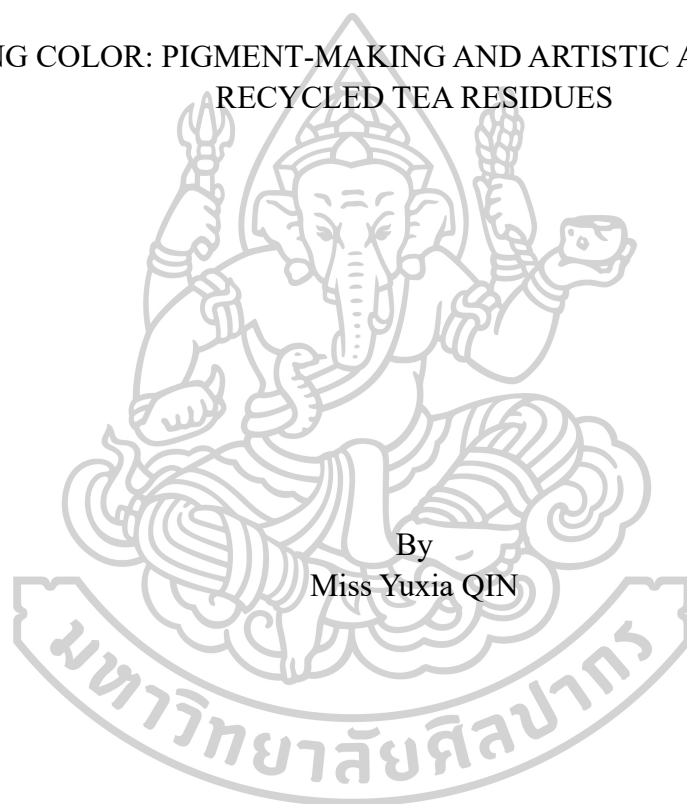




BREWING COLOR: PIGMENT-MAKING AND ARTISTIC APPLICATIONS OF
RECYCLED TEA RESIDUES



A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Fine Arts Program in Design
Silpakorn University
Academic Year 2024
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MissYuxia QIN

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 Recycled Tea Residues
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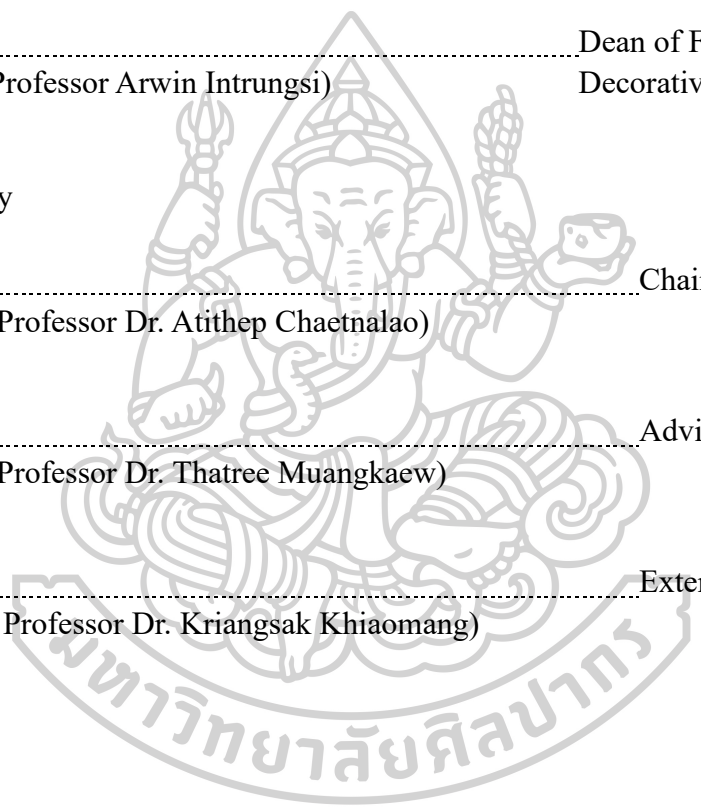
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Miss Yuxia QIN : Brewing Color: Pigment-Making and Artistic Applications of Recycled Tea Residues Thesis advisor : Assistant Professor Dr. Thatree Muangkaew

In contemporary academic discourse, sustainable design has emerged as a pivotal frontier in artistic and material research. With the global proliferation of milk tea consumption—particularly in Asian nations like China and Thailand—tea residues are generated in substantial quantities as a byproduct of beverage production. Although these residues lose their functional value for brewing after initial steeping, they retain significant potential as natural pigment sources. Guided by principles of "waste valorization" and sustainable design, this study aims to utilize tea residues as a foundational material to develop an ecologically oriented natural pigment system, exploring its practical applications and artistic expressions in painting.

The research employs an experimental art methodology as its primary approach, supported by theoretical frameworks from material aesthetics and ecological cycle theory. The study is structured in three phases: material exploration, pigment synthesis with medium adaptability testing, and artistic expression linked to theoretical analysis. The core objectives are threefold:

- 1.To assess the feasibility of repurposing tea residues as a secondary-use material.
- 2.To synthesize pigment powders from tea residues through chemical reagent integration.
- 3.To evaluate the synthesized tea-based pigments via practical painting trials.

In material selection, teas were categorized into four types: Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea. Tea residue samples were collected from bubble tea shops, traditional teahouses, and other venues. All residues underwent initial dehydration, drying, crushing, labeling, and storage for subsequent experimental grouping.

During pigment synthesis, researchers combined tea residue samples with various chemical reagents. Key additives were classified into three categories:

Mordants: e.g., alum, to enhance pigment adhesion and color stability;

Color modifiers: e.g., copper sulfate, iron oxide solution, and citric acid, to adjust hue and tone;

Precipitants: e.g., slaked lime and edible alkali, to facilitate pigment

precipitation for powder formation.

By modulating reaction time, pH levels, and reagent ratios, researchers synthesized diverse tea residue pigment precipitates with distinct color properties. All precipitates were vacuum-dried, air-flattened, ground, and sieved to yield fine, blendable pigment powders.

Subsequently, the study advanced to pigment-medium adaptability testing. Pigment powders were mixed with four adhesive types to suit different painting media:

1.Chinese painting pigments: mixed with gelatin or animal glue, suitable for rice paper and brushwork, emphasizing granular texture and ink wash effects;2.Watercolor pigments: blended with gum arabic, natural ox bile, and honey to enhance fluidity and transparency;3.Oil painting pigments: combined with linseed oil to form viscous paints for canvas applications;4.Crayon pigments: fused with beeswax and vegetable oil, then cooled and solidified for experimental art or educational use.

Building on pigment preparation, the study incorporated expert interviews and user surveys. Experts spanned fields including traditional Chinese pigment production, natural dye research, sustainable design, and ecological art education. Interviews focused on four dimensions: material innovation, color expressiveness, medium adaptability, and application potential. An online survey revealed that most respondents affirmed the sustainable attributes and material aesthetics of tea residue pigments, with nearly 70% expressing willingness to use such natural pigments in future artwork.

Following pigment development, painting experiments with study sketches were conducted to verify operability and expressiveness in creative processes. A one-year color stability test showed:

1.Most colors remained stable in dry, room-temperature environments;2.Lighter tones (e.g., green and yellow) exhibited slight fading after 12 months, though barely noticeable;3.Pigment stability was optimized through chemical reagent and adhesive integration;4.Crayon pigments demonstrated comparable stability under identical conditions.

Notably, chemical reagents in this study were used not to enhance chromatic vibrancy but to improve pigment stability and preservation for long-term artistic use. For future directions, three recommendations were proposed:

1.Expand adaptability testing on diverse surfaces (e.g., fabric, wood,

plastic);2.Extend color preservation testing cycles with biannual fading documentation;3.Compare chromatic vividness against commercial standard pigments to establish visual evaluation metrics.

In conclusion, this study demonstrates the feasibility and aesthetic potential of tea residues as sustainable pigment materials through systematic recycling, experimentation, and design. Tea residue pigments represent not only sustainable material reconstruction but also an artistic exploration of human-nature-material relationships. The research methodology and design framework offer a replicable paradigm for advancing waste-to-art transformations.



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Yuxia QIN



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CHAPTER 1

INTRODUCTION

1.1 Research Background

As an art form with a long-standing history, the development of painting is inherently intertwined with the evolution of materials and the expansion of artistic media. Particularly in pigment application, materials not only dictate visual presentation methods but also profoundly influence the linguistic structure and epochal characteristics of artistic creation. From the initial mineral grinding to plant extraction and subsequent modern industrial synthetic pigments, humans have consistently pursued chromatic richness, physical stability, and expressive freedom throughout the history of pigment development. However, this evolutionary trajectory has increasingly highlighted human dependency on natural resources, particularly through the direct mining and overexploitation of mineral and plant raw materials, which has exerted sustained pressure on ecosystems to varying degrees.

Taking traditional Chinese painting as a case study, its pigments primarily derive from natural minerals (e.g., cinnabar, azurite, indigo) and plant dyes (e.g., madder, gardenia), processed through manual grinding and colloidal adhesive addition. While this material system exhibits aesthetic elegance, chemical stability, and unique cultural texture, its production process relies heavily on direct natural resource extraction. For instance, azurite requires extraction from lapis lazuli, and cinnabar depends on cinnabar ore. The mining of these mineral resources is not only economically costly but also unsustainable within long-term ecological frameworks. Additionally, traditional plant pigments feature lengthy extraction cycles and relatively limited color gamuts, struggling to meet contemporary art's demands for material diversity and experimentalism.

Concurrently, global social movements centered on "sustainable development," "waste recycling," and "green design" have gained momentum in recent years. The United Nations' *2030 Sustainable Development Goals* (SDGs) explicitly advocate promoting sustainable consumption and production patterns, emphasizing the importance of reducing resource waste and enhancing recycling (United Nations, 2015). Against this backdrop, the art and design fields have actively engaged with this global agenda, infusing traditional creations with contemporary values through experimental material adoption, waste repurposing, and ecological mindfulness. This has inspired the art world to explore how material innovation in artistic practice can mitigate environmental harm and extend material life cycles.

Simultaneously, with accelerating urbanization and diversifying consumer culture, tea-based beverages—especially milk tea—have become a staple in the daily lives of young people in countries like China and Thailand. Due to milk tea's preparation methods, tea leaves are typically discarded after single use, generating

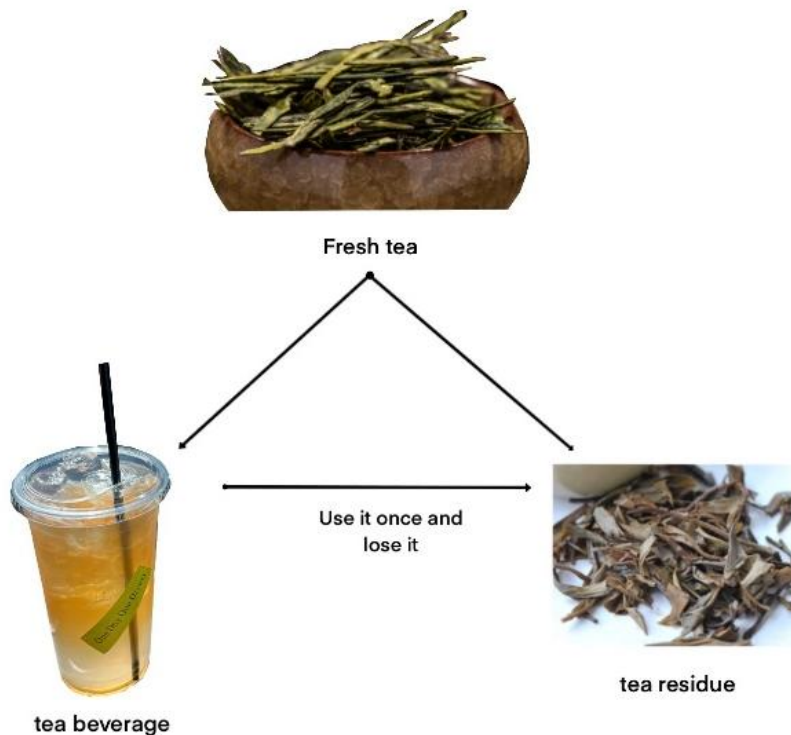
substantial tea dregs. Despite their rich organic composition, tea dregs have an extremely short usage cycle, mostly becoming waste within a day, thus causing resource depletion.

Based on this observation, this study aims to transform discarded tea dregs into pigment materials for visual art creation, addressing global imperatives for waste conversion and green artistic practice. By investigating the reactive mechanisms of different tea types (e.g., Chinese black tea, Chinese green tea, Thai black tea, Thai green tea) in combination with various chemical adjuvants (fixatives, color modifiers, precipitants), this research not only explores the extraction processes and chromatic properties of tea dreg pigments but also attempts to apply them across painting systems—including Chinese ink painting, watercolor, oil painting, and pastels—to verify their usability and expressiveness in practical creation.

In alignment with circular economy principles, this study explores extending waste life cycles to endow them with secondary utility. Tea residues, as readily accessible byproducts, hold potential for artistic pigment transformation through combination with other substances. This not only extends tea's usage cycle but also offers new possibilities for artistic creation. A core objective is to breathe new life into waste by extracting and applying pigments from tea residues, establishing them as renewable art materials.

Figure 1

Relationship between fresh tea leaves, milk tea and tea residues



Note. drawn by the author.

1.2 Research Hypothesis

1.2.1 Group 1: The Diversity and Applicability of Tea Residue Pigments

The diversity of tea residue pigments focuses on investigating pigment powders derived from Chinese black tea, green tea, and Thai black tea/green tea under different color-modifying agents and precipitating agents. Through the extraction of tea residue pigments, this study examines color variations and precipitation formation during reactions with substances such as citric acid, edible alkali, alum, and slaked lime. Reactions between different tea types and various agents yield variations in pigment powder hue, saturation, and texture.

These distinct pigment powders are employed in formulating diverse painting pigments, including watercolors, oil paints, Chinese ink pigments, and pastels. For the same pigment powder, the addition of different binding agents—such as gum arabic, beeswax, or natural resins—alters the final pigment’s chromaticity, transparency, gloss, and viscosity. This phenomenon highlights the critical role of binding agent selection in pigment production, as it influences not only physical properties but also color expression across different art forms. Consequently, the complex interactions between tea residue pigments, color-modifying media, and binding agents represent key factors affecting the final chromatic and textural characteristics of the pigments.

1.2.2 Group 2: Exploring the Feasibility and Limitations of Tea Residue

Pigments in Painting Creation Systems

As a pigment derived from waste materials, tea residue pigments demonstrate feasibility for integration into painting creation systems, yet exhibit inherent limitations. Specifically, they exhibit considerable potential in visual expression, material integration, and creative performance, enabling completion of basic painting practices. However, they may lag behind traditional commercial pigments in color saturation, stability, durability, and expressiveness. Through a combination of experimental research and creative practice, this study aims to explore the applicability, limitations, and improvement prospects of tea residue pigments at the artistic level. The findings seek to provide theoretical and practical references for the application of sustainable materials in the field of art and design.

1.3 Research Objectives

1.3.1 Investigating the Feasibility of Repurposing Tea Dregs as a Secondary-Use Material

By investigating the current tea dregs management practices in the milk tea industries of China and Thailand, and integrating sustainable development concepts with relevant policies, this study aims to evaluate the reuse potential of waste tea

dregs as eco-friendly art materials. It analyzes whether their physical and chemical properties are suitable for conversion into basic raw materials for painting pigments. Through collecting various tea dregs (such as black tea and green tea), observing their color release, extractable components, and stability, this research determines their applicability within art material systems. This objective not only responds to contemporary societal demands for "waste utilization" under sustainable development frameworks but also provides a theoretical and practical foundation for the recycling of tea dregs.

1.3.2 Synthesizing Pigment Powders from Tea Residues via Combination with Various Chemical Agents

Through systematic experimentation, this study investigates the color variations and precipitation effects of tea dregs following reactions with diverse chemical substances (e.g., alum, citric acid, blue vitriol, rust water, slaked lime, etc.). During the experiments, tea dregs are first boiled to extract the tea liquid, after which precipitants are gradually added to induce the formation of differently colored precipitates. These precipitates are then dried and ground to yield pigment powders. The objective is to explore how different variables impact color, hue, saturation, and stability, thereby providing a scientific foundation for the subsequent artistic application of these pigments.

1.3.3. Evaluating Synthesized Tea-Based Pigments via Practical Painting Trials

This study employs the synthesized tea residue pigment powders in conjunction with media such as watercolor binders to conduct practical painting trials for evaluating their expressiveness in artistic practice. The evaluation encompasses systematic observation and analysis of the pigments' workability, color coverage, dry-wet color variation, chromatic stability, and visual effects. Through the creation and documentation of small-scale artworks, this research verifies the comprehensive performance of these waste-derived pigments in terms of artistic expression, aesthetic quality, and usability. Concurrently, it explores the feasibility and limitations of integrating such pigments into painting creation systems as alternative materials.

1.4 Expected Benefits

Waste Utilization and Resource Recycling to Prolong Tea's Utility Value:

Through the innovative conversion of tea residues into pigments, this study aims to achieve the reuse and circular recycling of tea resources, thereby reducing waste. This practice not only extends the life cycle of tea after its primary use but also endows tea residues with new functional purposes, integrating environmental and economic value. By implementing this resource recycling model, the research

explores how to leverage daily-life waste in artistic creation to form a circular ecosystem, demonstrating the tangible value of waste in both art and environmental protection.

Exploring Combinations with Diverse Substances to Enrich Color Expression of Tea Residue Pigments:

An in-depth investigation will be conducted into the chromatic variations of tea residues under the influence of different fixing agents, precipitants, and binders. By integrating tea residues with these chemical reagents, the study systematically observes and documents resulting color transitions and textural changes. This exploration aims to decode the reactive mechanisms behind pigment diversification, providing a scientific basis for expanding the chromatic palette of tea-derived art materials.

1.5 Research Scope

The discussion and experiments of this study focus on the following aspects:

Material Source Scope:

Four types of tea dregs—Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea—are selected as primary material sources, from which pigment powders are extracted for comparative analysis.

Chemical Treatment Scope:

Representative chromatic modifiers and precipitants (e.g., blue vitriol, citric acid, rust water, slaked lime) are employed in color reaction experiments to analyze variations in their visual performance.

Painting Pigment Scope:

Focusing on four painting mediums—Chinese ink painting, watercolor, oil painting, and pastels—this study explores the integration potential and application prospects of tea dreg color powders with these materials.

Combination of Experiment and Creation:

Building upon pigment experiments, this research extends to small-scale painting practices to test pigment efficacy and their expressive possibilities in artistic creation.

Theoretical Framework:

The study theoretically anchors in ecological cycle theory, material aesthetics, and experimental art methodology, analyzing the subject through three dimensions: sustainable development, material mediation, and creative practice.

