14]
- **Clitoria** is useful for crop rotation as its roots produce large, circular nodules that contain nitrogen-fixing bacteria. For decades, people have grown Clitoria to provide pleasant hay for cattle. Animal diets with it typically contain less acid fibre than meals provided with other legumes. The low amount of acid fibre increases the feed's energy density while retaining its high nitrogen content.[16] The bioactive elements in Clitora extracts that show insecticidal and antibacterial activities are most likely developed for host defence, but they might find utility in agriculture and medicine. [17]

Materials and Methods:

Materials

The materials used for the study included fresh raw plant sources such as beetroot, purple cabbage, and *Clitoria*, along with alum and lemon for acid–alkali testing. Corn flour or arrowroot powder was used for powder preparation, and distilled water served as the primary solvent. Various reagents were required, including 0.2 N Tris–acetate solution, 0.2 N dilute hydrochloric acid, 0.2 N acetic acid, and 0.2 N sodium acetate solution. The experimental setup utilized essential equipment such as a filtration unit and a centrifugation unit. Standard laboratory glassware, including petri plates, test tubes, conical flasks, and beakers, was also employed. Additional miscellaneous materials comprised a mortar and pestle, Bunsen burner, muslin cloths, filter papers, and cotton cloth strips.

Methods

The procedure involved pigment extraction from raw materials followed by product preparation, including inks, dyes, and powder colors. Tissue paper tests were then conducted to determine acidity, alkalinity, and turbidity, along with pH tests to assess the exact pH values of the extracted pigments. Finally, phytochemical tests were performed to detect the presence of naturally occurring compounds in the prepared samples.

Protocol

Pigment Extraction from Raw Materials

Wash the fresh raw materials (Beetroot/ Purple Cabbage/ Clitoria flower petals)

↓

Cut and grind the materials in a mortar and pestle

↓

Weigh 100gm of grinded material

↓

In a clean conical flask, squeeze and strain out the extract from the crushed material using a muslin cloth

↓

Measure the volume, and divide the extracts into two equal volumes in test tubes

↓

Let the one left undisturbed, while boil the other extract, and label them as A and B respectively

↓

Note the difference in colour or smell, and store it in a refrigerator (4°C)

Figure 1: Raw Materials – Beetroot, Purple Cabbage and Clitoria

Product Preparation

Dye Preparation Protocol

Chilled extracts were taken and a few milliliters were transferred into separate petri plates. Then, 1 ml of alum water was added to each plate. Small pieces of cotton cloth were dipped into the petri plates and allowed to soak in the solution for 1–2 hours. After soaking, the cloth pieces were pinned on a drying stand to air-dry. The dyed cloth was observed at intervals of 1 hour, 2 hours, 24 hours, and 48 hours to assess color persistence.

Ink Preparation Protocol

Five milliliters of the extract were placed into a clean test tube. Two to three crystals of Arabic gum were boiled in 2 ml of distilled water without burning the gum. After cooling for a few minutes, the Arabic gum solution was added to the test tube containing the extract. The mixture was shaken to dissolve completely and then cooled on ice for 5–10 minutes. The consistency of the solution was checked and adjusted by adding a controlled amount of distilled water. Finally, the ink was stored in airtight bottles.

Powdered Color Preparation Protocol

In a clean and sterilized petri dish, 2 grams of corn flour or arrowroot powder were added. One milliliter of the pure extract was then added to the dish. The contents were mixed thoroughly under sterile conditions, with sterile gloves worn to prevent contamination. Care was taken to mix well without forming lumps. The mixture was allowed to settle for 24 hours. After settling, 1 ml of extract was added again, and the process was repeated 2–3 times. The final powdered color was stored in a sealed packet.