1.5.1 Types of Tea Residues

1.5.1.1 Chinese Black Tea

1.5.1.2 Chinese Green Tea

1.5.1.3 Thai Black Tea

1.5.1.4 Thai Green Tea

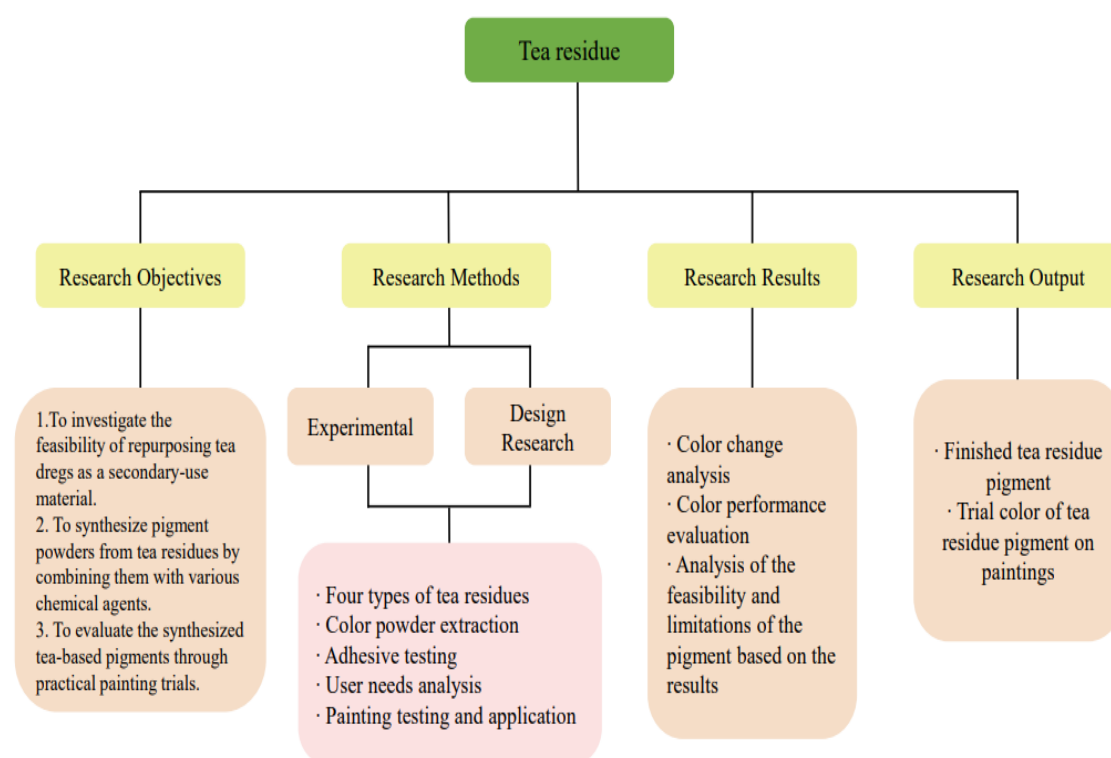
1.5.2 Chromatic Modifiers, Fixatives, and Precipitants

1.5.2.1 Acidic/Alkaline Substances and Color Fixatives

- 1.5.2.2 Extraction of Color Powders via Precipitation Reactions
- 1.5.3 Precipitate Drying Processes
 - 1.5.3.1 Vacuum Filtration Followed by Drying
 - 1.5.3.2 Direct Drying Without Filtration
- 1.5.4 Pigment Formulation with Different Binders
 - 1.5.4.1 Chinese Ink Pigments
 - 1.5.4.2 Watercolor Pigments
 - 1.5.4.3 Oil Paint Pigments
 - 1.5.4.4 Pastel Pigments
- 1.5.5 Color Testing, Color Card Production, and Painting Application

1.6 Research Framework

Figure 2
Research framework



Note. drawn by the author

1.7 Research Methods

This study utilized tea residues (specifically, residues from Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea) to synthesize painting pigments by inducing reactions with acid-base agents and iron ions, yielding specifically

colored powders. These powders were then mixed with various binders to formulate pigments. Employing a mixed-method research design, this study integrates qualitative insights from interviews and questionnaire surveys with quantitative experimental analyses to evaluate the colorimetric properties and operational performance of the pigments in practical applications.

1.8 Definition Of Terms

Keywords: tea residue, sustainable development, pigment production, material experiment

1.8.1 Tea residue:

Tea residue refers to the post-brewing waste generated in milk tea shops or during daily tea consumption, typically discarded after single-use infusion. As a common byproduct in the tea industry, tea residue generally loses its original edibility. This study takes tea residue as the primary research subject to explore its reuse potential in pigment production, transforming it into painting pigments through extraction of natural colorants. This practice not only extends the life cycle of tea but also unlocks new avenues for waste repurposing.

1.8.2 Sustainable development:

Sustainable development denotes the balanced progression of economy, society, and environment, ensuring that resource exploitation avoids long-term environmental degradation while fostering economic growth and social advancement. The United Nations' Sustainable Development Goals (SDGs) accentuate waste reduction and resource reuse, to which this study responds. By transforming tea residues into painting pigments, this research actualizes waste recycling, explores the application of eco-friendly materials in artistic creation, and provides a practical exemplar for sustainable development principles.

1.8.3 Pigment production:

Pigment production entails the extraction of colorants from natural or synthetic materials, followed by their conversion into painting pigments through the addition of various media (e.g., binders and fixatives). This study centers on pigment production using tea residues as the raw material. Through systematic experimentation, it investigates the feasibility of combining tea residues with diverse chromatic modifiers, precipitants, and binders to develop pigments of varying colors and textures. This research advances pigment innovation and fosters the sustainable development of artistic creation materials.

1.8.4 Material experiment:

Material experimentation refers to the systematic exploration and testing of raw materials' performance, compatibility, and application methods in design or artistic creation, aiming to uncover their potential in visual expression, structural attributes, and practical utility. In this study, material experiments encompass not only the chemical extraction of pigments from tea residues but also the exploration of combining these pigments with various binders (e.g., gum arabic, ox bile, honey). This dual approach seeks to validate their feasibility, stability, and expressiveness as painting materials. Through such experimentation, researchers can both identify the potential of tea residues as pigment sources and delineate their limitations, providing empirical foundations and theoretical references for sustainable art practices..



CHAPTER 2

LITERATURE REVIEW

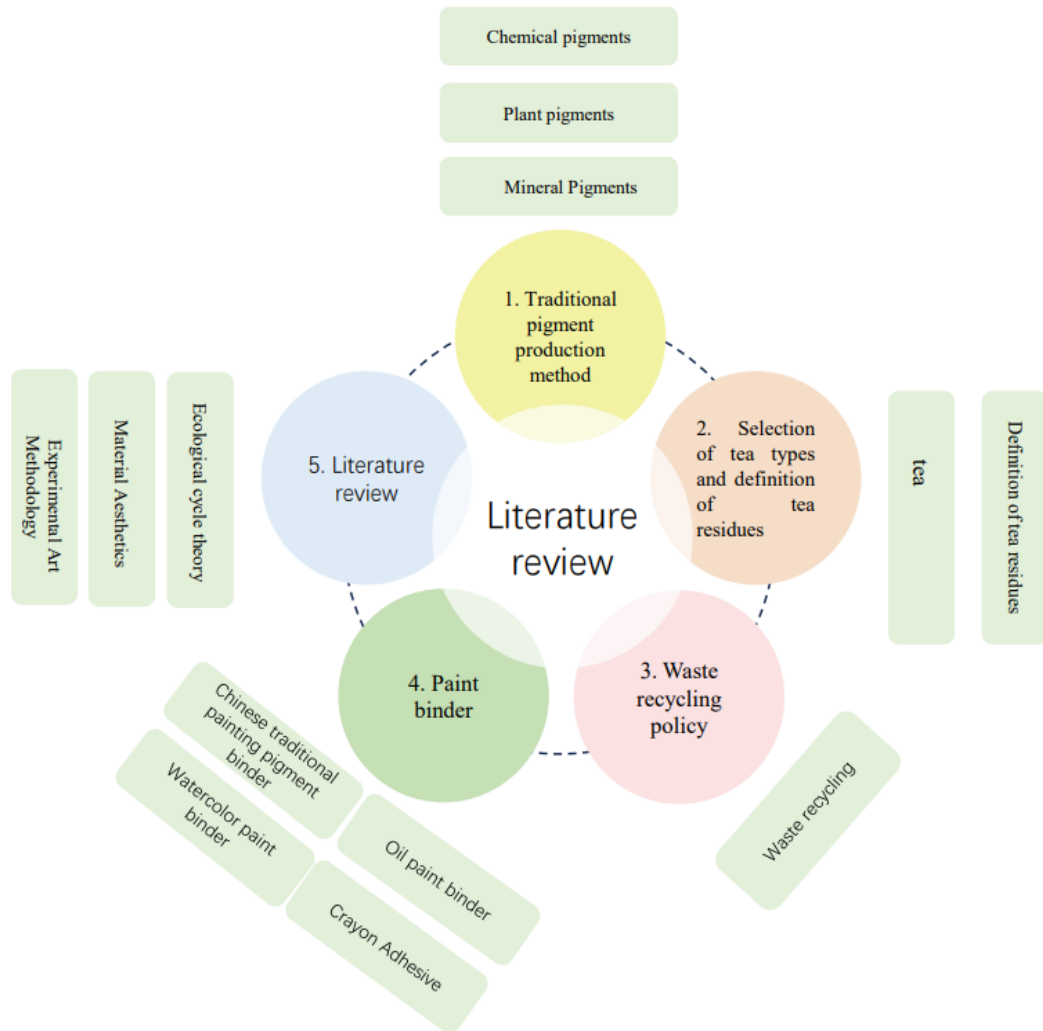
Driven by the global paradigm of sustainable development, resource recycling has emerged as a pivotal theme in contemporary art and scientific research (Odoh et al., 2014). This study aims to explore the synthesis of painting pigments from tea residues and their application in color testing on paper substrates.

The tea varieties selected for this research include Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea. Waste tea residues were collected from milk tea shops, sorted, and classified before being subjected to experiments with various chromatic fixatives, modifiers, and precipitants. Through a comprehensive literature review, this study establishes the theoretical and practical foundations for tea residue pigment research, demonstrating its applicability in painting. First, the history and evolution of painting pigments are discussed in conjunction with literature on traditional pigment production, providing a reference for tea residue pigment synthesis. Secondly, the definition of tea residues and the structural composition of tea leaves are analyzed. Next, an overview of waste recycling policies is presented, followed by an explanation of binding agents in Chinese painting, watercolor, oil painting, and pastel pigments. Finally, art theories are explored, including the application of semiotic and ecological aesthetics theories in artistic creation.

To this end, this chapter examines the multi-dimensional context through five key aspects

1. Traditional pigment production techniques
2. Selection of tea varieties and definition of tea residues
3. Waste recycling policy frameworks
4. Compositions of painting binders
5. Art theoretical frameworks

Figure 3
Literature review framework



Note. drawn by the author

2.1 Traditional pigment production

In traditional painting pigment production, pigment sources are typically categorized into mineral pigments, plant pigments, and chemical pigments. Each category possesses distinct production methods and characteristics, with different types of pigments synthesized through varied extraction techniques and binding media.

2.1.1 Mineral pigments

Mineral pigments are colorants extracted from natural ores. These minerals undergo crushing, sieving, purification, and grinding into fine powders with impurities removed, followed by mixing with binders to form pigments. Renowned for their durability, high chromatic saturation, and lightfastness, mineral pigments are widely used in traditional Chinese painting and other artistic practices. However, mineral pigments are scarce and costly, with some—such as realgar and orpiment—being toxic, necessitating professional processing. (LeCroy, 2022)

Traditional Production Methods:

Mineral pigment production typically involves multiple grinding of ores (e.g., malachite, azurite, cinnabar) until reduced to fine powders. After grinding, impurities are washed away, and pigments are classified by particle size into different grades. For Chinese painting pigments, traditional colloid binders (e.g., animal glue or gelatin) are added to complete the formulation.

Case Study: Realgar Ore

Raw Material:

Realgar, an arsenic sulfide mineral commonly occurring as orange-yellow granular solids or powders.

Production Steps:

1. Crush realgar ore into small fragments, rinse to remove surface debris, and tweeze out residual impurities.
2. Grind the purified ore into a fine powder using a grinder.
3. Wash the powder with water, allowing finer particles to suspend; decant the suspension. Repeating this process yields powders of varying particle sizes.
4. Select powders based on specific painting requirements.
5. Combine the screened fine powder with appropriate binders to form pigment slurries for artistic use.

Figure 4

The process of grinding mineral pigments with water.



Note. Internet, source: https://www.cdstm.cn/gallery/wzl/upack/201712/t20171207_655641.html. Search time: 2024.

2.1.2 Plant pigments

Plant pigments are natural colorants extracted from plant sources, typically derived from leaves, flowers, fruits, or bark. These plant materials undergo grinding, boiling, and extraction, followed by separation of pigments and addition of precipitating agents to form sediments, which are then processed into usable pigments. Renowned for their soft and natural hues, plant pigments are widely suitable for producing painting colors and textile dyes. (Ngamwonglumlert et al., 2017)

Traditional Production Methods:

Plant pigment production typically involves harvesting plant materials (e.g., petals or leaves), boiling them to extract colorants, and subsequently filtering and evaporating excess water. Mordants such as alum are often incorporated to enhance pigment stability and binding capacity.

Case Study: Indigo

Raw Material: Indigo, a blue dye extracted from the leaves of *Indigofera tinctoria*.

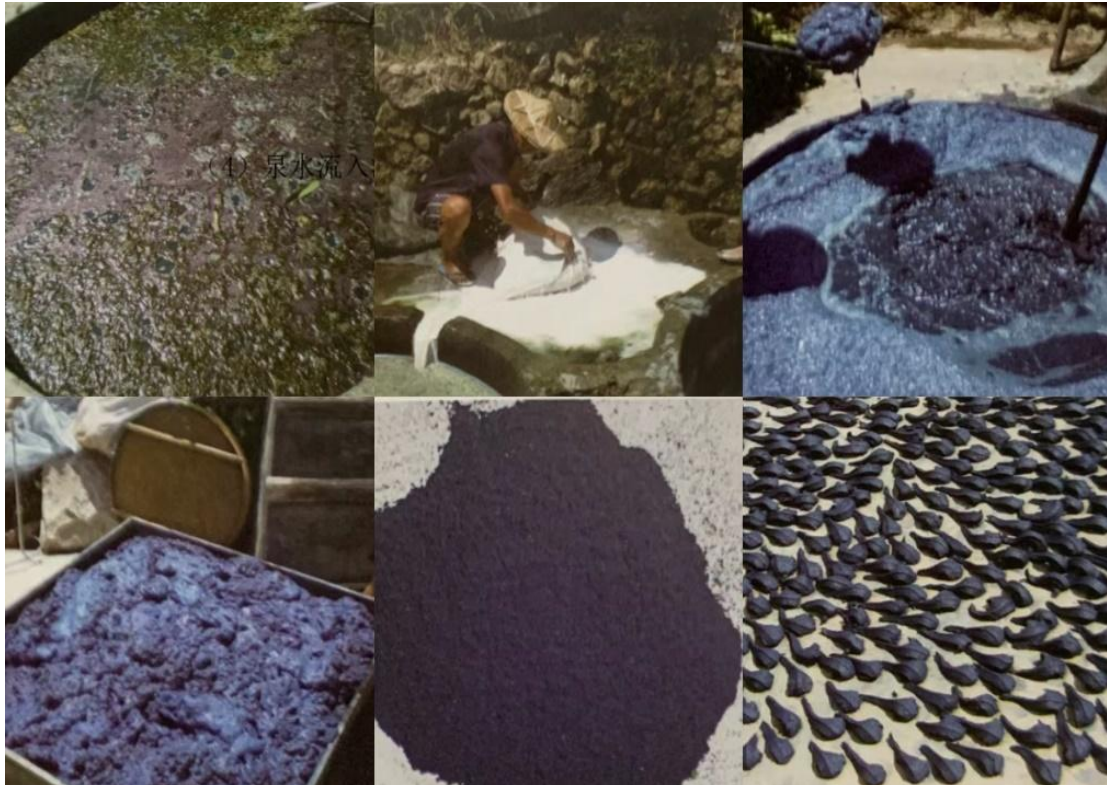
Production Steps:

1. Collect indigo plant leaves and soak them in water for fermentation.

2. Introduce oxygen through stirring to oxidize the fermented solution, forming a dark blue indigo precipitate.
3. Filter and evaporate the mixture until concentrated indigo paste remains.
4. Combine the indigo paste with colloidal binders to formulate the pigment.

Figure 5

The process of making plant-based "indigo" pigment.



Note. Online, source: "Chinese Plant Dyeing Techniques". Search time: 2024.

2.1.3 Chemical pigments

Chemical pigments are colorants synthesized in laboratories through chemical reactions to produce specific hues. Characterized by high stability and chromatic diversity, these pigments find extensive use in modern industry and painting.

Traditional Production Methods:

Chemical pigment synthesis involves complex procedures, typically requiring the mixing and reaction of chemical reagents. For instance, synthetic blue pigments like Prussian blue are produced via reactions between metal salt solutions and other chemical compounds. (Solomon et al., 2011)

Case Study: Prussian Blue

Raw Materials: Iron salts (e.g., ferric chloride) and cyanide solutions.

Production Steps:

1. Mix iron salt with potassium cyanide solution to initiate a chemical reaction, yielding a blue precipitate.
2. Filter and wash the blue precipitate to remove impurities.
3. Dry the precipitate, grind it into a fine powder, and blend it with binders to formulate the pigment.

Figure 6

Prussian blue pigment powder.



Note. Online, source: <https://www.puedomezclar.com/tintes-y-pigmentos/pigmentos-tatuajes-y-estetica/puedo-mezclar-pigmento-azul-black-buddha-con-tinta-roja-dringenberg/>. Search time: 2024.

These three categories of pigments each exhibit distinct advantages and application contexts. The production processes of these pigments not only showcase the richness of traditional craftsmanship but also offer technological and material references for the research on tea residue pigments.

2.2 Selection of Tea Varieties and Definition of Tea Residues

2.2.1 Tea

1. The structure of the tea tree (*Camellia sinensis*) comprises buds, leaves, stems, roots, flowers, fruits, and seeds, with each component playing a crucial role in the tree's growth and the quality of tea products.

Buds:

Tea tree buds typically refer to tender shoots, commonly known as "tea buds" or "tea tips." Characterized by their delicate form and rapid growth, they require frequent harvesting.

Leaves:

Tea leaves are the primary harvested parts of tea trees, categorized into young and mature leaves. Young leaves are abundant in amino acids, aromatic compounds, and phenolic substances, serving as key determinants of high - quality tea. Although mature leaves are less flavorful and aromatic compared to young leaves, they are suitable for producing low - cost tea or extracting tea polyphenols.

Stems:

As conduits for nutrient transport in tea trees, stems store and transfer plant metabolites, contributing to the aroma and taste profiles of tea.

Roots:

The tea tree root system is well - developed, consisting of a main root and lateral roots. These roots enable the plant to deeply absorb minerals and water from the soil.

Flowers:

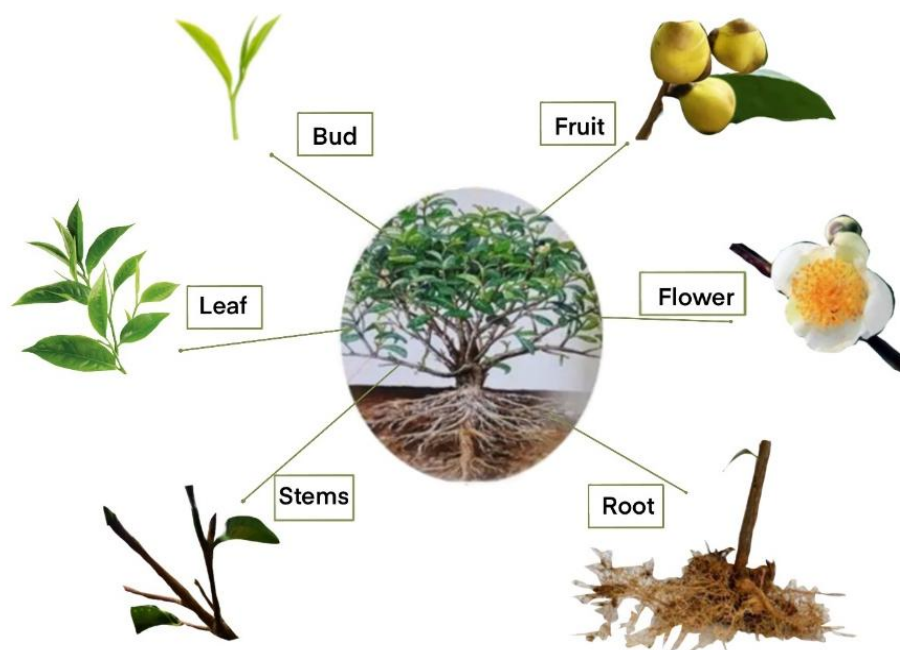
Tea tree flowers are small, white, and emit a strong fragrance.

Fruits and Seeds:

The fruit of the tea tree is a triangular capsule housing seeds. These seeds are utilized for propagating new tea trees and also contain oils that can be extracted for applications in cosmetics and other industrial sectors.

Figure 7

Basic structure of a tea tree



Note. drawn by the author

2. Chinese black tea and green tea

Black tea is a fully fermented tea. During the tea - making process, through rolling and fermentation, tea polyphenols are oxidized to produce theaflavins and thearubigins, endowing it with a deep red hue.

Figure 8

Chinese black tea liquid.



Note. Photo taken by the author.

Green tea is an unfermented tea, in which chlorophyll and tea polyphenols are preserved through high-temperature fixing. It features an emerald green or yellow-green color.

Figure 9

Chinese green tea liquid



Note. Photo taken by the author.

3. Thai black tea and green tea

Thai black tea is often blended with spices during production, resulting in a darker tea soup than Chinese black tea. It exhibits a deep red hue and a robust aroma.

Figure 10

Thai black tea liquid.



Note. Photo taken by the author.

Thai green tea, influenced by Chinese green tea, emphasizes maintaining the freshness and fragrance of tea leaves during production.

Figure 11

Thai green tea liquid



Note. Photo taken by the author.

To ensure the scientific rigor and comparability of subsequent pigment extraction experiments, this study categorized tea samples into four groups: Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea. This classification is based on the color characteristics of the brewed tea soup, integrated with the differences in tea-making techniques and consumption habits between China and Thailand.

In the Chinese tea system, black tea undergoes full fermentation, yielding a tea soup typically in orange-red, dark brown, or even red-black hues. These hues are associated with high pigment concentration and pronounced dyeing capacity. By contrast, green tea is unfermented, preserving its yellow-green or grass-green tones that reflect its lighter natural plant pigmentation. In Thailand, traditional and commercial black teas often incorporate spice or syrup flavorings. The tea leaves themselves undergo deep fermentation, resulting in an orange-red soup, while Thai green tea—similar to its Chinese counterpart—exhibits lighter coloring and grassy or jasmine notes.

Thus, this study classifies teas by soup color: orange-red varieties as "black tea" and yellow-green varieties as "green tea," with origin (China/Thailand) serving as a secondary discriminator. This approach not only facilitates subsequent comparative analysis of pigment reactions but also enables tracking of relationships between color tone, precipitation efficiency, and pigment extractability across tea types under chemical treatment.

2.2.2 Definition of tea residues

1. Source and Composition of Tea Residues

Tea residues denote the solid byproducts remaining after tea brewing or processing, primarily composed of tea fiber, residual polyphenols, and minerals. Despite the extraction of most flavor compounds, tea residues retain measurable pigments and antioxidants, rendering them valuable for recycling.

Figure 12

Tea waste from a milk tea shop photographed during the survey



Note. Photo taken by the author.

Figure 13
Tea leaves from a milk tea shop



Note. Photo taken by the author.

2.Characteristics of Tea Residues

High Moisture Content:

Tea residues typically exhibit elevated moisture levels, necessitating sun-drying or oven-drying for storage and subsequent processing.

Pigment Retention:

Black tea residues often contain residual thearubigins, whereas green tea residues preserve chlorophyll and carotenoids—components amenable to natural pigment extraction.

3.Environmental and Economic Significance of Tea Residue Recycling

Waste Mitigation:

Recycling tea residues extends their lifecycle, endowing them with renewed utility to reduce waste accumulation.

Resource Circulation:

As a low-cost, renewable resource, tea residues facilitate the advancement of a green economy by promoting material recycling.

Statistically, tea's global popularity generates substantial tea residues. Through rational recycling, these residues can yield economic value while mitigating environmental pollution. The conversion of tea waste into painting pigments exemplifies a circular economy model, aligning with sustainable development objectives. (Debnath et al., 2021)

2.3 Recycling of waste

Statistically, tea's global popularity generates substantial tea residues. Through rational recycling, these residues can yield economic value while mitigating environmental pollution. The conversion of tea waste into painting pigments exemplifies a circular economy model, aligning with sustainable development objectives.

2.3.1 Theoretical Framework of Sustainable Development and Material Circulation

In alignment with the UN 2030 Agenda for Sustainable Development, Sustainable Development Goal (SDG) 12—"Responsible Consumption and Production"—advocates for significant reduction of waste generation and promotion of recycling and lifecycle extension (Bexell & Jönsson, 2017). Within this framework, "material circulation" and "lifecycle extension" have emerged as foundational design principles for innovative initiatives.

Waste recycling represents a pivotal strategy to maximize resource efficiency and mitigate environmental pollution, closely aligning with UN SDGs. Specifically, SDG 12 underscores the necessity of reducing waste through circular economy models, which reconceive waste as a potential resource for value rediscovery and reuse.

Figure 14

The picture comes from the Internet. United Nations Sustainable Development Goals, Goal 12, 12.5



Note. From web page file [Goal 12 | Department of Economic and Social Affairs](#). Search time: 2024.

Figure 15

Circular economy Action plan proposed by the European Union



Note. From web page file [Circular economy action plan - European Commission](#). Search time: 2024.

Economic Benefits of Recycling:

Waste recycling serves not only as an environmental protection strategy but also enhances waste economic value through innovative products (e.g., pigments). The development of tea residue pigments exemplifies how waste can be transformed into secondary processing resources, promoting synergistic economic-ecological development.

Case Studies and Policy Support:

Numerous domestic and international success stories illustrate that waste recycling relies on policy support and market participation. For instance, China's *Solid Waste Pollution Prevention and Control Law* and Thailand's *Green Economy Initiative* both underscore the role of waste reuse in sustainable development. Research on tea residue recycling thus represents a tangible practice to foster the green economy and sustainable development.

Design scholar Manzini (Manzini & Jégou, 2003) has advocated that "low-energy materials" and "local material recycling" should become core directions for future green design. He emphasizes that materials should be evaluated not only for functionality but also for their social and ecological impacts. Artistic creation is shifting from the traditional model of "high material consumption + high-energy manufacturing" toward low-carbon material utilization and cultural reuse.

In this context, "renewable pigments" have emerged as a frontier in environmental art—where pigments function not merely as expressive tools but as media for reflecting on human-nature relationships. For example, the concept of *sustainability-driven design thinking* proposes that designers should source creative materials from local waste resources, reestablishing connections between materials and indigenous culture. (Garcia & Dacko, 2015)

2.3.2 Existing Research and Development Trends of Waste Pigments

This study has identified existing research on natural pigments and waste-derived pigments, which share a common characteristic with tea residues as food waste—thereby offering methodological references for this research.

Example: Peel Dyes

Studies on onion peels have demonstrated that adjusting pH and using mordants (e.g., alum) can yield diverse color tones, with preliminary applications in textile and paper dyeing. (Gumrukcu et al., 2008)

2.4 Paint binder

As a quintessential form of artistic expression, painting has traversed diverse historical epochs, its development shaped not only by cultural and historical contexts but also by advancements in materials and techniques. The expressiveness of pigments—critical components of painting—hinges on both the source of colorants and the binder systems used to fix them. In artistic creation, pigment selection and

binder application are determinant factors for visual outcomes, as different painting genres (e.g., Chinese ink wash, watercolor, oil painting, and pastel) impose distinct requirements on pigment attributes: physical properties, dry/wet behavior, gloss, and fluidity.

Binders serve as the medium anchoring pigment particles to canvas or paper, with variations in binder composition—dictated by genre-specific techniques—giving rise to unique artistic expressions. Understanding the binder systems of traditional pigments is foundational to transforming tea residues into viable pigments and integrating them into artistic practice.

The following sections provide a brief overview of painting forms relevant to this study, along with their pigment characteristics:

2.4.1 Chinese traditional painting pigment binder

Traditional Chinese painting primarily employs rice paper and silk as supports, with pigments derived from natural minerals (e.g., azurite) and plants. The binder system typically consists of natural colloidal substances like gelatin or deer glue (Li & Zhang, 2020), imparting the artwork with delicate transparency. Due to the high water absorbency of rice paper and the challenge of color coverage, Chinese painting pigments exhibit specific characteristics:

1. Color Pigments: Require fine particle size, dilutability, and resistance to flaking.
2. Binders: Must form a rapid-drying film without compromising transparency.

In this study, tea residue-derived color pigments were incorporated into colloidal binder systems. Testing revealed favorable sedimentation properties and penetration behavior, making them particularly suitable for achieving smudging and color diffusion effects. Compared to traditional azurite and ochre, tea residue pigments exhibit a grayish tone, which aligns with the aesthetic of "natural simplicity" in artistic expression.

Figure 16
Exhibition of traditional Chinese paintings



Note. Photo taken by the author.

Figure 17
Traditional Chinese painting pigment binder: gelatin



Note. Photo taken by the author.

2.4.2 Watercolor pigment binder

Watercolor is celebrated for its luminosity and transparency, with pigment transparency and fluidity infusing artworks with dynamic vitality. Watercolor binders primarily consist of gum arabic, natural ox bile, honey, and trace glycerin (Gärtner, 2021), though binder compositions may incorporate diverse media. These binders enhance pigment adhesion while preserving color vibrancy, offering a flexible medium that facilitates experimental exploration of tea residue pigments.

Key requirements for watercolor pigments include:

1. High solubility and transparency;
2. Color stability across dry-wet transitions;
3. Excellent water-mixability for rapid application and color blending.

Tea residue pigments demonstrate optimal flow properties when combined with gum arabic. The addition of honey and natural ox bile further enhances their fluidity, gloss, and diffusion characteristics, making them suitable for large-scale washes and layering. While slightly lower in color saturation, the unique granular texture of tea residue pigments introduces new dimensionality to watercolor expression.

Figure 18

Watercolor painting display



Note. Photo taken by the author.

Figure 19
Watercolor paint binder



Note. Photo taken by the author.

2.4.3 Oil paint bonding medium

Oil paints typically employ drying oils (e.g., linseed oil) as binders, yielding saturated hues with strong covering power. These pigments maintain colorfastness for decades, suitable for layering and impasto techniques. In tempera painting, egg yolk serves as the traditional binder (Johnson & Packard, 1971). For this study, oily binders (linseed oil and walnut oil) were selected for container preservation, enabling exploration of tea residue pigments' performance in lipid-based systems.

Pigment Particle Requirements:

1. Uniform particle size with stable dispersion;
2. No oil separation after binder incorporation;
3. Intrinsic covering power of pigment particles.

Tea residue pigments, containing fibrous particles and exhibiting colorfastness, form natural matte color blocks when mixed with linseed oil. Noteworthy is their slightly low oil dispersibility, prone to particle stratification or uneven coverage—challenges mitigated by repeated grinding and mixing. Thus, in oil painting, tea residue pigments are better suited for textural effects or color blending rather than high-coverage primary colors.

Figure 20
Oil painting display



Note. Photo taken by the author.

Figure 21
Oil paint medium



Note. Photo taken by the author.

2.4.4 Crayon adhesives

In Anglophone contexts, "crayons" typically denote drawing sticks with wax, fat, and/or oil binders (Ellis & Yeh, 1998). Crayon pigments consist of solid color blocks formed by combining pigment particles with wax binders (e.g., white beeswax, carnauba wax, resin), where the wax matrix imparts unique textural effects suitable for bold color blocking and tactile expression. The integration of tea residue pigments in crayon formulation not only upcycles waste materials but also explores the expressive potential of color layering.

Pigment Particle Requirements:

1. Fine particle size with stable wax compatibility;
2. Wax-to-pigment ratio and hardness directly influence application feel;
3. Post-application wax film formation provides paper coverage while resisting excessive layering.

Tea residue pigments combined with beeswax yield crayons with a hard consistency and natural granular texture. Their colorfastness and rough tactility suit themes like landscapes, tree bark, and natural textures. Notwithstanding, lower color intensity compared to commercial crayons positions them ideally as experimental tools for "natural pigment crayon" art practices.

Figure 22
Crayon drawing display



Note. Photo taken by the author.

Figure 23
Crayon Adhesive



Note. Photo taken by the author.

This chapter establishes the theoretical framework for subsequent analyses, offering a multi-dimensional perspective to illuminate the artistic potential and expressiveness of tea residue pigments across diverse painting genres.

2.5 Art theory

Art theory provides theoretical underpinning for artistic creation. This study foregrounds "cyclical continuity" as its core theme, integrating ecological cycle theory with semiotic theory to interpret creation through philosophical and artistic lenses, thereby imparting deeper semantic layers to artistic work.

2.5.1 Ecological cycle theory

Ecological cycle theory emphasizes the sustainable utilization of resources and the cyclical dynamics of natural systems. Originating in ecological research, this theory has permeated the artistic domain, offering creators novel conceptual frameworks. It advocates using artistic practices to galvanize environmental awareness and resource recycling. In painting, the application of cyclical theory extends beyond formal aesthetics to material selection—such as repurposing tea waste as pigment sources—thereby illustrating art's intimate dialogue with nature.

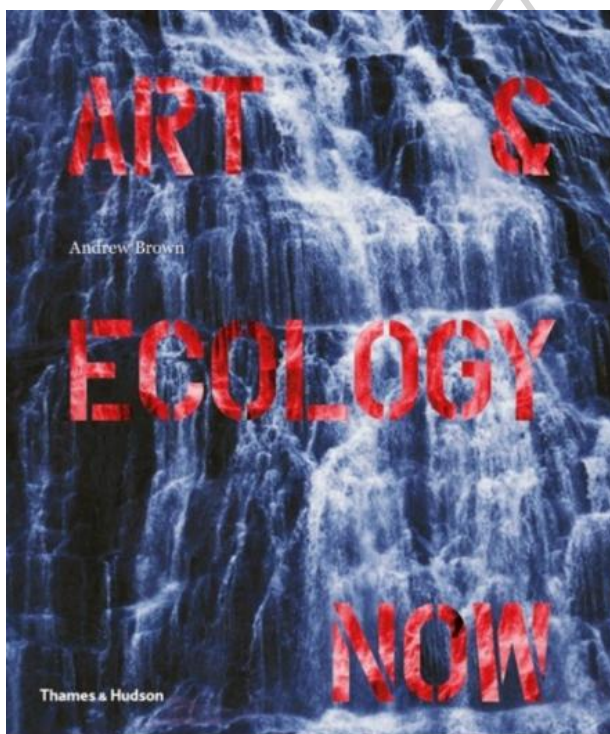
Andrew Brown posits in *Art and Ecology Now* that ecological art transcends mere naturalistic representation, instead advocating proactive intervention in restoring and redefining natural systems (Brown, 2014). Building on this premise, this study

reintegrates tea residues—minor waste products of consumer society—into material systems, establishing an internal circulation model: "short-term consumption → material transformation → artistic production".

Through the extraction, sedimentation, and reconstitution of tea residue pigments, this research achieves not only the physical reuse of waste but also a symbolic cycle from "uselessness to meaning". The tea residue pigments employed in artworks function as "visible cycles", embodying a non-exploitative, non-linear cooperative relationship between humanity and nature.

Figure 24

Book: Art and Ecology Now.



Note. The image is from the literature cited in the article and the cover of the book. Search time: 2025.

2.5.2 Material aesthetics

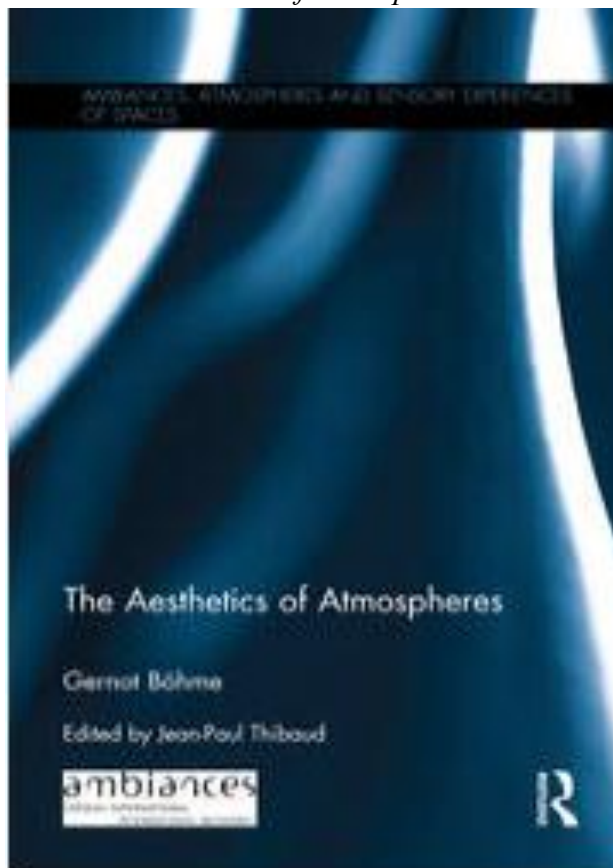
Material aesthetics foregrounds the perceptual experience, cultural significance, and aesthetic value of materials in artistic creation. In traditional art, pigments and paper are often viewed as vehicles for conveying imagery and meaning; however, from a material aesthetic perspective, materials themselves constitute part of the artwork's semantic structure. The origin, texture, processing, and application of materials collectively form the "material language" of artworks.

As a theoretical framework, material aesthetics asserts that materials possess inherent aesthetic value—they are not merely expressive tools but carriers of meaning,

memory, culture, and temporality. German philosopher Gernot Böhme posits in *The Aesthetics of Atmospheres*: "Material is not neutral; it has the capacity to project meaning into the world."(Böhme & Thibaud, 2016)

Figure 25

Book :*The Aesthetics of Atmospheres*.



Note. The picture comes from the literature cited in the article and the cover of the book. Search time: 2025.

In contemporary art, an increasing number of creators are mining expressive resources from material attributes—including texture, provenance, historical context, and social significance. El Anatsui's iconic use of discarded bottle caps in sculpture exemplifies this material aesthetic practice, where recycled materials retain their "identity" while acquiring new artistic meaning. Similarly, tea residues in this study preserve the cultural memory of their prior role as consumable beverage components, even after transformation into artistic materials.(Binder, 2008)

Figure 26
Works by El Anatsui



Note. Image source: web search editorial-elanatsui-0014-cmyk.jpeg (1000×667), Search time: 2025.

Tea residue pigments, characterized by heterogeneous particles, muted gray tones, and a restricted color gamut, embody their "non-industrial" and "naturally derived" identities. These textural qualities become integral to visual language, enabling creators to convey multi-layered meanings about nature, consumption, and regeneration through materiality itself.

The tea residue pigments employed in this study originate from beverage industry byproducts, re-entering artistic contexts after dissociating from their original functional role. This material transmutation not only addresses contemporary society's sustainable development imperatives but also positions artistic creation as an agent for ecological intervention, demonstrating a fusion of material form and conceptual intent. Although tea residues are categorized as waste, their natural texture, unique chromaticity, and temporal characteristics introduce novel aesthetic expressions during pigment transformation. In this regard, materials serve not merely as expressive media but as vital carriers for environmental consciousness, aesthetic inquiry, and cultural reflection.(Ingold, 2013)。

2.5.3 Experimental art methodology

Experimental art methodology emphasizes integrating scientific thinking, cross-media exploration, and material experimentation into the creative process to

transcend the medium constraints and expressive conventions of traditional art. This approach highlights process openness and uncertainty, treating "experimentation" as an inherent component of artistic inquiry. Within this framework, artists function not merely as expressers but as active explorers, iteratively refining their creative trajectories through multi-faceted experiments on material properties, medium dynamics, and visual effects (Candy & Edmonds, 2018).

As noted in *Theories and Documents of Contemporary Art*, "Experimental art is defined by its subversion of established norms, expansion of material boundaries, and primacy of perceptual experience." The inherent instability and unpredictability of tea residue pigments—As non-traditional materials—embody these experimental art principles, with their uncontrollable qualities becoming integral to the creative practice. (Stiles & Selz, 2012)

Guided by this rationale, the study eschews pre-set color objectives, instead prioritizing the "material reaction process" to explore synergies between diverse additives and binding media. The work does not aim to replicate the effects of traditional watercolor, Chinese ink painting, or oil painting but centers on tea residue pigments, developing novel expressions rooted in their physical attributes and aesthetic potential.

Furthermore, experimental art's tenet that "materials are ideas" aligns profoundly with this study's concept of "imparting a second life to waste." Under this methodological framework, tea residues transcend their role as "resource-deficient substitutes," emerging as media for articulating philosophical thought.

This study employs an experimental methodology: subjecting various tea residue types to chemical reactions, extracting pigment powders, and formulating them with binders to create paintable pigments. The process encompasses multiple stages, including material screening, chemical reaction control, and color stability testing.

Through this experimental approach, the study not only expands the frontiers of art materials but also investigates how natural waste can engage with contemporary artistic creation in innovative forms. Emphasizing "knowledge generation through process," this methodology provides a material- and process-driven knowledge production mechanism for artistic practice.

2.5.4 Theoretical integration: Double circulation of materials and meaning

In summary, ecological cycle theory provides the philosophical foundation of this study, material aesthetics grants materials inherent aesthetic and symbolic status, and experimental art methodology guides the practical approach and intellectual trajectory. These three theories operate in parallel, collectively constituting a comprehensive logical framework of material-method-meaning: ecologically, the integration of tea residues into artistic systems represents "resource recycling"; aesthetically, tea residue pigments function as "semantic symbols"; experimentally, they embody "the deconstruction and reconstruction of visual language."

Table 1
Theoretical summary table

Theoretical Dimension	Core Viewpoint	Performance in this study
Ecological cycle theory	Materials should be integrated into the closed-loop system of resource-use-regeneration.	Tea residues, transformed from beverage waste into pigments, re-enter the creative ecosystem.
Material Aesthetics	Materials embody historical, cultural, and symbolic values.	Tea residues preserve their natural texture and cultural memory, thus constituting integral components of the artwork's narrative.
Experimental Art Methodology	Emphasis on process-driven approaches, open-ended media, and material primacy.	Rejecting standardized color matching and emphasizing how materials "dictate" creative style.

Note. drawn by the author

2.6 Case Study

To deepen the understanding of natural materials in contemporary artistic practice, this article examines the creative practices of select representative contemporary artists who employ natural pigments, plant-based materials, or organic waste-derived pigments. Their artistic explorations not only expand material discourse but also provide theoretical frameworks and aesthetic orientations for the transformation of tea residue pigments in this study. The following presents an analytical summary of four to five paradigmatic cases:

2.6.1 Case 1: Su Yu-Xin - Telling Geographical Memory with Natural Minerals

Taiwanese-born contemporary artist Su Yu-Xin, based in Los Angeles, manually collects natural minerals—including pearls, volcanic dust, meteorites, and crystals—grinding them into pigment powders for her practice. Each material originates from geographical locations she has engaged with: for instance, using Taiwanese sulfur or Hunan malachite to address land memory and material narratives.