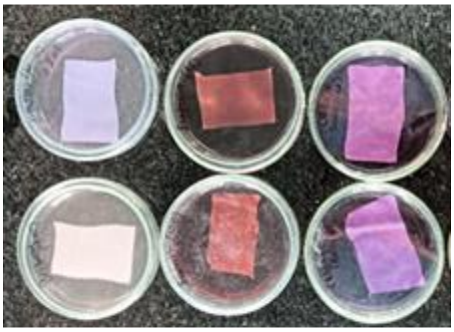

Figure 2: Cotton Cloths soaked under petri plates for 1 hour
(Row 1- Pure Extract, Row 2 – Water Extract)

Tissue Paper Test Protocol

Table 4: Protocol for Tissue Paper Test

Solution Type	Composition
Pure Extract	1 ml
Citrus (Lemon Juice)	1 ml Extract + 1 ml Citrus Juice
Alum Water Solution	1 ml Extract + 1 ml Alum Water
Tween 20 Detergent	1 ml Extract + 1 ml Tween 20

The chilled extract was first checked and observed for any sediments. Eight test tubes were then prepared, and solutions were made according to the table below, mixing the extract with citrus juice, alum water, and Tween 20 detergent in specified ratios. This mixing allowed observation of physical changes in color as well as alterations in the concentration of hydroxyl ions and hydronium ions in the extract. A drop of each prepared solution was placed on a folded tissue paper and allowed to dry for a few minutes. The tissue paper was then observed for any changes in color or texture.

pH Tests

Using acetic acid and sodium acetate, a set of pH dilutions was prepared as indicated in Table 5, covering a pH range from 2.0 to 13.0. Each dilution was prepared in 50 ml total volume with precise volumes of acetic acid, sodium acetate, Tris-acetate, and dilute HCl as specified. One milliliter of the pure extract was then added to each dilution and mixed gently. The resulting solutions were observed for any color changes, which indicated the pH-dependent behavior of the natural pigments.

Table 5: Dilution Sets for pH Range 2.0 – 13.0

pH	Acetic Acid (ml/50ml)	Sodium Acetate (ml/50ml)	Tris-Acetate (ml/50ml)	Dilute HCl (ml/50ml)
2	48.2	1.8	-	-
3	46.3	3.7	-	-
4	41.0	9.0	-	-
6	14.8	35.2	-	-
7	-	-	-	-
9	-	-	45.0	5.0
10	-	-	46.8	3.2
12	-	-	47.6	2.4
13	-	-	49.2	0.8

Phytochemical Tests

A series of phytochemical tests were performed in clean test tubes to identify the naturally occurring bioactive compounds in the extracts. Each test involved mixing the extract with specific reagents and observing color changes or other physical reactions as indicators of the presence of target compounds. The tests, protocols, and expected positive results are summarized in Table 6.

Table 6: Protocol for Phytochemical Tests

Tests	Protocol	Positive Results
Reducing Sugars	1 ml Extract + 1 ml Fehling's A + Fehling's B + Heat	Brick Red Precipitate
Salkowski Test	1 ml Extract + 2 ml CH3Cl + 2 ml Conc. H2SO4	Red–Brown Coloration
Phenols and Tannins	1 ml Extract + 2 ml 2% FeCl3	Blue green/black color
Flavonoids	1 ml Extract + 2 ml NaOH (aq)	Yellow Color
Saponins	1 ml Extract + 2.5 ml Distilled Water, shake 30 s	Stable foam even after 30 seconds
Steroids	1 ml Extract + 1 ml CH3Cl + 2 ml Conc. H2SO4 (sideways)	Red color on lower CH3Cl
Alkaloids	1 ml Extract + 1 ml 1% HCl + Heat + 1 ml Mayer's/Wagner's	Turbidity

Results:

Pigment Extraction

The pigment extraction from the selected raw materials yielded distinct colors. From beetroot, the extract produced a dark reddish-colored solution. Purple cabbage yielded a dark purple-blue solution upon straining. The extract from Clitoria resulted in a dark blue-colored pigment. These observations confirm successful isolation of natural pigments from all three plant sources.