Su's methodology embodies the tenet that "materials are meanings," yielding a unique visual language at the nexus of ecological consciousness and cultural identity. Her practice of handcrafting natural pigments provides a valuable precedent for the experimental exploration and aesthetic interpretation of tea residue pigments in this study.

Figure 27

The Guardian (2025). *Su Yu-Xin uses handmade pigments to paint place, time and memory.*



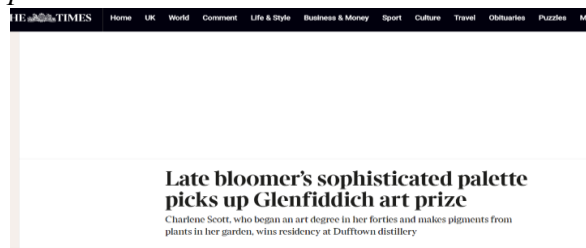
Note. Image source: [The landscape artist who makes her paint from pearls, crystals and volcanic dust | Painting | The Guardian](#). Search time: 2025.

2.6.2 Case 2: Charlene Scott - Self-Grown Plant Dyes and Ecological Paintings

Scottish artist Charlene Scott cultivates dye plants in her garden and extracts natural pigments using artisanal techniques for paper-based artwork. Her practice emphasizes a minimalist chromatic vocabulary, integrating ecological principles into every stage of art material processes. This end-to-end control—encompassing planting, pigment extraction, and artistic application—embodies sustainability while reinforcing the "local" and "non-industrial" attributes of natural materials. Her methodology closely aligns with this study's approach to repurposing tea residues as ecologically sustainable artistic media.

Figure 28

The Times (2025). *Late bloomers: artist wins Glenfiddich award with natural dye palette.*



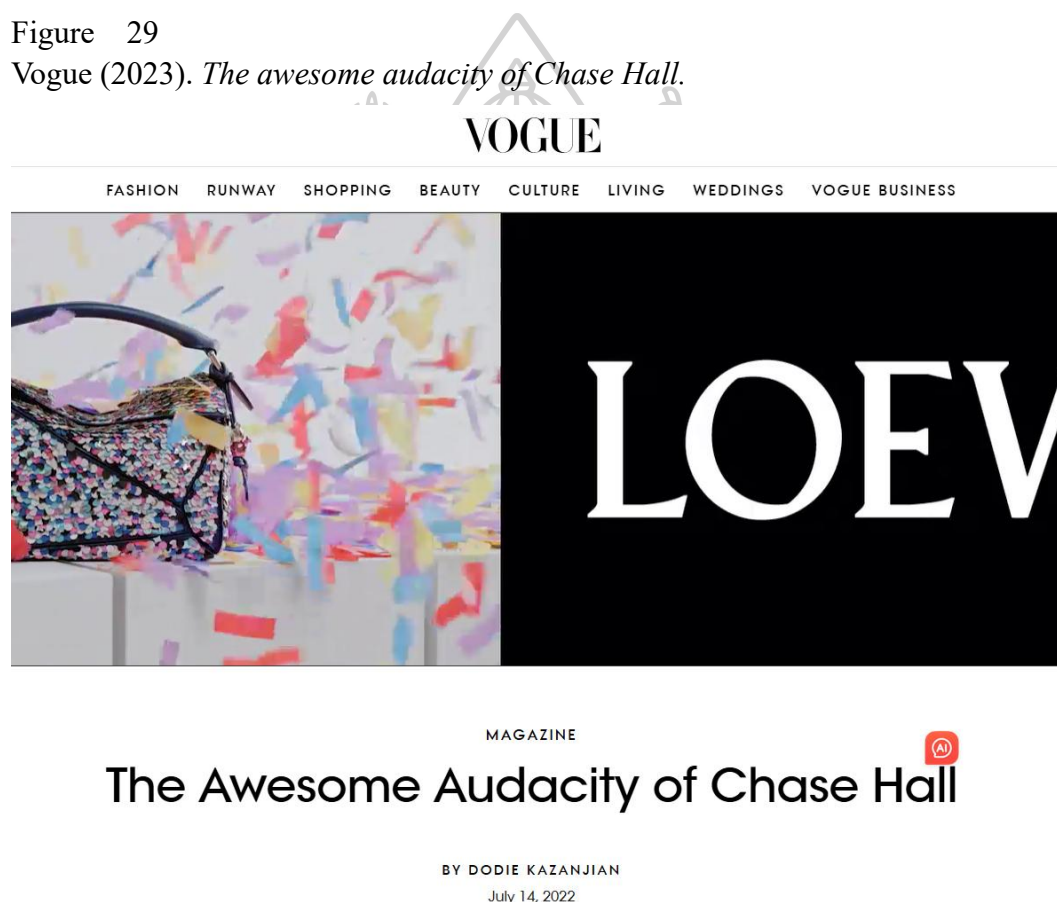
Note. Image source: [Late bloomer's sophisticated palette picks up Glenfiddich art prize](#). Search time: 2025.

2.6.3 Case 3: Chase Hall - Social Symbol Translation of Coffee Grounds

American artist Chase Hall employs used coffee grounds to create portraits on untreated cotton canvas, addressing African identity and historical memory without priming the substrate. His use of unaltered domestic waste constitutes both a material experiment and a cultural expression through the symbolism of "coffee". The brownish texture and natural particulate matter in his works thereby enhance their social critique. This approach to integrating waste materials into artistic expression provides a parallel "material-identity-society" symbolic transformation trajectory for tea residue pigments.

Figure 29

Vogue (2023). *The awesome audacity of Chase Hall*.



Note. Image source: [The Awesome Audacity of Chase Hall | Vogue](#). Search time: 2025.

2.6.4 Case 4: Antony Gormley et al. - Environmentally friendly creation of seaweed ink

In the *Art for Your Oceans* environmental art project, Antony Gormley and collaborators created works using ink extracted from Scottish seaweed. Rich in natural colloids and organic pigments, this seaweed-derived ink serves as an

eco-friendly alternative to petrochemical-based pigments, yielding a visually dense and pure aesthetic. Artists employed this medium to address climate change and natural cycle issues, demonstrating how renewable natural resources can be harnessed for artistic expression. This extraction and creative use of sustainable materials not only expands the expressive potential of natural pigment materials but also offers methodological insights for the transformation of tea residue pigments.

Figure 30

The Guardian (2025). *Artists swap paint for seaweed ink in ocean-themed challenge.*

Seascape: the state of our oceans
Oceans

Seascape: the state of our oceans is supported by

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About this content

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Wed 23 Apr 2025 05:00 BST

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'It's almost like Vaseline': artists including Antony Gormley swap paint for seaweed ink in art challenge

Ocean-inspired artworks created using kelp-based pigment will be sold to raise funds for conservation



Caragh Thuring says the smell of the ink evoked her childhood in the west of Scotland.

Note. Image source: ['It's almost like Vaseline': artists including Antony Gormley swap paint for seaweed ink in art challenge | Oceans | The Guardian](#). Search time: 2025.

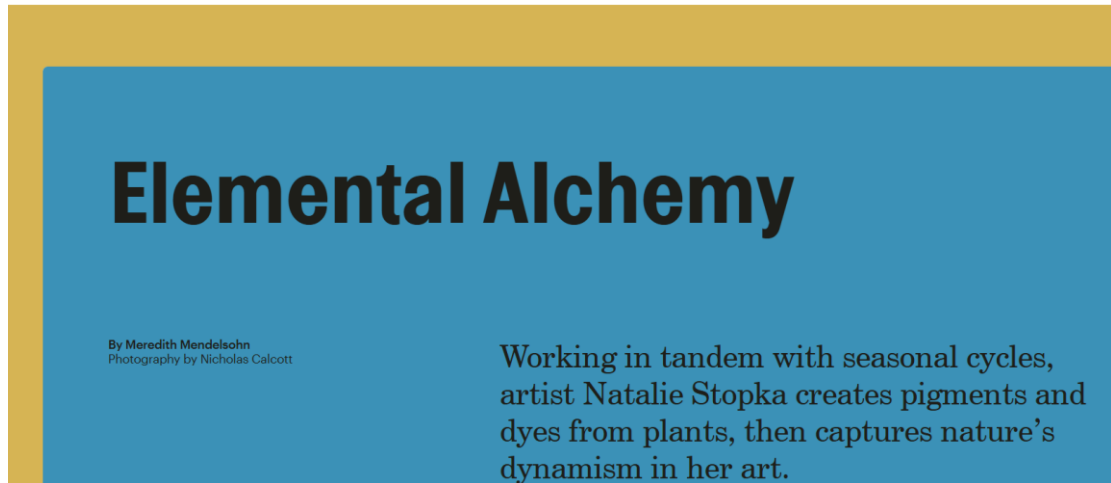
2.6.5 Case 5: Natalie Stopka - Plant dyes and marble pattern experiments

American artist Natalie Stopka has dedicated her practice to handcrafted plant dyeing and paper marbling, extracting pigments from natural sources like madder, hollyhock, and indigo. Through traditional *ebru* marbling techniques, she creates unique textural patterns, emphasizing the natural chromatic shifts, pigment-water interactions, and "uncontrollable" poetic qualities inherent in materials. Stopka's integration of botanical pigments with pattern design offers a novel experimental

paradigm for this study's exploration of tea residue pigments' expressivity and medium adaptability.

Figure 31

Eames Institute (2024). *Elemental Alchemy: the color work of Natalie Stopka*.



Note. Image source: [Botanic Pigments & Dyes— Artist Natalie Stopka | Kazam! Magazine](#). Search time: 2025.



CHAPTER 3

RESEARCH METHODS

This study employs a mixed-methods approach combining qualitative and quantitative research to ensure a comprehensive and systematic inquiry into the development and application of tea residue pigments. The qualitative component centers on pigment design and artistic expression, investigating their expressive potential through material trials and artistic production, analyzed through theoretical lenses of "ecological cycle" and "material aesthetics." The quantitative research focuses on gathering stakeholder feedback via structured surveys, particularly user experience metrics and evaluative feedback on tea residue pigments, to validate material acceptability and practical applicability.

Furthermore, the study engaged with painting and pigmentation experts for semi-structured interviews, soliciting professional evaluations and recommendations to enhance research credibility and practical relevance. The methodological framework is outlined as follows:

1. Material Preparation & Process Optimization
2. Chromatic Analysis & Performance Testing of Tea Residue Pigments
3. Binder Compatibility Testing for Pigment Formulation
4. Stakeholder Feedback & Expert Consultation Analysis
5. Mixed-Method Data Collection & Multivariate Analysis
6. Findings Synthesis & Theoretical Framework Validation

3.1 Preliminary preparation stage

Prior to the formal initiation of this study, researchers undertook systematic preliminary work to ensure the scientific validity and feasibility of tea residue pigment production experiments. Spanning several months, these preparations involved literature review, on-site interviews, material collection, and preliminary testing, laying the groundwork for experimental design and data analysis.

First, by examining scholarly literature and technical protocols on traditional Chinese painting pigments and plant dye production, researchers gained insights into common extraction mechanisms and dyeing principles in natural materials, with particular focus on pigment chromatic properties, medium interactions, and preservation techniques. Traditional pigments, predominantly mineral- or plant-based and blended with colloidal media, provided a reference framework for this study's methodological approach.

Furthermore, to deepen understanding of practical operations and technical nuances in plant-based pigment production, researchers conducted interviews with experts in plant dyeing, acquiring first-hand knowledge on natural dye application and formulation. This process not only enriched the study's theoretical foundation but also

offered technical guidance and practical insights for subsequent tea residue pigment experiments. Photographic documentation of expert interviews and experimental procedures will be presented as supplementary materials to enhance research transparency and credibility.

Figure 32

Learn to use plants to extract pigments and make them into pigment powder



Note. Photo taken by the author.

Figure 33
Interview with pigment experts



Note. Photo taken by the author.

Figure 34
Learn to use plants to extract pigments and dye



Note. Photo taken by the author.

Figure 35
Production and fermentation of indigo pigment



Note. Photo taken by the author.

Subsequently, to assess the feasibility and variability of tea residues, researchers investigated standard pigment extraction and stabilization protocols in natural plant dyes—including alum, citric acid, baking soda, lime, and other reagents—to establish a chemical formulation basis for this study.

For pigment extraction, tea residues were first boiled in water to obtain a pigment solution, after which acidic or alkaline reagents were added to induce chromatic variations. These chemicals were classified into three functional categories: color fixatives, chromatic modifiers, and stabilizers.

Finally, through field surveys and material procurement, researchers collected four types of tea residues—Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea—along with drying apparatus, grinding instruments, and pigment binders. Completion of these preparatory steps established a robust foundation for subsequent material extraction, pigment synthesis, and artistic experimentation.

3.2 Implementation phase

3.2.1 Method

(1) Residue Collection Protocol

Researchers conducted field surveys at milk tea shops to collect tea residues, ensuring contamination-free collection and preventing admixture with other food waste.

(2) Taxonomic Processing

Collected residues were categorized by tea variety and origin into four groups: Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea—preserving each type's unique pigment properties. Classified residues were stored in labeled containers to maintain process accuracy.

(3) Drying and Archiving

Sorted tea residues were air-dried in sunny, ventilated areas to prevent mold growth. Dried materials were stored in sealed, moisture-proof containers to maintain stability.

Figure 36

Sorting and drying tea dregs



Note. Photo taken by the author.

2. Experiment on Color Fixatives, Chromatic Modifiers, and Precipitants

For pigment extraction from tea residues, the materials are first boiled in water to obtain a pigment solution. Acidic or alkaline reagents are then added to induce chromatic variations. Color fixatives stabilize hue consistency, chromatic modifiers adjust tonal characteristics, and precipitants facilitate the transformation of liquid pigments into solid deposits.

(1) Color Fixatives

Color fixatives are used to bind and stabilize pigment molecules in tea residue solutions during production, preventing discoloration or loss during drying or application. By enhancing pigment-fiber adhesion, fixatives improve colorfastness. Key fixatives employed in this study include:

Alum:

As a common fixative containing aluminum ions, alum stabilizes pigments and promotes substrate adhesion. It enhances chromatic vibrancy and improves fade resistance by cross-linking pigment molecules with the binding medium. (Lipson, 1935)

Odor: Odorless

Appearance: White powder or transparent crystalline solid

Chemical Composition: Potassium aluminum sulfate ($KAl(SO_4)_2 \cdot 12H_2O$)

Rationale for Selection: Alum, a conventional natural dyeing adjuvant, exhibits excellent metal ion complexing properties. It forms stable complexes with organic molecules within pigments, thereby enhancing color adhesion and longevity. In the context of tea residue pigments, alum effectively inhibits pigment migration during the drying process, improves the stability and shelf - life of color powders, and is compatible with watercolor and Chinese ink painting systems for subsequent pigment formulation.

(2) Color modifiers:

Color modifiers are employed to adjust the hue of pigments. Typically, this is achieved by altering the pH value or introducing various metal ions, which in turn influence the color's lightness and darkness. Diverse color modifiers can induce a wide array of chromatic transformations, thereby enhancing the versatility of tea residue pigments. The following color modifiers are utilized in tea residue pigments:

Copper sulfate: A copper - based compound, when added to the tea solution, imparts a green hue to the pigment. This phenomenon is prevalent among numerous plant - derived pigments. (Beever & Lipson, 1934)

Odor: Odorless, with a faint metallic scent when moist

Appearance: Bright blue crystalline solid

Chemical Composition: Copper sulfate ($CuSO_4 \cdot 5H_2O$)

Rationale for Selection: Copper sulfate reacts with tea polyphenol pigments, altering their chemical structure to induce chromatic shifts. Its metal ions (Cu^{2+}) significantly impact natural flavonoids, tannins, and other tea components, driving coloration toward blue-green or dark gray tones. In this experiment, copper sulfate was employed to explore the diversity of hue modulation in tea residue pigments.

Figure 37

Adding blue vitriol to the tea residue pigment solution.



Note. Photo taken by the author.

Figure 38

Adding blue vitriol to the tea residue pigment solution.



Note. Photo taken by the author.

Citric Acid: An organic acid that modulates pigment hue by adjusting solution acidity, typically enhancing color vibrancy. (Apelblat, 2014)

Odor: Fresh, acidic aroma

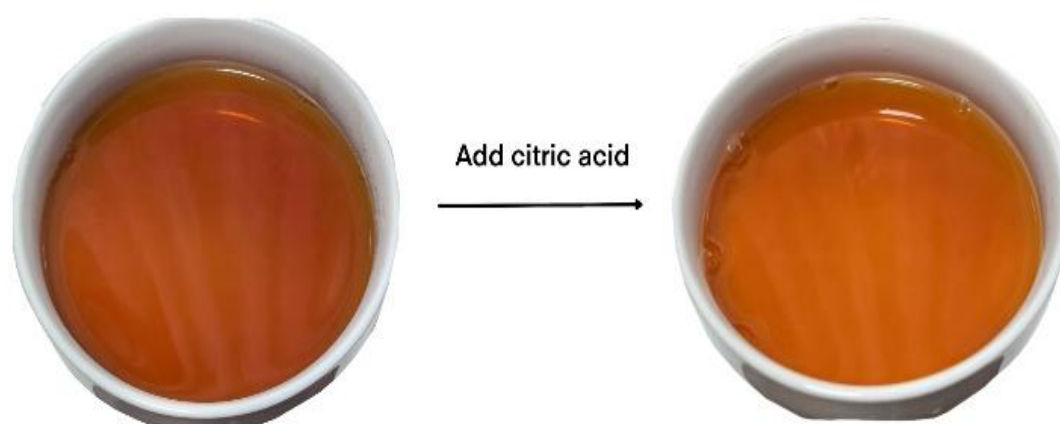
Appearance: White crystalline powder

Chemical Composition: $C_6H_8O_7$ (tricarboxylic acid structure)

Rationale for Selection: As a natural organic acid, citric acid regulates the pH environment of tea pigments, thereby influencing pigment structure and visual hue. In experiments, reducing the system pH with citric acid shifts certain tea pigments from orange-red to pink or light red, making it suitable for achieving soft chromatic tones. Its mild reactivity also enables compatible use with various other reagents.

Figure 39

When citric acid is added to the black tea residue pigment solution, the liquid becomes brighter.



Note. Photo taken by the author.

Rust Water: Containing iron ions, rust water induces yellow-brown or gray-black tones, suitable for pigments requiring stable coloration. When added to tea residue solutions, it typically shifts the hue to blue-black, appearing nearly black to the naked eye. (Katz et al., 2012)

Odor: Faint iron - like odor

Appearance: Brown to dark brown liquid

Chemical Composition: Predominantly trivalent iron ions (Fe^{3+}) and iron oxide particles

Rationale for Selection: As a traditional dyeing chromatic modifier, rust water engages in redox reactions with natural pigments, deepening hues or shifting them to gray - green. Iron ions chelate with phenolic hydroxyl and carboxyl groups in plant pigments, inducing color changes. In tea residues, this manifests as a transition from

reddish - brown to dark green and grayish - olive, enriching the pigment system with deeper tonal variations.

Figure 40

Adding rust water to the tea residue pigment solution



Note. Photo taken by the author.

(3) Precipitants

Precipitants facilitate pigment precipitation from solutions, enabling easier extraction and conversion into solid blocks. Their use in pigment production aids in obtaining color powders with uniform particle distribution and saturated hues.

Precipitants employed for tea residue pigments include:

Baking Soda: Functioning as a precipitant, it regulates solution pH to promote tea residue pigment precipitation. Additionally, an alkaline environment enhances the stability of certain pigments. (Ziegler, 1926)

Odor: Slight alkaline scent

Appearance: White fine powder

Chemical Composition: Sodium bicarbonate (NaHCO_3)

Rationale for Selection: As a weak alkaline regulator, baking soda alters the pH of tea pigment solutions, inducing chromatic shifts and precipitation reactions. During tea residue pigment extraction, it forms colloidal particles with tea polyphenols and pigment compounds, causing the originally clear tea solution to precipitate light-colored yet fine-textured color powders.

Calcium Hydroxide: Functions as an efficient precipitant in pigment production, combining with tea residue pigments to form more stable precipitated solids. Its application yields finer and more stable pigment particles. (Foreman & Barnes, 1990)

Odor: Faint earthy odor

Appearance: White powder

Chemical Composition: Calcium hydroxide (Ca(OH)_2)

Rationale for Selection: Slaked lime elevates solution alkalinity, converting soluble tea pigments into insoluble precipitates to expedite solid color powder formation. Concurrently, it reacts with plant acidic components to yield larger-particle precipitates, facilitating the acquisition of high-saturation yellow-green pigment

deposits. In traditional natural dye extraction, slaked lime is widely employed for pigment precipitation due to its safety and cost-effectiveness.

Figure 41

A precipitant is added to the tea residue pigment solution to generate a precipitate.



Note. Photo taken by the author.

These color fixatives, chromatic modifiers, and precipitants offer multiple possibilities for the extraction and color adjustment of tea residue pigments, rendering the colors of the resulting painting pigments more diverse.

Table 2

Summary table of fixatives, color change agents, and precipitants

Type	Materials used	Functional Description	Role and performance in this study
Fixing agent	Alum	Enhance the adhesion between pigment and carrier, improve the stability and preservation of pigment	Promote the adhesion of tea residue color powder on the paper surface, delay color shedding and fading
Color Changing Agent	chalcantite	Changing the chemical reaction path of tea residue pigments to significantly change the original color	The solution exhibits a greenish hue, improving color contrast and diversity

Type	Materials used	Functional Description	Role and performance in this study
	Citric Acid	Adjusting the acid-base environment to cause redox reactions in tea polyphenols will make the color brighter.	Make the color lighter and brighter
	Rusty water	Provides trivalent iron ions to promote pigmentation reaction and darken the color	When combined with black tea, it produces dark brown or gray-black, improving the performance of dark colors
Precipitant	Edible alkali	Change the pH of the solution to make the pigments in the tea residues and the metal ions form insoluble precipitates	Accelerate pigment sedimentation and precipitation, improve toner collection efficiency
	Slaked lime	Enhances precipitation reaction, partially participates in neutralization process, and adjusts pigment stability	Combined with Thai black tea, it produces a grayish brown or dark color, expanding the expression of cool colors

Note. drawn by the author

3. Filtration, grinding and sieving.

(1) Precipitate Acquisition Methods

Two techniques were employed to obtain blocky precipitates: vacuum filtration and flat-bed drying.

Vacuum Filtration:

The setup included a filtration funnel, conical flask, and vacuum filtration apparatus. This method rapidly drains filtrate to isolate precipitates, though pigment deposits obtained exhibit lower color saturation. (Svarovsky, 2001)

Figure 42
Vacuum filtration device



Note. Photo taken by the author.

Flat-Lay Drying:

The solution with added precipitant is poured onto white tiles or smooth glass surfaces and air-dried over several days to form precipitates. Although time-consuming, this method allows precipitates to maximally absorb pigments from the liquid, yielding deposits with superior chromatic expression.

Figure 43
Lay flat to dry



Note. Photo taken by the author.

(2) Precipitate-to-Powder Conversion

Transforming extracted tea residue pigment precipitates into fine powder is a critical step.

Grinding Protocol

First, dried pigment precipitates are ground to enhance particle uniformity and fineness. Manual grinding typically employs a mortar and pestle to crush precipitates evenly. While time-intensive, this method ensures more uniform pigment particles and better fineness control.

Figure 44
Manual grinding



Note. Photo taken by the author.

Sieving and Refinement:

Ground pigment powders often contain particles of varying sizes, necessitating sieving. This process is accomplished using sieves with different mesh sizes. In this experiment, a 200-mesh sieve was utilized, as finer powders facilitate pigment production by ensuring uniform particle distribution and optimal chromatic consistency.

Figure 45
Screening with a 200-mesh sieve



Note. Photo taken by the author.

The finely ground and sieved pigment powder should be collected and stored in a sealed container to preserve its quality, ensuring it is ready for subsequent use in formulating watercolor paints.

4. Add pigment binder (Newman, 1996)

(1) Traditional Chinese Painting Binder

The primary binder for Chinese painting pigments is a gelatin (animal glue) solution. In the experiment, traditional gelatin or fish glue was used, soaked in water at a 1:10 ratio, heated to dissolve, filtered to remove impurities, and cooled before use. A small amount of alum was added, serving to stabilize pigment color and prevent mildew. Gelatin improves pigment adhesion and enhances water resistance. This binder exhibits excellent water solubility and flexibility, suitable for highly water-absorbent substrates like rice paper.

(2) Watercolor Pigment Binder

Binder addition is critical for preparing tea residue watercolor pigments. Gum arabic provides adhesion and film-forming properties, enabling even pigment spread and enhancing transparency. Natural ox bile improves fluidity and diffusion for uniform coloration. Honey enhances gloss and prevents pigment cracking. Reasonable adjustment of these components ensures tea residue pigments mimic traditional watercolor texture and expression, suitable for artistic creation.

(3) Oil Paint Binder

Oil paints use drying vegetable oil as a medium. In this study, linseed oil was employed for its moderate drying speed, balancing gloss and color retention. The oil-based pigment preparation process is as follows: grind tea residue color powder into a fine consistency, gradually add linseed oil, and thoroughly blend with a palette knife until a uniform, fine oil color mass forms.

(4) Crayon Binder

Crayons utilize beeswax and talcum powder as the main base, with small amounts of petrolatum or vegetable oil to adjust texture. In the experiment, beeswax was heated to melt, then mixed with tea residue color powder and talcum powder at an approximate ratio: 40% beeswax, 30% talcum powder, and 30% tea residue color powder. Appropriate vegetable oil improves crayon softness and plasticity, facilitating writing and coloring.

3.2.2 Questionnaire design and respondent analysis

This study targeted two primary groups: painting enthusiasts aged 18–35 and professionals in painting/pigment-related fields. Selection criteria aligned with research objectives: evaluating real-world usage experiences from potential users and acquiring professional assessments of artistic, technical, and innovative value.

The questionnaire for painting enthusiasts centered on the following core dimensions:

1. Color Acceptance: Exploring users' subjective evaluations of color saturation, transparency, and naturalness in tea residue pigments.
2. User Experience: Including coloring smoothness, comparisons with traditional watercolor pigments, and performance on different paper types.
3. Sustainability Perception: Assessing users' acceptance of sustainable materials and whether tea residue pigments foster environmental awareness.
4. Aesthetic Preference: Gauging users' recognition of the unique chromatic temperament exhibited by tea residue pigments.
5. Actual Usage Intentions: Measuring willingness to incorporate these innovative pigments in future creative work.

These questions aim to establish cognitive and emotional connections between users and materials, guiding subsequent material optimization and dissemination strategies.

3.2.3 Analysis of expert opinions

This study also gathered feedback from experts in painting and pigment production through structured interviews. Expert 1, Suwanya Saksombat, specializes in natural plant pigment production research and owns a commercial natural plant pigment brand. Expert 2, Yang Fang, is a National Inheritor of China's Intangible Cultural Heritage of batik (Bin et al., 2020), renowned for unique insights and formulas in plant dye extraction. Expert 3, Xie Heping, an apprentice of Yang Fang and another Intangible Cultural Heritage inheritor, has developed plant dyes beyond indigo and promotes batik and plant pigments professionally.

Expert Opinions on Advantages and Prospects:

1. Distinct Sustainable Philosophy: Experts universally acknowledged the material's research value in sustainable development, noting its strong alignment with green design principles.
2. High Experimental Significance: The pigment's unique source, combined with its chemical reactivity, reflects deep artistic exploration in material experimentation.
3. Unique Artistic Expression: Some experts highlighted that tea residue pigments exhibit soft tones and natural textures, offering unique visual language and expressive potential.

Deficiencies and Improvement Suggestions:

While experts provided positive feedback and professional recommendations, interviews revealed areas for development:

- Several experts suggested that tea residue pigments could improve in color saturation and fastness.
- Concerns were raised about process repeatability and standardization. Experts emphasized the need for systematic standardization and testing of extraction

methods, chemical reaction protocols, and preservation techniques before broader promotion.

These insights guide subsequent optimization and reflect the multifaceted considerations with experimental materials transitioning from artistic creation to practical application. Future research should strengthen systematic design in experimental control and performance evaluation to comprehensively address the pigments' potential and limitations.

3.3 Design phase analysis

3.3.1 Data analysis

In this phase, researchers systematically analyzed questionnaire data and expert interview records to derive actionable insights for subsequent design iterations. For questionnaire data, descriptive statistics and difference analysis were employed to quantify user feedback on tea residue pigment usage experiences, intuitively highlighting variations in color preferences, usage habits, and material acceptance across different user groups.

For expert interviews, content analysis was applied to extract keywords and high-frequency themes from interview transcripts, focusing on experts' perspectives on material feasibility, art education, and environmental trends. By categorizing and synthesizing *thematic content* and *pragmatic suggestions*, the analysis further clarified the advantages and limitations of tea residue pigments in artistic expression, medium integration, and material stability.

Cross-analysis of the above data provides empirical support and directional guidance for the design stage, bridging user experience insights with professional expertise to optimize material application and development strategies.

3.3.2 Design output

Building upon the literature and field research compiled during the preliminary preparation phase, along with comprehensive insights derived from qualitative and quantitative analyses, this study undertook multi-dimensional design explorations guided by the framework of "material experimentation + visual expression" at this stage. The design outcomes not only prioritize the technical feasibility and chromatic performance of the pigment but also emphasize its aesthetic potential and sustainable value within painting practices.

In terms of specific implementation, researchers integrated user feedback on color attributes (including luminance, saturation, and transparency) from questionnaire data to optimize the formulation ratios and presentational modalities of tea residue pigments. Concurrently, they refined the process workflows and medium compatibility protocols based on expert recommendations, aiming to demonstrate the

practical applicability of tea residue pigments as an innovative medium within the painting system.

3.4 Experimental summary phase

3.4.1 Market research conclusion

Through an investigation and analysis of the current operational status of milk tea shops in the preliminary stage, this study revealed that tea dregs, as a by-product of beverage production, are discarded in large quantities during daily operations—particularly in regions like China and Thailand, where tea-drinking cultures thrive, yielding sustainable and large-scale tea dreg outputs. Based on survey and interview findings, it can be preliminarily concluded that tea dregs possess the resource potential for redevelopment as design raw materials, thereby not only aligning with the social trend of sustainable development but also addressing the design field's innovative demands for ecological materials.

3.4.2 Experimental design summary

Drawing on the production processes of traditional pigments, researchers designed a novel pigment experimental protocol centered on tea residues. By integrating fundamental steps including color powder extraction, drying, and grinding, and incorporating diverse binders, they constructed a pigment combination experimental system tailored for different painting genres. The entire process referenced the processing methodologies of plant dyes and natural mineral pigments, with professional feedback solicited from pigment experts to establish a more systematic design foundation and operational framework.

3.4.3 Experimental feasibility, difficulties and suggestions

The experimental component of this study reveals the following key attributes:

(1) Advantages:

Tea residue pigments demonstrate robust chromatic performance, particularly in natural brown, reddish-brown, and gray-green hues, exhibiting unique visual textures.

With low raw material acquisition costs and stable sourcing, they offer economic and ecological benefits for adoption as art materials.

Experimental data show that under optimal formulation ratios and processing conditions, tea residue pigments achieve effective adhesion and drying across diverse painting media.

(2) Challenges and Limitations:

The stability and lightfastness of certain tea residue color powders remain inconsistent, vulnerable to air oxidation or photodegradation.

In select binder systems, issues such as color powder sedimentation, stratification, or uneven film formation were observed.

The production process relies heavily on manual operations, limiting scalability and hindering large-scale replication.

(3) Improvement Proposals:

Investigate industrial-grade processing techniques (e.g., spray drying or ultrafine grinding) to enhance the consistency and process controllability of tea residue color powders.

3.5 Data collection and analysis methods

To ensure the scientific rigor and verifiability of the research at the data level, this paper employs a mixed - methods approach that integrates quantitative and qualitative research methods (Sandelowski, 2000) . Through questionnaire surveys, literature reviews, and expert interviews, the data are systematically collated and analyzed, thereby providing a solid foundation for the design and assessment of pigment experiments.

3.5.1 Quantitative data collection and analysis methods

The researchers developed a structured questionnaire and disseminated it via an online platform (Wenjuanxing). The questionnaire encompassed various dimensions, including awareness of sustainable pigments, usage intent, and color satisfaction. Its primary objective was to gather feedback data regarding the target population's experience with tea dregs pigments.(Sheard, 2018)

3.5.2 Qualitative data collection and analysis methods

In the realm of qualitative research (Bachiochi & Weiner, 2004) , the researchers undertook a systematic analysis along three key dimensions:

First, through consultations with professional literature and journals on traditional pigment production techniques and plant dyeing methodologies, they gained a profound understanding of the theoretical logic and historical context underlying the use of natural materials in visual arts.

Second, they collated and analyzed sustainable design cases, ecological art practices, and material aesthetics theories related to tea dregs, thereby establishing a theoretical framework for the study.

Third, based on expert interview transcripts and reflective records, they systematically synthesized the performance of tea dregs pigments within practical painting systems, extracting critical issues and viable development directions.

The collected qualitative data were analyzed using thematic categorization and content analysis methods to distill practical experiences, aesthetic values, and material potentials relevant to the design phase, providing referential insights for optimizing pigment formulations and expanding their applications.

3.6 Research Methodology Framework

The overall structure of this study adheres to the research framework depicted in Figure 2. Centered on the natural waste material "tea residue," the study is structured into four main research components: research objectives, research methods, research findings, and research outcomes. Methodologically, it integrates theoretical perspectives from experimental art methodologies, material aesthetics, and ecological cycle theory.

3.6.1 Basic structure of research methodology

In line with the illustrated framework, this study employs a synthesis of experimental and design research methods, broadly following the trajectory of "commencing with material experimentation → constructing application frameworks → generating artistic outcomes → informing theoretical reflections." The key focus of each stage is as follows:

3.6.1.1 Research Objectives: This study sets three goals:

1. To investigate the feasibility of repurposing tea dregs as a secondary-use material.
2. To synthesize pigment powders from tea residues by combining them with various chemical agents.
3. To evaluate the synthesized tea-based pigments through practical painting trials.

3.6.1.2 Research Methods:

The research methodologies are structured along two primary dimensions: experimentation and design:

1. Experimental Component:

Categorization of tea residues into four types (Chinese and Thai black tea, Chinese and Thai green tea)

Extraction of pigment powders

Binder performance testing

2. Design Research Component:

User needs assessment (e.g., questionnaire surveys)

Expert interviews

Painting experiment feedback based on empirical data

Through these steps, researchers establish a systematic design and experimental logic spanning from material sourcing to final application.

3.6.2 Methodological support and theoretical embedding

To achieve the research objectives and chart the research trajectory, this study integrates the following three theoretical-methodological frameworks:

3.6.2.1. Experimental art methodology

This study conceives of the "pigment preparation process" as an extension of artistic practice. Guided by experimental art methodology, researchers are not merely engaged in pigment production but frame every instance of trial-and-error and each chromatic transformation as integral to the artistic creation process. The color, textural, and particulate changes resulting from chemical reactions between diverse tea residue types and chemical agents constitute a unique experimental visual language, providing a foundation for subsequent painterly expression.

3.6.2.2. Material aesthetics

The theory of material aesthetics emphasizes the "perceptual value" and "cultural attributes" inherent in materials themselves. As daily waste, tea residues embody qualities of "non-standardization," "uncertainty," and "unreplicability," which thus become integral to their aesthetic significance. Through pigment preparation and painterly realization, this research shifts focus from the "functionality" of materials to their emotional resonance and semantic depth within artistic language. The "User Needs Analysis" and "Painting Testing" depicted in the figure embody the evaluative framework of user acceptance throughout this process.

3.6.2.3. Ecological cycle theory

Within the overall research trajectory, ecological cycle theory forms the ethical foundation of the methodology. As a frequent by-product of consumer society, tea residues—when repurposed into art materials—embody a design practice that responds to the "prolongation of material life cycles." Through the closed loop of "waste-reuse-creation," this study constructs a tangible ecological cycle model. As illustrated, the pigment stability and applicability tests in the "Research Findings" serve as empirical validation of this theoretical framework.

3.6.3 Practical reflection and generation path of research methods

Aligned with the research framework's structure, the research process unfolds as a cohesive continuum from materials to methods, results, and artworks:

1. Material Processing: Classification and drying of tea residues
2. Color Powder Experimentation: Precipitation, chromatic variation, and color fixation tests

3. Binder Integration: Four application systems (Chinese painting, watercolor, oil painting, and crayon)

4. Survey Feedback: Questionnaire data and expert interview insights

5. Practical Painting Tests and Documentation

6. Pigment Evaluation and Optimization Proposals

This process not only addresses the research objectives but also facilitates a transition from sustainable development theory to analyses of usability and expressiveness within artistic systems, ensuring both theoretical rigor and practical feasibility.



CHAPTER 4

ANALYSIS AND DESIGN

This chapter seeks to comprehensively present the systematic findings of this study on the developmental process, user feedback, expert evaluations, and painterly applications of tea residue pigments. Through a multi-dimensional approach integrating experimentation, surveys, and design practices, the research explores the feasibility, stability, and application potential of tea residues—used as waste materials—in pigment production and artistic expression. The findings provide an empirical basis for the design of sustainable art materials while validating the operational framework that integrates material experimentation, artistic creation, and environmental stewardship concepts.

The chapter is structured into four sections. First, the initial section conducts a quantitative analysis of questionnaire results from two target groups: painting enthusiasts and experts in painting and pigment studies. Employing descriptive statistical analysis, variance analysis, and Pearson correlation analysis, it delves into users' subjective evaluations and behavioral tendencies regarding chromatic performance, usage experience, and environmental perceptions following practical use of tea residue pigments. These analytical outcomes offer reliable data support for material optimization and dissemination strategies.

The second section focuses on experimental data from the pigment color testing phase, systematically presenting the color powder effects generated by various tea residue types under different media (chromatic agents, precipitants). This includes color categorization, covering power, particle texture, and preliminary observations of storage stability, providing foundational parameters for subsequent artistic applications.

In the third section, researchers synthesize survey data and expert group consultations to conduct professional evaluations of tea residue pigments' artistic properties, material aesthetic characteristics, experimental potential, and application prospects. Expert opinions—encompassing perspectives on artistic expression, process workflows, and environmental sustainability—affirm the material's experimental significance while identifying areas for improvement in standardization and long-term performance.

Finally, the fourth section showcases the results of color test painting experiments using the developed pigments. Through multiple small-scale artworks that integrate different substrates and techniques, it explores the expressiveness of tea residue pigments in artistic creation. Additionally, by documenting and comparing color changes in artworks after a preservation period, the study analyzes chromatic stability and durability, providing intuitive evidence for assessing the practicality and sustainability of tea residue pigments.

In summary, this chapter presents the research process and key findings through dual dimensions of data and imagery, further supporting the paper's core proposition on "the feasibility of developing waste-derived pigments in art design" and laying groundwork for theoretical discussions and research conclusions in the subsequent chapter.

4.1 Data analysis

4.1.1 Descriptive statistics analysis

The age distribution of Questionnaire 1 respondents clustered between 18 and 35 years, with the highest prevalence in the 25–30 age bracket (41.85%), followed by 31–35 years (32.62%) and 18–24 years (25.54%). Gender representation was nearly equitable (51.08% male, 48.92% female). With respect to painting techniques, the majority of participants exhibited proficiency in oil painting (65.54%), watercolor (58.46%), and crayon work (50.77%), suggesting the experimental outcomes are generalizable across diverse artistic media. (George & Mallery, 2018)

The overall post - usage experience assessment of tea dregs pigments indicates that 74.46% of respondents rated it as "good", 17.85% as "very good", and a mere 7.69% as "average", with no negative responses recorded. Regarding the usage experience, 83.38% of respondents perceived the tea dregs pigments to possess "subtle tones", and 66.46% concurred with their pertinence to the "sustainable development" concept. Moreover, 65.23% of respondents reported that upon learning about tea dregs pigments, they entertained the notion of exploring other waste - derived pigments. This suggests that tea dregs pigments exhibit significant inspirational value and hold great potential for environmental communication at the user level.

Table 3
Descriptive statistics analysis table

Options	Number of people (n)	percentage (%)
very good	58	17.85
good	242	74.46
generally	25	7.69
Poor/bad	0	0.00

Note. drawn by the author

Table 4
Descriptive statistics analysis table

project	category	Number of people (n)	percentage (%)
age	18–24	83	25.54
	25–30	136	41.85
	31–35	106	32.62
gender	male	166	51.08
	female	159	48.92

Note. drawn by the author

Findings from Questionnaire 2 show a slight female majority among expert respondents (52.68% vs. 47.32%). Notably, 92.86% of experts affirmed the need for "innovation in painting pigments," while 94.64% agreed that "using tea waste to produce pigments represents a meaningful sustainable approach." All respondents (100%) concurred that the research and artworks effectively convey the theme of sustainable material cycles. Additionally, 95.54% of experts expressed willingness to recommend the pigments to others, underscoring the high level of professional endorsement for this research.