Beetroot	**Purple Cabbage**	**Clitoria**
After Straining the extract, A dark **Reddish** colored Solution was observed	After Straining the extract, A dark **Purple-Blue** colored Solution was observed	After Straining the extract, A dark **Blue** colored pigment was observed

Product Formation

Dyes

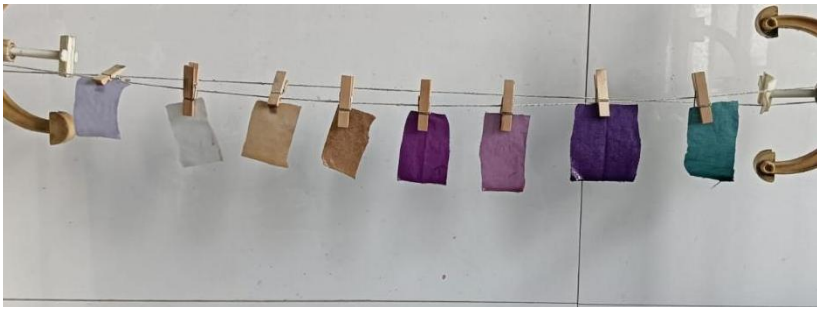

Figure 3: Pigment-soaked Dried clothes after 2 days

After Staining the cotton cloths with the extracted pigments and drying them for 24-36 hours days24-36 hours, it was observed that the clothes retained the hues but started to fade as time progresses.

Inks

Figure 4: Pigments incorporated with binding reagent to form inks- Beetroot, Purple Cabbage and Clitoria

The chilled extracts were mixed with Arabic gum (a binding reagent), that made the inks more stable and fixed on the paper, resulting in a thick now-flowy hued ink.

Powder Colors

After repeated addition of pigment extracts to the arrowroot powder after intervals of time, the powder started to retain the colors, giving a bright hue of various shades of reddish-pink, purple and blue.

Figure 5: Powder colored of different shades – Beetroot, Purple Cabbage, Clitoria

Tissue Paper Test

Figure 6: Tissue Paper Test result for Beetroot

Addition of respective beetroot extract mixtures on sets of tissue papers showed that extracts with lemon made the solution appear more **darkened**, while alum extract made it **paler** and extract with Tween 20 solution made the solution more **thickened** and **molecularly bonded.**

Figure 7: Tissue Paper Test result for Purple Cabbage

Addition of respective purple cabbage mixtures on sets of tissue papers showed that extract mixed with lemon juice made the solution a little **pale** than before, while alum extract made it **brighter** and extract with Tween 20 solution made the solution more **viscous.**

Figure 8: Tissue Paper Test result for Clitoria

Addition of respective Clitoria extract mixtures on sets of tissue papers showed that, extract mixed with lemon juice made the solution acidic changing it color to **pink**, while alum extract made it basic turning it into bright **purple** and extract with Tween 20 solution made the solution more **viscous** and **pale pink.**

pH Tests

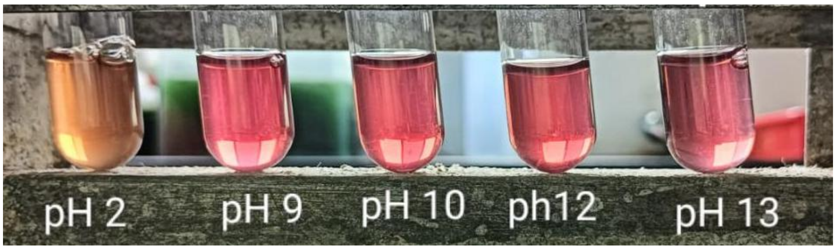

Figure 9: Ph Test result for Beetroot

After adding the pigment extracts to the prepared Ph dilutions, beetroot showed a color change with respect to changes in Ph, resulting in **reddish orange** in acidic Ph, **Redish Pink** in Neutral and in basic Ph turned **bright red**.