Table 5
Descriptive statistics analysis table

Question Number	Summary	Highly Agreeable Ratio (%)
Q2	I think that paint needs innovation	92.86%
Q3	Agree that tea residue pigment is a sustainable method	94.64%
Q7	Believe that it expresses the recurring theme and is meaningful	100.00%
Q11	Would like to recommend this pigment	95.54%

Note. drawn by the author

4.1.2 Analysis of variance

In Questionnaire 1, a one-way ANOVA was performed to examine age-based differences in the experience of using tea residue pigments, with "age group" (Question 1) as the independent variable and "overall experience evaluation" (Question 5) as the dependent variable. Results indicated no statistically significant differences in experience scores across age groups ($p > 0.05$), demonstrating high consistency in acceptance of tea residue pigments among the target demographic aged 18–35. While the 25–30 age group exhibited slightly higher evaluation scores, this variation did not reach statistical significance, confirming the representativeness of this age bracket without excluding applicability to other age groups. (Larson, 2008)

This result supports the rationality of choosing 18-35 years old as the target user group.

In Questionnaire 2, a one-way ANOVA was employed with "gender" (Question 1) as the independent variable and "Do you think painting pigments need innovation?" (Question 2) as the dependent variable. The analysis revealed no statistically significant gender differences in responses to the need for pigment innovation ($p > 0.05$), demonstrating strong consensus on this perspective across expert groups of different genders.

Table 6
ANOVA table

gender	Mean Rating (converted value)	Standard Deviation	p
male	1.08	0.27	> 0.05
female	1.07	0.26	

Note. drawn by the author

4.1.3 Pearson correlation analysis

In Questionnaire 1, to explore the relationship between respondents' environmental attitudes and their willingness to try other waste-derived pigments, Pearson correlation analysis was performed on Question 6 ("Do you appreciate its sustainability?") and Question 7 ("Do you have the intention to explore other waste materials?"). (Cleophas et al., 2018)

The analysis revealed a moderately strong positive correlation between the two variables ($r \approx 0.56$, $p < 0.01$), indicating that respondents with higher endorsement of the "sustainability concept" exhibited stronger intent to explore other eco-friendly art

materials. This finding further validates that the environmental focus of this study's material development has a positive psychological basis among users.

Table 7
Pearson correlation analysis table

Variable A (X)	Variable B (Y)	Pearson r	Significance level (p)
Think tea residue pigment is a sustainable development method	Would you like to recommend this pigment?	0.44	< 0.01

Note. drawn by the author

In Questionnaire 2, to explore whether experts' endorsement of sustainable development influences their willingness to recommend the pigment, Pearson correlation analysis was conducted using Question 3 ("Do you consider tea residue pigment a sustainable approach?") and Question 11 ("Are you willing to recommend it to others") as variables. The results showed a moderate positive correlation between the two ($r \approx 0.44$, $p < 0.01$), indicating that experts who more strongly agree with the sustainability of tea residue pigments are more inclined to recommend them.

Table 8
Pearson correlation analysis table

Variable A (X)	variable B (Y)	Pearson r	Significance level (p)
Do you agree with the sustainable value of tea residue pigment?	Are you willing to try pigments made from other waste materials?	0.56	< 0.01

Note. drawn by the author

In conclusion, the questionnaire surveys and data analyses conducted among two distinct groups—painting enthusiasts and experts—reveal that tea dregs pigments, as sustainable materials, enjoy broad acceptance and evoke significant interest among users. Additionally, they have garnered substantial recognition and a high willingness to be recommended within the professional realm. Painting enthusiasts predominantly

focus on the visual performance and sustainable ethos of these pigments, whereas experts offer constructive insights regarding material stability, application potential, and process enhancement. Both groups exhibit a remarkable degree of consensus in their understanding of "recycling" and "material innovation." This convergence provides robust social and theoretical underpinnings, enabling this study to delve deeper into the artistic applications and experimental significance of tea dregs pigments.

4.2 Pigment color test data analysis

This section primarily documents the color test outcomes of pigment powders derived from tea residues combined with various chemical substances across four distinct painting systems. By integrating binders appropriate for Chinese painting, watercolor, oil painting, and crayons, the experimenters formulated different types of painting pigments. They then created color cards to observe visual performance, stability, fluidity, glossiness, and other properties on substrates such as paper and canvas.

4.2.1 Description of toner and adhesive classification

In the initial experimental phase, color powder samples were extracted from Chinese black tea, Chinese green tea, Thai black tea, Thai green tea, and various chemical media (including blue vitriol, citric acid, rust water, slaked lime, etc.). To ensure optimal coloration and dispersibility, all samples underwent drying, grinding, and sieving processes.

The color test experiment in this stage was designed based on a matrix of 4 tea types \times 6 chemical treatments \times 4 binding media, as follows:

1. Color Fixative: Alum
2. Color Change Agents: Blue vitriol, citric acid, rust water
3. Precipitants: Edible alkali, slaked lime

In accordance with the requirements of traditional and modern painting media, four representative adhesive types were selected:

- (1) Chinese Painting Pigment Binder: Predominantly composed of gelatin and alum, engineered for strong adsorption and compatibility with rice paper.
- (2) Watercolor Pigment Binder: A blend of gum arabic, natural ox bile, and honey, formulated to enhance transparency and fluidity.
- (3) Oil Painting Pigment Binder: Linseed oil, chosen to emphasize covering power and impart gloss.
- (4) Crayon Binder: A combination of beeswax, talcum powder, and a small quantity of vegetable oil, enabling solidification and smooth color application.

Following adhesive mixing and adjustment, the prepared color powders were standardized through testing using brushes, paintbrushes, palette knives, and other

tools. The pigments were uniformly applied to specific substrates (rice paper, watercolor paper, canvas, sketch paper) to create standardized color cards.

Table 9
Summary of the four types of pigments

Media Type	Adhesive ingredients	Tea residue adaptability performance	Suitable art style or purpose
Chinese painting	Animal glue, gelatin	Good adhesion, strong settling power, suitable for blending	Landscape, freehand brushwork, and meticulous painting
Watercolor painting	Gum Arabic, Honey, Ox Bile	Strong fluidity, suitable for coloring, natural particles	Watercolor, natural scenery
oil painting	Linseed Oil	Low hiding power, suitable for thick coating of texture	Rough texture style, mixed media creation
crayon	Beeswax, vegetable wax	Pale color, rough texture	Teaching experiment, natural painting, handicraft art development

Note. drawn by the author

4.2.2 Color expression in four types of painting media

Through color comparison, it was observed that the same tea dregs color powder exhibits distinct visual effects and physical properties across different media:

Chinese painting pigments yield soft, stable hues that pair ideally with rice paper.

Watercolor pigments disperse uniformly when wet, with certain color powders revealing natural granularity and rich textural effects.

Oil painting pigments display more saturated tones and robust covering power, particularly in dark shades (e.g., tea powder mixed with rust water).

Crayon-formulated pigments feature relatively muted colors but offer smooth tactile application.

Key characteristics of tea residue color powders include:

1. Naturally grayish-brown tones, more subdued than traditional plant pigments.
2. Effective expansion of the color gamut via chromatic agents: rust water induces grayish-green hues, while blue alum produces bluish tones.

3. Pronounced influence of binders on gloss and adhesive properties.

4. Slightly lower compatibility with oily media compared to superior performance in water-based systems.

Representative findings include:

Thai green tea + alum + crayon binder: Yields orange-ochre pigment with pronounced graininess, suitable for rough linework.

Figure 46

Crayon Color Display

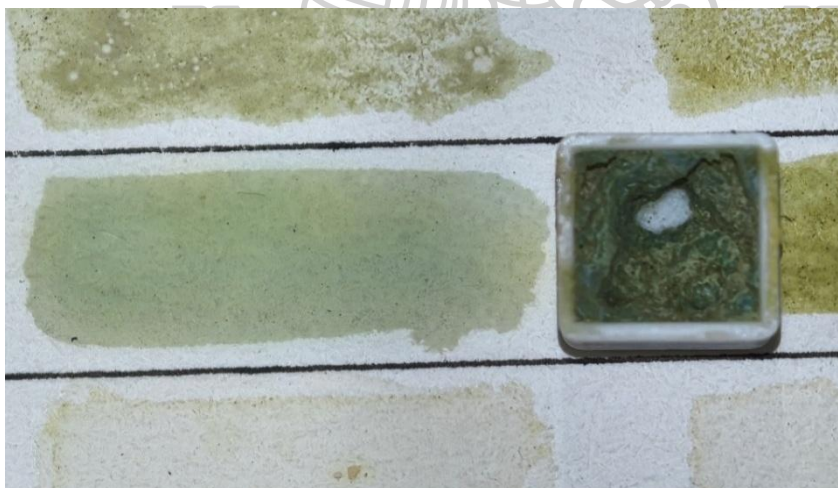


Note. Photo taken by the author.

Thai green tea + blue vitriol + watercolor binder: Exhibits a green hue with high transparency and excellent fluidity.

Figure 47

Watercolor paint color display

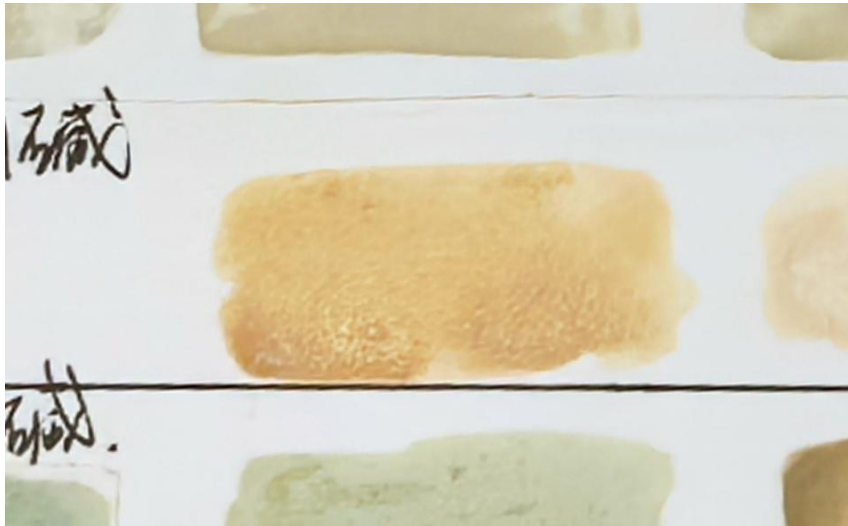


Note. Photo taken by the author.

Chinese green tea + rust water + leather glue (for traditional Chinese painting):
Presents a brownish-yellow tone, which appears calm and subdued when applied,
making it suitable for landscape painting.

Figure 48

Chinese painting pigment color display

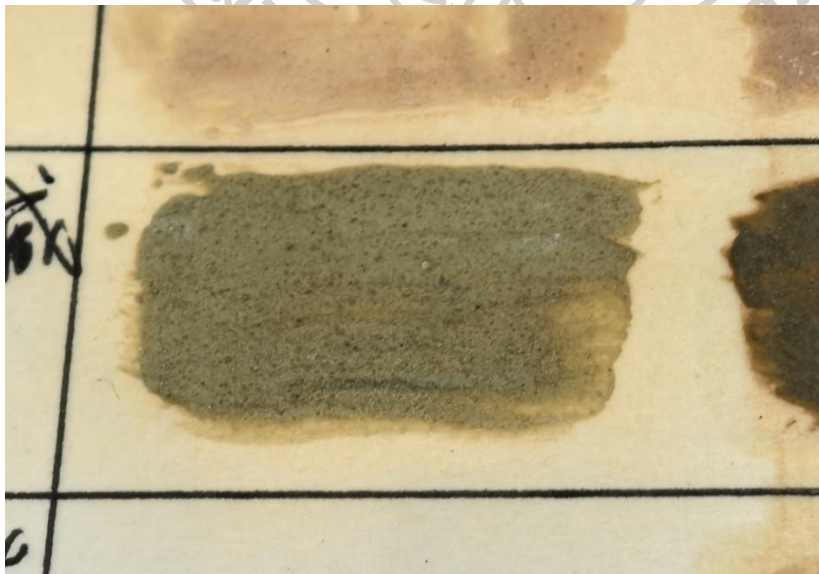


Note. Photo taken by the author.

Chinese black tea + blue vitriol + linseed oil: Exhibits dark green hue with robust
covering power and a unique granular texture.

Figure 49

Oil paint color display



Note. Photo taken by the author.

4.2.3 Color card presentation and description

The experimental results are documented in color charts, with each set of images showcasing the performance of color powders from the same tea source across four media. This facilitates observation of properties such as transparency, saturation, particle distribution, and dry-wet state changes.

During the R&D of tea residue pigments, this study established a set of fundamental design criteria based on the production of various pigment types to ensure usability and stability. These standards include:

Color Stability: Pigments should remain relatively stable under varying environmental conditions (e.g., humidity, temperature, light) and resist fading or degradation.

Color Gamut: Explore available color ranges through combinations of different teas and chemical reagents to meet diverse creative needs.

Pigment Texture: The fineness and solubility of pigment powders must adhere to standards for different pigment types to ensure smooth application.

















Compatibility: Pigments should be compatible with common binders to maintain fluidity and adhesion during use.

These design standards not only guide pigment production but also provide a reference for future optimization in different application scenarios.

The author selected Chinese black tea, Chinese green tea, Thai black tea, and Thai green tea to react with various substances, investigating the interactions of tea residue pigment solutions with acidic/alkaline agents and iron ions. The following presents reactions of four tea types with 8 groups of experimental substances, yielding a total of 32 experimental outcomes.

Table 10

















Reaction results of four kinds of tea with alum and slaked lime respectively

Alum+ Edible alkali	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Original Color				
+ Alum				
+ Edible alkali				
+Watercolor Binder				

Note. drawn by the author

Table 11

Results of reaction of four kinds of tea with alum and edible alkali respectively






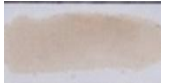






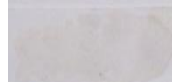

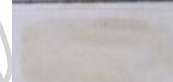
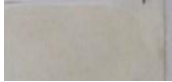
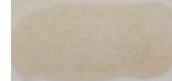


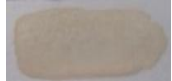
Alum+ slaked lime	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Original Color				
+ Alum				
+ Slaked lime				
+Watercolor Binder				

Note. drawn by the author

In Experiments detailed in Tables 10 and 11, the same color fixative was combined with different precipitants. Results indicate that when using alum as the color fixative, pigment precipitates formed with slaked lime exhibit darker tones than those produced with edible alkali.

Table 13

Reaction results of four kinds of tea with citric acid and hydrated lime respectively.

Citric acid + slaked lime	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Original Color				
+ Citric acid				
+ Alum				
+ Slaked lime				
+Watercolor Binder				

Note. drawn by the author

Table 12

Four kinds of tea were boiled with alum and then cooled with edible alkali

Alum(heated) + edible alkali	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Solution + alum (heat until it does not change color)				
+ edible alkali				
+Watercolor Binder				

Note. drawn by the author

In the experiment documented in Table 12, the addition of an acidic color-changing agent and slaked lime resulted in a lighter coloration approaching white. The solution with the acidic color-changing agent showed no significant reaction with the edible alkali precipitant, yielding no pigment precipitate. In the experiment outlined in Table 13, the author added alum to four types of tea, boiled the mixtures, and after cooling, introduced edible alkali. The resulting precipitate exhibited a brighter color than the precipitate observed in Table 10.

Table 14














The reaction results of four kinds of tea with blue vitriol, slaked lime and edible alkali

Chalcanthite	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Original Color				
+ Chalcanthite				
Plan 1				
+ Slaked lime				
+Watercolor Binder				
Plan 2				
+ Edible alkali				
+Watercolor Binder				

Note. drawn by the author

Table 15

The reaction results of four kinds of tea with rusty water, slaked lime and edible alkali































Rusty water	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
Original Color				
+ Rusty water	Darkening reaction is not obvious			
Plan 1				
+ Slaked lime				
+Watercolor Binder				
Plan 2				
+ Edible alkali				
+Watercolor Binder				

Note. drawn by the author

Table 14 documents a reaction experiment involving four tea varieties with blue vitriol, followed by the addition of slaked lime and edible alkali as precipitants to observe precipitate colors. Precipitates from both precipitants exhibit green hues, with those from slaked lime appearing darker. When the watercolor binder is added to the precipitate from edible alkali, it initially shows a yellow tone that oxidizes to green. Table 15 details a reaction experiment between tea residues and rust water, where rust water darkens the solution, but adding precipitants lightens the color to a brighter yellow.

Presented below are color charts for Chinese painting pigments, watercolors, crayons, and oil paints, comprising a total of 82 color results.

Table 16
Chinese traditional painting pigment color card

+Chinese traditional painting pigments	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
① Alum+ slaked lime				
② Alum+ Edible alkali				
③ Citric acid+ slaked lime				
Alum(heated)+ edible alkali				
Chalcanthite+ slaked lime				
Chalcanthite+ Edible alkali				
Rusty water+ slaked lime				
Rusty water+ Edible alkali				

Note. drawn by the author

Table 17
Watercolor paint color card

+Watercolor Binder	Chinese Black Tea	Chinese Green Tea	Thai Black Tea	Thai Green Tea
① Alum+ slaked lime				
② Alum+ Edible alkali				
③ Citric acid+ slaked lime				
Alum(heated) + edible alkali				
Chalcanthite+ slaked lime				
Chalcanthite+ Edible alkali				
Rusty water+ slaked lime				
Rusty water+ Edible alkali				

Note. drawn by the author

Table 18
Crayon paint color card

+ Crayon Adhesive

Chinese Black Tea:
 Chalcantite+Edible
 alkali



Chinese Green Tea:
 Chalcantite+Edible
 alkali



Thai Black Tea:
 Chalcantite+Edible
 alkali



Thai Green Tea:
 Rusty water+slaked lime



Chinese Green Tea:
 Rusty water+slaked lime



Chinese Green Tea:
 Rusty water+ Edible
 alkali



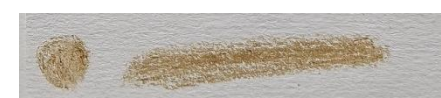
Chinese Green Tea:
 Citricacid+slaked lime



Thai Black Tea:
 Chalcantite+ slaked
 lime



Thai Green Tea:
 Alum+ Edible alkali



Chinese Black Tea:
 Chalcantite+ slaked
 lime



Note. drawn by the author

Table 19
Oil paint color card
 + Oil paint binder

Thai Black Tea: Alum+ Edible alkali	
Chinese Black Tea: Chalcanthite+ slaked lime	
Thai Green Tea: Chalcanthite+ slaked lime	
Chinese Black Tea: Alum+ Edible alkali	
Chinese Black Tea: Citricacid+slaked lime	
Chinese Green Tea: Citricacid+slaked lime	
Chinese Black Tea: Chalcanthite + Edible alkali	
Chinese Green Tea: Chalcanthite + Edible alkali	
Thai Green Tea: Chalcanthite + Edible alkali	
Chinese Green Tea: Rusty water+slaked lime	
Thai Black Tea: Rusty water+slaked lime	
Thai Green Tea: Rusty water+slaked lime	

Note. drawn by the author

Figure 50
Pigment powder



Note. Photo taken by the author.

Figure 51
Watercolor paint



Note. Photo taken by the author.

Figure 52
Oil paint



Note. Photo taken by the author.

Figure 53
Crayons



Note. Photo taken by the author.

4.3 Expert consultation analysis

To further validate the practical feasibility and application potential of tea residue pigments in artistic creation and material design, the researchers recruited three experts with expertise in pigment production, artistic creation, traditional painting materials, and sustainable art research. Additionally, 112 professionals from related fields—including painting creation, pigment research, sustainable art, and design education—were invited to participate in questionnaire surveys and in-depth consultations. The expert consultation aimed to gather rational and technical feedback to supplement user experience insights, enabling comprehensive evaluations from multiple perspectives: material performance, artistic expression, environmental value, and promotion strategies.

4.3.1 Overall tendency of expert feedback

According to the questionnaire results, the expert group generally affirmed the research direction of tea dregs pigment: 92.86% of experts agreed that "painting pigments need innovation", reflecting the professional field's support for material diversity and experimental art. 94.64% of experts recognized that "tea dregs pigment represents a sustainable material transformation approach". 99% of experts stated that "the material aligns with creative themes and can express concepts of circulation and continuity". 95.54% of experts expressed willingness to recommend the pigment to others, demonstrating its strong potential for industry communication.

Overall, experts highly commended the sustainable attributes, artistic potential, and material creativity of tea dregs pigment, particularly emphasizing its significance within the context of green art and sustainable design.

Based on the collected interview records and feedback forms, the researchers synthesized expert opinions into the following key dimensions:

4.3.1.1 EVALUATION OF THE INNOVATION OF MATERIALS

Most experts agree that tea residues, as a base material for pigments, demonstrate strong innovativeness by breaking free from the limitations of traditional mineral or synthetic pigments and proposing a green material development pathway centered on "waste resource utilization." Specifically, Expert 1 noted:

"Tea is a ubiquitous material in daily life. Using it as a pigment not only aligns with the concept of sustainable development but also evokes a connection between humans and nature."