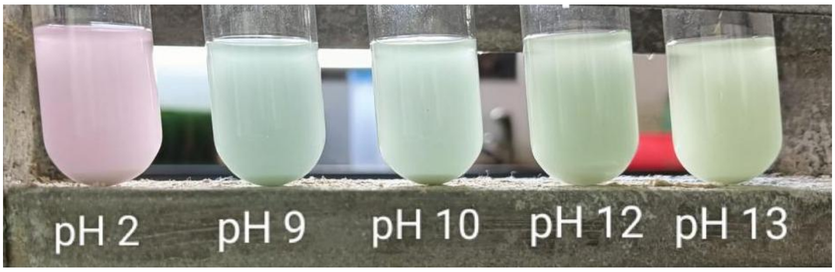

Figure 10: Ph Test result for Purple Cabbage

After adding the pigment extracts to the prepared Ph dilutions, Purple Cabbage showed a color change with respect to changes in Ph, resulting in **pink** in acidic Ph, **Purple** in Neutral and in basic Ph turned **blue to green** as the Ph increases.

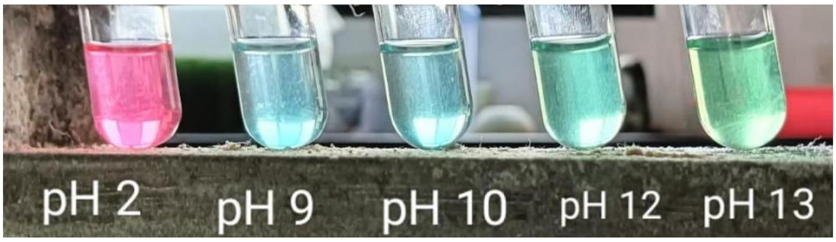

Figure 11: Ph Test result for Clitoria

After adding the pigment extracts to the prepared Ph dilutions, Clitoria showed a color change with respect to changes in Ph, resulting in **bright pink** in acidic Ph, **Blue** in Neutral and turned **Green**, as Ph increases.

Phytochemical Tests

Figure 12: Phytochemical Positive Test Results

Table 7: Results for biochemical test of the samples

Tests	Beetroot	Purple Cabbage	Clitoria	Inferences
Reducing Sugars	Strongly Positive	Positive	Positive	Brick red precipitate was formed
Salkowski Test	Negative	Negative	Positive	A yellow ring formation was observed
Phenols and Tannins	Positive	Strongly Positive	Strongly Positive	Solution turned bluish black in color
Flavonoids	Negative	Positive	Strongly Positive	Yellow coloration was seen in positive cases
Saponins	Positive	Positive	Positive	After vigorous shaking, foam persisted for some time
Steroids	Negative	Negative	Negative	No significant change was observed
Alkaloids	Negative	Negative	Positive	Addition of reagents caused solution to become viscous and turbid

Test Results for Clitoria

- Test for Flavonoids → Yellow coloration (+)
- Test for Phenols and Tannins → Bluish-black coloration (+)
- Test for Reducing Sugars → Red precipitation (+)
- Test for Steroids → No specific change (-)
- Test for Saponins → Persistent foam (+)
- Test for Salkowski → Yellow ring formation (+)
- Test for Alkaloids → Increase in turbidity observed (+)

Discussion:

During the process flow, some observations were recorded like browning of cotton cloth stained with beetroot pigment, indicating that the color was not being retained for longer period and was turning pale as the time passes. The solution investigated for the above problem included the use of alum and salt solution mix as a binding material that holds the color molecules and cloth fabrics for a longer time, making the fabric retain its bright hues and freshness.

Figure 13: Purple Cabbage-Stained cotton clothes

The cloth on the left was stained with dye mixed with Alum- Salt Solution making it brighter than the cloth stained on right, that faded as the time progressed.

During ink production, consistency and viscous nature of the color ink mattered really a lot, to make it stable for paper use as well as making it free flowing for smoother writing experience. Usage of Arabic gum solution helped to overcome the problem as it thickened the extract and made it viscous enough for the usage. Disadvantages of Arabic gum may include solidification of the ink if used more than the required concentration, making it not suitable for further usage.

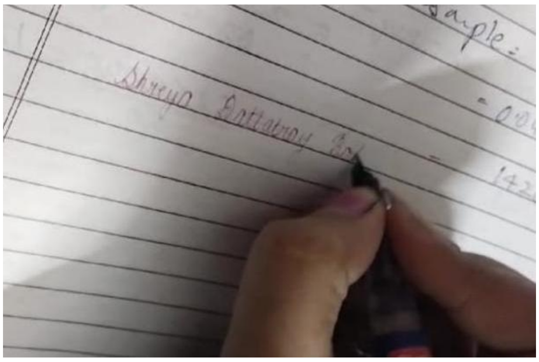

Figure 14: Ink produced from the pigment extracted from Beetroot

Vibrant red colored ink was observed as stable and viscous enough for smooth writing.

During powdered color production, it was observed that the hue started to fade with 23-36 hours of storage, which can be overcome by repeated and controlled addition of the extracts for several times. But this fade also explains that the product is easily washable, eco-friendly and can be sustainably used for celebrations, being safe for human use (skin).

Figure 15: Beetroot Extract Powder colors
The powder on the left was processed with several repeated extract addition at regular intervals making the color more retained to it, while the powder on right started fading.

Figure 16: Material Extract Powder colors
The image shows the safety of these bio colors for human use (skin), making it a better alternative than toxic and synthetic colors.

All these measures and specifications make the natural product useful for various purposes that includes cultural celebrations, education, textile, food and cometic industries, agriculture, spiritual and religious beliefs. Being naturally produced, they possess no toxic effects towards human usage as well as environment, making it a solid alternative for chemical-based colors and products.

Products Summary:

Plant-based pigments are effective tools for industrial sectors ranging from rich food colourings and cosmetic tints to trendy fabrics and more. Beetroot, purple cabbage, and the Clitoria flower are all excellent examples of a sustainable palette of reds, blues, and purples created from Betalains and anthocyanins. These natural assets are being used progressively to produce environmentally friendly dyes for food, clothing, and personal hygiene items, offering sustainable alternative for synthetic colorants. [18]

Table 8: Summary of Plant-Based Colorant Products.[18] [19]

Features	Beetroot	Purple Cabbage	Clitoria
Pigment	Betalains (Betanin)	Cyanidin	Delphinidin (Anthocyanin)
Colour	Reddish-Pink	Purple	Bluish-Purple
Food and Beverage	Natural red dye for yogurts, desserts, and beverages	Natural colorant for beverages, jams, confectionery, and fermented foods	Natural blue colouring for teas, rice dishes, desserts, and cocktails
Cosmetics	Used in lip tints, blushes, and hair dyes for a temporary reddish hue	Used in soaps, lip balms, and other products for its natural colour	Valued for its vibrant blue hue, used in cosmetics and personal care products
Textiles	Used as an eco-friendly dye for fabrics, producing red and pink shades (temporary)	Used in traditional and eco-friendly textile dyeing methods	Used as dyeing material, serving as a substitute for synthetic blue dyes
Unique Applications	Temporary skin staining (blush)	pH indicators	Colour-changing beverages

Conclusion:

This research shows that *Clitoria ternatea*, purple cabbage, and beetroot are reliable and sustainable sources of natural pigments that may produce a variety of colorant products, including dyes, inks, and powder colors. The results of the experiment show that although anthocyanins and betalains have great visual potential, the pH level, temperature, mordants, and storage conditions all affect how well they work. Applications in food systems, textile dyeing, pH indicators, and natural cosmetics are supported by pH assays that showed consistent and vivid color changes in anthocyanin-based extracts. The existence of bioactive substances, such as flavonoids, phenols, and saponins, was also revealed by phytochemical analyses, supporting the significance of these pigments in functional and health-related applications.

Optimizing extraction efficiency, improving pigment stability through green technologies, and increasing their integration into modern sectors like eco-textile engineering, intelligent packaging, and medicinal formulations should be the top priorities for future developments. All these results confirm that plant-derived colorants have a lot of promise to support a more ethical and environmentally friendly colorant industry.

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