Experts widely acknowledge that tea residues offer advantages of broad availability, safe processing, and environmental friendliness, making them particularly suitable for experimental directions in ecological art, educational promotion, or new material development.

4.3.1.2. AFFIRMATION AND LIMITATION OF COLOR EXPRESSION

Experts unanimously agree that tea dregs pigments exhibit naturally soft tones, making them particularly suitable for expressing themes of "land, time, and ecology." However, some experts have noted limitations in achieving "high-saturation hues" and meeting "strong covering power demands."

For instance, Expert 2 commented:

"While the colors may lack vibrancy, this quality itself constitutes a visual language—ideal for conveying tranquility and natural simplicity, but less suited for creating bright, bold visual focal points."

Most experts recommend exploring combinations with other plant materials or natural mineral pigments in future research to expand the color gamut.

4.3.1.3. OPINIONS ON THE ADAPTABILITY OF DIFFERENT MEDIA SYSTEMS

Expert 3 noted that tea dregs pigments demonstrate optimal performance in watercolor and Chinese painting systems, as these media emphasize transparency, granular texture, and natural fluidity—qualities highly congruent with the pigments' inherent characteristics. Conversely, their performance in oil painting systems is subpar, prone to delamination, while in crayon systems, they are well-suited for "natural-style" children's art materials or experimental painting tools. Once formulated, Chinese painting pigments using tea dregs are ideal for freehand landscape painting workshops or educational activities.

As one expert emphasized:

"Watercolor techniques like 'blank space' and 'blotting' can enhance the visual appeal of tea dregs pigments, potentially offering greater expressiveness than heavy, opaque coverage."

4.3.1.4. SUGGESTIONS ON PROMOTION OF SUSTAINABILITY

Most experts propose transforming the study's findings into educational resources, handmade pigment experience kits, children's art education material packages, and other promotable applications. Examples include: environmental education courses at art galleries; experimental materials for design curricula in higher education; and collaborations with tea or cultural creative brands to develop green artworks.

Several experts also recommend conducting long-term experiments—such as "colorfastness testing" and "light fading tests"—to enhance the viability of tea residue pigments for formal artistic creation or market integration.

Table 20
Expert opinion summary

Dimensions	Expert opinion summary	Research Response and Enlightenment
Material innovation	Using daily waste to make pigments is forward-looking and echoes the green design trend	Strengthen the experimental system and theoretical foundation, and enrich the "re-materialization" method
Color performance	Suitable for natural tonality expression, not suitable for high saturation visual needs	Emphasize the aesthetic value of color tone, not pursue industrial standards
Media adaptability	High adaptability to watercolor/traditional Chinese painting, medium adaptability to oil painting/crayon	Strengthen media testing to avoid using it for expressions that require strong coverage
Promotion and educational significance	Can be applied to art teaching, environmental protection promotion, and children's material development	Explore and form expansion forms such as workshops, teaching packages, and online video courses

Note. drawn by the author

4.3.2 Keyword summarization in feedback

Through content analysis of expert opinions and suggestions, the researchers extracted the following high-frequency themes:

Artistic Expression: Many experts highlighted the unique visual style of tea residue pigments, noting their particular suitability for creating works requiring natural, low-saturation aesthetics.

Material Stability: Some experts expressed concerns about pigment lightfastness and color retention, recommending long-term light resistance tests for future research.

Teaching and Communication: Numerous experts recognized the material's promising applications in art education and environmental workshops, emphasizing its potential to guide the public in re-evaluating waste value.

Standardization and Reproducibility: Some experts proposed enhancing standard process extraction and documentation in pigment production to improve repeatability and communication efficiency.

These insights reflect the expert group's multifaceted concerns regarding the material itself, its usage paradigms, and cultural dissemination, providing a professional foundation for the study's subsequent optimization directions.

4.3.3 Expert suggestions and research optimization directions

Based on expert insights, the study outlines several key design and research directions:

Enhance Material Performance: Improve the stability and practicality of tea residue pigments by further investigating additives or anti-corrosion mechanisms.

Expand Artistic Applications: Apply tea residue pigments to diverse substrates (e.g., fabric, wood) and broader artistic contexts to push experimental boundaries.

Advance Educational Outreach: Integrate tea residue pigments into public aesthetic education, green design curricula, and sustainable cultural education projects to amplify their social impact.

Establish Material Specifications: Develop concise, actionable production protocols and teaching manuals to facilitate future replication and educational use.

Expert feedback on the application of tea residue pigments is as follows:

Table 21
Expert advice and research optimization direction

Evaluation direction	Expert specific opinions	Expert feedback tendency	Response and analysis of this study
Material innovation	Tea dregs as a new art material have sustainable development significance, and the selection direction has both cultural and environmental value.	Highly affirmative	The study starts from tea from China and Thailand, emphasizing cultural relevance and material ecology

Evaluation direction	Expert specific opinions	Expert feedback tendency	Response and analysis of this study
Color expression	The colors are natural and simple, but the color range is small and the saturation is not high; the graininess is strong, which is suitable for a specific style	More neutral	Enhance the color level through multiple color changers; accept its heterogeneity as part of the material language
Stability in use	Pay attention to the preservation, light resistance and fixing ability of the pigment, and recommend conducting longer-term tests	Constructive suggestions	A one-year control experiment was designed, and it was found that the bonding system between oil painting and Chinese painting was relatively stable, and the subsequent testing efforts need to be strengthened.
Education and Outreach	It is recommended to develop production processes and toolkits suitable for art teaching and public activities, suitable for material aesthetic education and environmental education promotion	support	This study suggests developing "handmade kits" and teaching courses in the future to expand the social application path of tea residue pigments

Note. drawn by the author

The expert interviews not only validated the research value of tea residue pigments but also clarified their advantages and breakthroughs as experimental materials within artistic creation systems. In the future, integrating interdisciplinary collaboration across material science, sustainable design, and art education is expected to further deepen the application depth and cultural dissemination value of this material.

4.4 Test color painting results

To further verify the practical application potential of tea residue pigments in artistic creation, this study conducted a series of painting experiments using the four types of pigments prepared in the early stage. The experiments aimed to observe their visual effects, technical adaptability, and color stability during actual operation. Meanwhile, a preservation test was established: artworks were placed for an extended period, and their degree of fading was observed to evaluate the feasibility and limitations of this eco-friendly pigment for long-term artistic use.

4.4.1 Purpose and methods of painting experiment

This experiment employs small-scale creative sketches to test the application of four pigment types (Chinese painting, watercolor, oil painting, and crayon). For each pigment, two artworks are selected: one utilizing tea dregs as the sole color source, and the other mixed with traditional media to observe the fusion effect.

Figure 54

Final product display



Note. Photo taken by the author.

Figure 55
Final product display



Note. Photo taken by the author.

Figure 56
Final product display



Note. Photo taken by the author.

Figure 57
Final product display



Note. Photo taken by the author.

Figure 58
Final product display



Note. Photo taken by the author.

Figure 59
Final product display



Note. Photo taken by the author.

Figure 60
Final product display



Note. Photo taken by the author.

Figure 61
Final product display



Note. Photo taken by the author.

Figure 62
Final product display



Note. Photo taken by the author.

Figure 63
Final product display



Note. Photo taken by the author.

Figure 64
Final product display



Note. Photo taken by the author.

Figure 65
Final product display



Note. Photo taken by the author.

4.4.2 Color preservation test and fading

The color fastness of tea residue pigments was also tested to evaluate their long-term application potential in painting. Experimental results showed that under natural storage conditions, these pigments exhibited good stability within one year, with no obvious color changes. The one-year color fastness test period was determined by the actual schedule of this master's research project, which was limited to one year. However, future research should further explore the color fastness of these pigments under long-term environmental exposure (e.g., light, humidity, and temperature fluctuations) to ensure their color stability over a longer period and enhance their practical application as sustainable art materials.

Key findings include:

1. Most colors remained stable in a dry, room-temperature environment.
2. After 12 months, lighter tones (such as green and yellow) showed slight fading, but the change was barely noticeable.
3. Pigment stability was optimally achieved through the addition of chemical reagents and binders.
4. Crayon pigments also demonstrated relative stability under the same conditions.

Figure 66
2024 Color Card Record.



Note. Photo taken by the author.

Figure 67
2025 Color Card Record



Note. Photo taken by the author.

4.5 Summary and analysis

The painting experiments not only validated the operability and visual expressiveness of tea residue pigments but also revealed their differential applicability and potential optimization directions across various media. Despite the relatively limited color gamut and pronounced granular texture, tea residue pigments exhibit unique aesthetic value within artistic contexts of "returning to nature" and "material recycling." Concurrently, fading tests urge researchers to prioritize durability, stability, and standardization in future material design, aiming to facilitate broader adoption of eco-friendly art materials in creative and educational systems.

This section systematically presents the interim findings of this study on tea residue pigment development through comprehensive analyses of survey data, pigment characterization experiments, expert consultations, and painting trials. Aligning with the study's three core objectives, the primary findings and outcomes are summarized as follows:

1. Feasibility of Repurposing Tea Residues as Secondary-Use Materials

Through investigations into tea residue sources, types, and accessibility, alongside classification experiments on Chinese and Thai tea varieties, this study confirms the practical viability of tea residues as "secondary-use materials" for artistic pigment development.

Stable Sourcing and Broad Accessibility: Tea residues offer consistent availability, particularly in urban settings with escalating milk tea consumption, providing a robust foundation for material acquisition.

Natural Organic Properties: As natural organic waste, tea residues possess inherent pigmentary potential and extractability. Following drying and pulverization, they serve as viable sources of color powders.

Social Acceptance: Both questionnaire surveys and expert evaluations highlight strong user recognition of tea residues' sustainable attributes as art materials, establishing a favorable social framework for their integration into artistic creation systems.

2. Synthesis of Pigment Powders from Tea Residues via Chemical Agent Integration

This study performed chemical treatment experiments on four tea varieties (Chinese black tea, Chinese green tea, Thai black tea, Thai green tea), incorporating color modifiers (blue vitriol, rust water, citric acid), mordants (alum), and precipitants (slaked lime, edible alkali). The experiments successfully synthesized diverse tea residue pigment powders with distinct hues, particle morphologies, and stabilities. Results indicate significant reaction dependencies between tea types and chemical reagents, yielding a spectrum of ecological tones—ranging from brown ochre and gray-green to olive-yellow—that enrich the pigment system. Following drying, grinding, and sieving, the pigment powders form base materials with uniform particle distribution and optimal adhesiveness.

3. Evaluation of Synthesized Tea-Based Pigments Through Practical Painting Trials

Post-synthesis, the pigment powders were applied across four media systems—Chinese painting, watercolor, oil painting, and crayon—and evaluated via color chart analyses and small-scale artworks. Painting performance and user feedback confirm that tea residue pigments excel in water-based media (e.g., Chinese painting, watercolor), exhibiting soft chromaticity and natural fluidity ideal for ecological themes and temporal narratives. Additionally, expert evaluations and colorfastness tests further validate the feasibility and material stability of tea residue pigments in artistic creation, providing foundational data for future application expansion.

In summary, the findings of Chapter 4 comprehensively address the study's three core objectives. From feasibility validation to experimental synthesis and expressive potential, the development of tea residue pigments not only enables waste resource recycling but also constructs an artistic pathway integrating circular aesthetics and material value within visual art practice. This framework underscores the dual significance of sustainable material innovation and cultural reinterpretation in contemporary artistic research.



Table 22
Records of three groups of people using tea dregs as paint

Participant Type

Using paint to record the picture

18-35 years old painting
enthusiast



Expert Group



author



Note. drawn by the author

CHAPTER 5

RESEARCH CONCLUSIONS AND DISCUSSION

This chapter aims to systematically summarize and theoretically discuss the entire research process while proposing viable recommendations for future research and practical applications. Following multiple stages of material experimentation, user surveys, expert consultations, painting creation, and result analysis, the research has preliminarily validated the multifaceted values of tea residue-based painting pigments in terms of material feasibility, artistic expressiveness, and sustainability.

First, the research conclusions revisit key findings from the overall research process, organizing comprehensive results on tea residue pigments' material transformation, visual expression, and integration of sustainable concepts. This section emphasizes their effectiveness within experimental art and material reuse systems. Second, the discussion compares and analyzes the study's results with recent research on waste-derived pigments, identifying differences and breakthroughs in this study's technical approach—specifically regarding material sourcing, color generation, and media adaptability. Finally, the recommendations propose extension directions and application potentials from the perspectives of research methodologies, material improvement, art education, and promotion pathways, providing references for subsequent related practices.

This chapter not only serves as a summary of the entire dissertation but also elevates a research project rooted in material experiments to a comprehensive discussion of the multidimensional intersection among artistic language, social culture, and ecological awareness. In doing so, it offers an inspiring empirical model for the research trajectory of "waste-art-recycling."

5.1 Research Discussion

This study focuses on the core topic of "the development of waste tea residue pigments and their application in various painting genres," integrating experimental art methodology, material aesthetics, and ecological cycle theory to conduct cross-disciplinary exploration and practice. The research aims to respond to contemporary society's demand for sustainable art materials and expand the application of waste in artistic creation. Through systematic experimental design, user research, expert consultations, and painting practice, this study verifies the feasibility, limitations, and research value of transforming tea residues into art pigments from multiple dimensions: material preparation, media adaptability, visual expressiveness, and theoretical relevance.

Firstly, in material experimentation, this study commenced with Chinese and Thai black and green teas, employing various color - modifying agents and precipitants to extract tea residue color powders of diverse shades. Following drying,

grinding, and sieving processes, basic pigment raw materials were successfully fabricated. Subsequently, by incorporating four types of medium binders—specifically those for Chinese painting, watercolor, oil painting, and crayon—four categories of tea residue painting pigments were synthesized, and systematic color testing and performance observations were conducted. The experimental outcomes indicate that, despite the limited color gamut of tea residue pigments, through distinct chemical reactions and medium - based adjustments, they can generate a natural color palette with visual expressiveness, demonstrating certain artistic application potential.

Secondly, regarding user research and expert consultations, the study executed two - way questionnaire surveys and feedback analyses targeting painting enthusiasts aged 18 - 35 and professionals in the painting and pigment fields. The survey results reveal that respondents generally hold a high level of recognition for the sustainable concept, artistic aesthetics, and material experimental nature of tea residue pigments. Experts also provided affirmative evaluations from the perspectives of visual expression, artistic language, and promotion viability, while highlighting that tea residue pigments still encounter challenges in standardized production, color stability, and consistent color performance.

Thirdly, in the realm of painting practice, researchers conducted small - scale painting trials using the self - produced tea residue pigments. The experimental artworks exhibited unique color characteristics. Additionally, preservation tests demonstrated that, without the addition of protective agents, most colors of tea residue pigments remained relatively stable for over one year during the research period, indicating their pigment - preserving capabilities.

The recycling of tea residues as an "abandoned material" not only prolongs their material life cycle but also stimulates artists and audiences to contemplate themes such as "consumption and regeneration" and "transience and continuity." This transformation from waste to artistic medium represents not only the renewal of materials but also the reconstruction of meaning and perspective.

In conclusion, this study has preliminarily established a set of operational models applicable to ecological art and material experimental creation within the closed - loop system of "material research - experimental production - art application - theoretical discussion." The development of tea residue pigments not only offers a novel direction for traditional pigment systems but also provides a new platform for artists, educators, and designers to integrate material innovation with sustainable concepts. Although it still confronts challenges in technical refinement and commercial replication, as an approach in art research, it has demonstrated positive experimental value and social significance.

5.2 Research discussion: Comparative analysis with related research results

To systematically evaluate the research positioning and innovative value of this study in the field of "sustainable pigment design," this section compares and analyzes the findings on tea residue pigments with domestic and international studies. The analysis focuses on similarities and differences in material selection, color generation methods, media application ranges, and artistic expression dimensions, aiming to clarify the theoretical contributions and practical significance of this research.

5.2.1 Similarities with existing waste pigment studies

In recent years, with the rise of "green design" and "ecological art" concepts, scholars have transformed natural waste—such as fruit peels, coffee grounds, onion skins, and rose petals—into pigments.

For example:

In research on coffee ground pigments, a monochromatic coffee-brown pigment was prepared via drying, extraction, and medium blending, then applied to watercolor systems, emphasizing its natural particulate texture and environmental value. (Duerr, 2011)

A plant dye experiment project (Shin et al., 2008) used traditional safflower plants to generate diverse hues through boiling, dyeing, and pH adjustment, highlighting the extraction logic of "plant source—single color—stability treatment."

An ecological art class study on anthocyanins in onion skins primarily achieved one or two color variations. (Boo et al., 2012)

These studies share similarities with the present research: both emphasize the "reconversion" of organic waste into visual media and adopt experimental approaches combining chemical preparation and medium fusion. This demonstrates that the current study aligns with the mainstream direction of sustainable art material research in both conceptual framework and methodological design.

Table 23

Similarities to existing waste pigment studies

Dimensions	Research on Traditional Plant Pigments	Coffee Grounds/Peels Research	This study (tea residue)
Sources	Safflower, indigo, onion skin, etc.	Coffee grounds, fruit peels, vegetable residues, etc.	Black tea/green tea dregs (made in China and Thailand)

Dimensions	Research on Traditional Plant Pigments	Coffee Grounds/Peels Research	This study (tea residue)
Color generation method	One plant gets one color or two variations	One base color for one material	A kind of tea residue can generate more than 3 colors through various media
Application media range	Watercolor/dyed cloth	Watercolor/teaching experiments	Four-system experiment of Chinese painting, watercolor, oil painting and crayon
Cultural attributes and research positioning	Most of them are traditional handicrafts	Focus on reusing daily materials	Combining tea drinking culture, ecological philosophy and contemporary art perspectives
Is there a color preservation test?	Rarely involved	Occasionally short-term observation	A one-year comparison is provided to test fading and stability
Are you interested in philosophy and artistic language?	Emphasis on material practicality	Emphasis on teaching and environmental protection	Integrating material aesthetics, ecological cycle and material experimentation

Note. drawn by the author

In summary, within the field of waste pigment development, this study not only inherits the experimental logic of predecessors in transforming natural materials into artistic media but also advances research on multiple key fronts. Concerning the selection of tea residues, it achieves a pathway for generating multiple colors from a single material through scientific blending. Simultaneously, through painting application tests and long-term preservation stability verification, this study further expands the applicable boundaries and aesthetic value of waste pigments within the art system. It thereby provides both methodological frameworks and visual languages for the research paradigm of sustainable material art.

5.2.2 Uniqueness and difference

Although sharing a similar methodological framework, this study proposes several substantial innovations in material exploration and experimental depth, which are primarily reflected in the following aspects:

5.2.2.1. Cultural continuity of material sources

As a prevalent byproduct of consumption in Chinese and Southeast Asian food cultures, tea residues embody strong cultural attributes and regional identity. Distinct from commonly used Western raw materials like coffee and flowers, they exhibit profound cultural connectivity and local characteristics.

5.2.2.2. Exploration path of one material, multi-color generation

Traditional plant pigments are typically extracted to yield one or two colors from a single plant. This study, however, introduces color-modifying and precipitating agents such as blue vitriol, citric acid, rust water, edible alkali, and slaked lime, enabling the same type of tea residues to produce three or more color variations. This approach offers novel insights for the systematic utilization of waste pigments.

5.2.2.3. Experimental expansion of multi-media painting system

This study does not merely stop at pigment extraction but further incorporates color powders into four medium systems—Chinese painting, watercolor, oil painting, and crayon—thereby forming diversified painting material experiments.

5.2.2.4. Comprehensive investigation of fading and artistic language

This study further designed a one-year storage cycle test for pigment color changes, addressing the prior lack of focus on "long-term stability." Additionally, it introduces the concept of an "ecological material language" from the perspective of visual expression, emphasizing the meaning-generating function of materials as symbols of circulation.

5.2.3 Supplement and reflection on the research of sustainable material art

Building on the preliminary validation of tea residue pigments' feasibility and aesthetic potential in artistic creation, future research can be expanded along the following trajectories:

1. Expanding Material Application Frontiers

In terms of material application, tea residue pigments should be tested on diverse substrate surfaces—including fabric, linen, recycled paper, handmade cotton paper, plastics, and composite materials—to explore their suitability for cross-disciplinary

design contexts such as installation art, textile design, and product packaging. This expansion will broaden application scenarios while enriching their design expressivity and ecological communication channels.

2. Enhancing Color Preservation Testing Protocols

Regarding color stability assessments, extending the testing timeline with semi-annual color change recordings is recommended. This protocol will systematically document how tea residue pigments evolve under environmental stressors (e.g., light, humidity, temperature), furnishing critical empirical data for material optimization and preservation methodologies.

3. Comparative Performance Analytics with Commercial Pigments

Future research should incorporate controlled comparisons with conventional commercial pigments, focusing on metrics like color saturation, chroma, and adhesion. Quantitative analyses using color measurement instruments (e.g., spectrophotometers or digital image analysis tools) to record RGB/Lab values will facilitate the creation of chromaticity comparison charts. Such data will scientifically underpin the visual characteristics of natural pigments, guiding their application positioning.

Addendum on Chemical Additive Functionality:

It is essential to clarify that chemical additives (e.g., alum, blue vitriol, rust water) were employed not to enhance chromatic vividness but to improve color fixation and storage stability. These agents enable solidification into color powders via precipitation reactions, extending pigment longevity in artworks. This strategy balances technical practicality with preservation of natural material properties, avoiding misperceptions of "cosmetic treatment" compromising authenticity.

Outlook for Sustainable Development:

While this study establishes a foundation for tea residue pigment development, substantial opportunities remain. With advanced material characterization methods and precision testing tools, these pigments are poised to manifest unique eco-aesthetic value across diverse artistic and design disciplines.

Conclusion: Integrating Technical Innovation and Ecological Discourse:

This research not only presents a technical protocol for multi-chromatic waste pigment extraction but also injects sustainable design perspectives into artistic creation and ecological philosophy. The "reactivation" of tea residues transcends material reuse, functioning as a semiotic rewriting that transforms waste into a mediating symbol between artistic concepts and ecological consciousness.

Distinguishing itself from prior studies, this work emphasizes experimental art's process openness, material culture's regional positioning, and creative philosophizing—collectively defining its niche in the field of waste-derived art material research.

5.3 Recommendations

This study utilizes tea residues as the foundational material and, through pigment experimentation, integration of diverse pigment binders, and artistic creation practices, has preliminarily validated their potential and limitations in sustainable art. To further expand the application depth and research value of such materials, this paper proposes the following recommendations from three perspectives—research deepening, practical promotion, and educational application—for reference in related fields.

5.3.1 Research recommendations

1. Strengthen Systematic Testing of Color Stability and Lightfastness

Although this study confirmed the color-retention capacity of tea residue pigments through a one-year storage test, professional lightfastness and aging evaluations under diverse environmental conditions (e.g., direct sunlight, high humidity, air oxidation) are lacking. Thus, future research will incorporate more rigorous colorfastness standards and spectral analysis tools—guided by expert recommendations—to scientifically validate their long-term reliability as artistic media.

2. Deepen Chemical Discourse on Color Change and Fixation Mechanisms

While this study used various color-modifying and precipitating agents to generate diverse hues, the research remains empirical. Subsequent investigations should introduce biological enzymes, natural preservatives, or eco-friendly nanomaterials to explore their impacts on color variation and stability, establishing clear "material-chromatic" reaction rules to underpin standardized production and replication.

3. Expand Composite Research with Other Waste Materials

It is recommended to blend tea residues with other organic wastes (e.g., coffee grounds, fruit peels, bamboo leaves) to assess the visual effects, structural stability, and processability of composite color powders. This approach not only broadens the color gamut but also facilitates the construction of a systematic "waste pigment database."

5.3.2 Practical recommendations

1. Explore Small-Scale Manual Production and Material Application Models

Given the stable sourcing of tea residues and relatively straightforward processing, it is proposed to develop a "tea residue pigment making kit" or "handmade material experiment guide" tailored for individual artists, small workshops, and environmental organizations. This initiative will facilitate the translation of research findings into socially accessible art materials, activating the tripartite connection among "waste-creation-education."

2. Optimize Binder Formulations and Process Ratios

While the binder systems for four media (Chinese painting, watercolor, oil painting, and crayons) have been successfully tested, improvements are still needed in crack prevention, gloss regulation, and flow properties. Future research should involve continuous adjustment of formula ratios, combined with experiments using modern eco-friendly synthetic adhesives or natural plant-based binders.

3. Establish a Visual Style for Sustainable Material Art

Tea residue pigments feature unique visual attributes—including granular texture, low saturation, and natural motifs. It is recommended that artists and designers leverage these inherent material qualities to develop a distinct "sustainable material art" performance paradigm, rather than imitating industrial pigment styles. This approach will enable eco-friendly pigments to establish an independent aesthetic in visual semiotics.

5.3.3 Suggestions on education and promotion

1. Integrate into Art College Curricula and Environmental Education Systems

It is recommended to incorporate tea residue pigment research findings into curricula for art design, material experimentation, and environmental education, utilizing them as case studies for material cognition training and experimental skill development. Through pedagogical approaches, students should be guided to understand the ecological significance of art materials and establish a creative philosophy that "materials embody concepts."

2. Organize Public-Involved Material Art Experience Activities

Promote tea residue pigment production and creation through workshops, exhibitions, and community co-creation initiatives. Such activities not only foster public awareness of waste recycling but also facilitate the extension of material research into public art and community-based artistic practices.

3. Establish an Open Research and Communication Platform

Propose developing an online resource hub for "sustainable art material experimentation," curating and sharing material test data, color formulation recipes, and visual case libraries. By providing collaborative tools for artists, researchers, and educators, this platform would facilitate the field's development by fostering a robust communication mechanism and expanding its disciplinary influence.

Table 24

Summary of three aspects of recommendations

Suggested dimensions	Specific recommendations	Expected Results
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Suggested dimensions	Specific recommendations	Expected Results
Research level	1. Strengthen color stability and light durability testing	Improve pigment reliability and facilitate entry into long-term painting application systems
	2. Explore the mechanism of pigment production and media reaction	Clarify the laws of material reactions and promote standardization and scientific replication
	3. Composite experiments with other organic waste	Expanding the color gamut and material combinations to enrich sustainable pigment types
Practical level	1. Launch small production packages and creative material models	Lower the threshold for use and encourage artists and the public to experiment and spread their knowledge independently
	2. Optimize the binder ratio to improve the fluidity and stability of the pigment	Improve the painting experience and enhance practicality and aesthetics
	3. Develop an independent visual style of sustainable material art	Establish a unique aesthetic language for environmentally friendly materials and enhance artistic recognition
Education Promotion	1. Incorporate art design and environmental protection curriculum system	Strengthen environmental awareness in art education and expand teaching methods
	2. Organize co-creation activities and workshops for public participation	Enhance social interaction and communication, and increase public attention and acceptance of sustainable materials
	3. Build an open sharing platform (publish records, recipes and cases)	Promote cross-disciplinary collaboration and create a sharing mechanism and sustainable development ecosystem for material art research

Note. drawn by the author

5.4 Summary

This study commenced with "tea residues"—a neglected daily waste—and initiated a comprehensive exploration of material experimentation, chromatic inquiry, and artistic practice. Through the transformation of tea residues from beverage byproducts into painting pigments and their integration into visual creation, the research not only endowed them with new material functions but also sought to construct their multi-dimensional significance in artistic language and ecological discourse.

The inquiry transcended the practical evaluation of mere "usability," progressively delving into the cultural implications and systemic design considerations underlying the materials. During experimentation, the natural textures and unpredictable hues of tea residues emerged as integral components of the creative lexicon.

Comparative analysis demonstrated that tea residues, as pigment raw materials, possess the fundamental attributes for integration into painting systems in terms of material properties, medium adaptability, and visual expressivity. While limitations persist in color saturation, durability, and industrial reproducibility, these constitute the unique value of "experimental materials"—offering an open, process-oriented creative mechanism rather than standardized outcomes.

More significantly, tea residue pigments are not intended to supplant conventional material paradigms but to broaden artists' material vocabulary while reinforcing ecological accountability. In the current context of sustainable development and green transition, art no longer serves merely as an expressive tool but as a carrier of sustainable thinking. This study responds to this possibility: when materials carry diverse contexts, they begin to communicate; when waste is repurposed, it becomes a wellspring of meaning.

The future of design and sustainable development demands further exploration and iteration. Yet it is certain that this journey does not originate from complex technologies but from a re-examination of "overlooked things" in daily life. Through this, art returns to materials, materials re-enter the realm of thought, and thought leaves its chromatic imprint.

APPENDIX

Supplementary page 1: IOC EXPERT EVALUATION AND ANALYSIS

RESULTS

Index of item objective congruence

Through the Index of item objective congruence and the applicability of research tools, the data collection is organized in the following table, and the experts' ratings in the per person section are as follows:

All variables and questionnaire questions in this research: The study of experience economy and service design for sustainable development: case study dunhuang area were obtained by consulting literature and previous works. In order to ensure the consistency of each variable and question in questionnaire, the questionnaire was evaluated the by the thesis advisor and three experts in related fields including:

Expert1: Suwanya Saksombat

Expert2: Yang Fang

Expert3: Xie Heping

The author uses index of Item Objective Congruence (IOC) to examine consistency between questions and objective or objective and content (Tumer & Carlson, 2009), it's can be calculate from formula:

$$IOC = \frac{\sum R}{N}$$

Where:

IOC= Consistency between questions and objective or objective and content.

$\sum R$ = Total assessment points that given from all qualified experts.

N= Number of qualified experts.

There are 3 levels of assessment point as follow:

Suitable (+1) means The questionnaire's questions are certainly consistent with the objective.

Not Appropriateness (0) means The questionnaire's questions are unsure to be consistent with the objective.

Not Suitable (-1) means The questionnaire's questions are inconsistent with the objective.

The consistency index value must have the value of 0.5 or above to be accepted.

Index of Item Objective Congruence (IOC) from three experts result are as followed:

QUESTIONNAIRE PART 1:

NO.	Expert1			Expert2			Expert3			Total Scores Σ	IOC $\Sigma R/N$	Data Analysis
	-1	0	1	-1	0	1	-1	0	1			
Q1			√			√			√	3	1	Acceptable
Q2	√					√			√	3	0.3	Reject
Q3			√	√					√	3	0.3	Reject
Q4			√			√		√		3	0.6	Acceptable
Q5			√			√		√		3	1	Acceptable
Q6			√			√		√		3	0.6	Acceptable
Q7			√			√		√		3	1	Acceptable
Q8			√			√		√		3	1	Acceptable



QUESTIONNAIRE PART 2:

NO.	Expert1			Expert2			Expert3			Total Scores Σ	IOC $\Sigma R/N$	Data Analysis
	-1	0	1	-1	0	1	-1	0	1			
Q1			√			√			√	3	1	Acceptable
Q2			√			√			√	3	1	Acceptable
Q3			√	√					√	3	0.3	Reject
Q4		√				√			√	3	0.6	Acceptable
Q5			√			√		√		3	0.6	Acceptable
Q6			√			√			√	3	1	Acceptable
Q7	√					√			√	3	0.3	Reject
Q8			√	√					√	3	0.6	Acceptable
Q9			√			√			√	3	1	Acceptable

$$IOC = \frac{\Sigma R}{N}$$

Where:

IOC= Consistency between questions and objective or objective and content.

ΣR = Total assessment points that given from all qualified experts.

N= Number of qualified experts.

Therefore

$$IOC = \frac{12.2}{13}$$

$$= 0.9$$

The value index of item objective congruence (IOC) assessment result of this questionnaire is equal to 0.9. There are Four questions which have IOC index less than 0.5.

The value of IOC is 0.9.

It is proved the questions in this questionnaire are consistent.

List of experts

Expert 1: Suwanya Saksombat
Natural Plant Pigments Studio

Expert 2: Yang Fang
Inheritor of China's national intangible cultural batik

Expert 3: Xie Heping
Inheritor of Chinese intangible cultural batik



Supplementary page 2:Index ofItem Objective Congruence (IOC)**Questionnaire****Consideration, Evaluation, Suggestions**

Research topic:

Repurposing tea residues: exploring the process of making pigments and their application in artistic creation

Researchers:

Miss. Qin Yuxia(MFA student of Silpakorn University)

Phone:+86 18907838766, E-mail:894969071@qq.com

Assistant Professor THATREE MUANGKAEW (Ph.D.)

Phone: +66 82 6345699 , Email: artopiazstudio@gmail.com

This research tool is used to answer the following research Questions:

1. To understand whether painting enthusiasts accept waste tea pigments and whether they find them meaningful
2. Whether this experience inspires awareness of sustainable development and exploration of other waste materials in art.

Clarification:

+1=the question is appropriate

0=Not sure whether the question is appropriate.

-1=the question is inappropriate

Tick(✓)in your comment box and write down suggestions for further improvement.

Part 1: Painting Enthusiasts (18-35) Questionnaire (target population after using tea residue paint)

Questions in the questionnaire	Expert Options			Suggestions
	Appropriate (1)	Uncertain (0)	Inappropriate (-1)	
1. What is your age? <input type="checkbox"/> 18-21 <input type="checkbox"/> 22-26 <input type="checkbox"/> 27-31 <input type="checkbox"/> 31-35				
2. What is your gender? <input type="checkbox"/> Male <input type="checkbox"/> Female				
3. What painting style or specialty are you good at? <input type="checkbox"/> Traditional Chinese painting <input type="checkbox"/> Oil painting <input type="checkbox"/> Watercolor painting <input type="checkbox"/> Crayon drawing				
4. How often do you engage in painting? <input type="checkbox"/> Daily <input type="checkbox"/> Weekly <input type="checkbox"/> Monthly <input type="checkbox"/> Occasionally				
5. How would you rate your overall experience using tea waste pigments? <input type="checkbox"/> Excellent <input type="checkbox"/> Good <input type="checkbox"/> Average <input type="checkbox"/> Poor				

<p>6. What did you like most about using tea waste pigments? (Select all that apply)</p> <p><input type="checkbox"/> Natural and eco-friendly materials</p> <p><input type="checkbox"/> Subtle color tones</p> <p><input type="checkbox"/> Connection to sustainability</p>				
<p>7. Did you have the idea to explore other waste products after learning that you could make paint from tea leaves?</p> <p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p>				
<p>8. Do you have any suggestions for the experiment of making tea residue into pigment?</p> <p><input type="checkbox"/> No, I think it's pretty good.</p> <p><input type="checkbox"/> Yes, _____</p>				



**Index of Item Objective Congruence (IOC)
Questionnaire
Consideration, Evaluation, Suggestions**

Research topic:

Repurposing tea residues: exploring the process of making pigments and their application in artistic creation

Researchers:

Miss. Qin Yuxia (MFA student of Silpakorn University)

Phone: +86 18907838766, E-mail: 894969071@qq.com

Assistant Professor THATREE MUANGKAEW (Ph.D.)

Phone: +66 82 6345699, Email: artopiaztudio@gmail.com

This research tool is used to answer the following research Questions:

1. To assess whether the experiment is valid
2. to understand experts' perspectives on the acceptance of innovative pigments made from tea waste.

Clarification:

+1 = the question is appropriate

0 = Not sure whether the question is appropriate.

-1 = the question is inappropriate

Tick (✓) in your comment box and write down suggestions for further improvement.



Part 2: Interview Questions for Experts

Questions in the questionnaire	Expert Options			Suggestions
	Appropriate (1)	Uncertain (0)	Inappropriate (-1)	
1. What is your gender? <input type="checkbox"/> Male <input type="checkbox"/> Female <input type="checkbox"/> Other				
2. Do you think that painting pigments need innovation? <input type="checkbox"/> Yes <input type="checkbox"/> No				
3. Do you think that using pigments made from tea waste is a meaningful sustainable development method? <input type="checkbox"/> Agree <input type="checkbox"/> Disagree				
4. What attracts you most about tea residue pigment? (multiple choices) <input type="checkbox"/> Reducing waste <input type="checkbox"/> Promoting sustainable practices <input type="checkbox"/> Choice of raw materials <input type="checkbox"/> Supporting recycling innovation				
5. Do you have any other ideas about using tea residue pigment or similar sustainable innovation? <input type="checkbox"/> No, I think it is already good. <input type="checkbox"/> Yes, _____				

<p>6. Do you think that the research and output of tea residue pigment can express the theme of sustainable circulation, and is this innovation meaningful?</p> <p><input type="checkbox"/>Yes, I think _____</p> <p><input type="checkbox"/>No, I think _____</p>				
<p>7. Do you have any additional suggestions for color fixers, color changers and precipitants in tea residue pigment experiments?</p> <p><input type="checkbox"/>Yes, _____</p> <p><input type="checkbox"/>No, no</p>				
<p>8. Will you introduce this pigment to your friends?</p> <p><input type="checkbox"/>Yes</p> <p><input type="checkbox"/>No, it needs to be considered</p>				
<p>9. Do you have any other suggestions for experiments on making pigments from tea residue?</p> <p><input type="checkbox"/>Yes, _____</p> <p><input type="checkbox"/>No.</p>				

Supplementary page 3: Personal Profile

Author Qin Yuxia

Qin Yuxia graduated from the Academy of Fine Arts, Minzu University of China, majoring in Fine Arts (Art Education), specializing in Chinese painting. During her studies, she systematically studied traditional Chinese painting techniques and materials, especially in the use of mineral pigments and plant pigments, which has aroused her strong interest in pigment materials themselves and color expression.

During her postgraduate studies, Qin Yuxia studied at the Faculty of Decorative Arts, Silpakorn University, Bangkok, Thailand, and continued to delve into the intersection of pigment and material experiments. In her master's research, she turned her perspective to the reuse of daily waste - tea dregs, and carried out systematic pigment extraction experiments around "sustainable development" and "material aesthetics", and combined Chinese painting, watercolor and other media for painting practice. Her research focuses on the combination of natural cycles, color composition and artistic philosophy, reflecting the integration of interdisciplinary thinking and ecological awareness.



Supplementary page4: Participate in the DESYNC2025 exhibition.

Exhibition pictures:

Figure 68

DESYNC2025 exhibition photos



Note. Photo taken by the author.

Figure 69

DESYNC2025 exhibition photos



Note. Photo taken by the author.

Supplementary page5:About periodicals

No. 660301.14.1.3 / 538



Faculty of Architecture
Khon Kaen University
Khon Kaen 40002,
Kingdom of Thailand

9th April 2025

Subject: Certificate of Publication

Dear Qin Yuxia,

We would like to inform you that your manuscript titled **Tea Leaf Waste: Pigment Production Process and Application in Painting** has successfully undergone evaluation by experts from various institutions, none of whom belong to the same institution as the three reviewers. The manuscript has also been reviewed by the journal's editorial board and has been approved for online publication in the Built Environment Inquiry Journal (BEI), Volume 24, Issue 68/2 (May-August 2025), with International Standard Serial Number (ISSN) 2651-1185 (Online).

On behalf of the editorial board, we would like to extend our heartfelt thanks for your interest in submitting your work for publication, and we hope to have the opportunity to publish more of your academic work in the future.

Please be informed accordingly.

Best regards,



Assist. Prof. Dr. Pattamaporn Wongwiriya

Deputy Dean for Strategic Planning, Quality Assurance, Research, and Innovation

Acting on behalf of the Dean of the Faculty of Architecture

Editorial Board of Built Environment Inquiry – BEI

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[Figure 4]. The process of grinding mineral pigments with water.

Internet, source: https://www.cdstm.cn/gallery/wzl/upack/201712/t20171207_655641.html. Search time: 2024.

[Figure 5]. The process of making plant-based "indigo" pigment.

Online, source: "Chinese Plant Dyeing Techniques". Search time: 2024.

[Figure 6]. *Prussian blue pigment powder*.

Online, source: <https://www.puedomezclar.com/tintes-y-pigmentos/pigmentos-tatuajes-y-estetica/puedo-mezclar-pigmento-azul-black-buddha-con-tinta-roja-dringenberg/>. Search time: 2024.

[Figure 14]. *The picture comes from the Internet. United Nations Sustainable Development Goals, Goal 12, 12.5*

From web page file [Goal 12 | Department of Economic and Social Affairs](#). Search time: 2024.

[Figure 15]. *Circular economy Action plan proposed by the European Union*

From web page file [Circular economy action plan - European Commission](#). Search time: 2024.

[Figure 26]. *Works by El Anatsui*

image source: web search editorial-elansui-0014-cmyk.jpeg (1000×667), Search time: 2025.

[Figure 27]. *The Guardian (2025). Su Yu-Xin uses handmade pigments to paint place, time and memory.*

Image source: [The landscape artist who makes her paint from pearls, crystals and volcanic dust | Painting | The Guardian](#). Search time: 2025.

[Figure 28]. *The Times (2025). Late bloomers: artist wins Glenfiddich award with natural dye palette.*

Image source: [Late bloomer's sophisticated palette picks up Glenfiddich art prize](#). Search time: 2025.

[Figure 29]. *Vogue (2023). The awesome audacity of Chase Hall.*

Image source: [The Awesome Audacity of Chase Hall | Vogue](#). Search time: 2025.
[Figure 30]. The Guardian (2025). *Artists swap paint for seaweed ink in ocean-themed challenge.*

Image source: [‘It’s almost like Vaseline’: artists including Antony Gormley swap paint for seaweed ink in art challenge | Oceans | The Guardian](#). Search time: 2025.
[Figure 31]. Eames Institute (2024). *Elemental Alchemy: the color work of Natalie Stopka.*

Image source: [Botanic Pigments & Dyes— Artist Natalie Stopka | Kazam! Magazine](#). Search time: 2025.



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