

Sustainable waste management and biorefinery potential: Revaluation of byproducts from Xiangyunsha dyeing and finishing processes

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Abstract

Stigmatization and accessibility obstacles persistently constrain conventional support networks, as university students encounter escalating mental health issues. This study assessed the impact of a mobile mental health application developed with user experience (UX) and user interface (UI) concepts to improve student well-being and engagement. We quantitatively evaluated the principal waste streams from Xiangyunsha production, comprising roughly 3,191 tons of *Dioscorea* (yam) residues, 13,564.8 kg of liquid waste, and 47.5 tons of weeds annually. Experimental research was carried out to transform these organic wastes into high value biorefinery products, notably assessing their viability for application in sheet materials, clay composites, and natural pigments. The functional attributes, such as coloring, durability, and antibacterial characteristics conferred by *Dioscorea*-derived tannins, were further confirmed. The experimental findings confirmed the effective conversion of these waste streams into commercially viable goods. The tannins obtained from *Dioscorea* were found to significantly enhance pigment, durability, and inherent antibacterial capabilities of the novel materials. This comprehensive strategy mitigates significant ecological challenges, including soil acidification and water eutrophication, while reinforcing the foundational ecological philosophy of the craft. Adding waste valorization to the Xiangyunsha production system creates a solid and sustainable base for a circular heritage business. This approach boosts the economy by creating new products and helps keep cultural traditions alive by combining old crafts with modern design, making Xiangyunsha a model for protecting the environment and preserving culture.

Keywords: Biorefinery potential, Circular economy, Diosyunsha by products, Sustainable craft, Waste valorization

Introduction

Xiangyunsha, a traditional silk textile originating from Shunde, Guangdong, China, constitutes a unique example of Intangible Cultural Heritage (ICH) [1]. Revered as "soft gold," its distinct manufacturing process involves the use of *Dioscorea* liquid, mineral-laden river sediment, and rigorous sun-drying techniques [2-5]. This intricate craftsmanship reflects centuries of ecological knowledge and cultural identity, exemplifying the synergy between human activity and the natural environment [6, 7].

The Xiangyunsha dyeing process generates substantial organic byproducts, primarily consisting of *Dioscorea* remnants, waste liquids, and large volumes of weeds from the processing fields. Unregulated disposal of these materials leads to significant ecological detriment. Studies on textile dyeing consistently show that high concentrations of chemical and organic residues trigger soil acidification, water eutrophication, and microbial imbalance, consequently destabilizing terrestrial

and aquatic ecosystems [8, 9]. The discharge of untreated wastewater also adversely affects biodiversity, elevates health risks for adjacent populations and compromises local food security [10]. These findings underscore the critical need to develop sustainable waste management strategies within traditional dyeing operations.

The Circular Economy (CE) framework offers a globally recognized solution to these challenges, promoting a transition from the linear "take-make-dispose" model to closed-loop systems that minimize waste and reintegrate byproducts into productive cycles [11]. Current CE conceptualizations emphasize the crucial integration of environmental, economic, and social elements, advocating for the adoption of CE principles across context-specific sectors, including traditional cultural heritage crafts [12]. Within this framework, waste is redefined as a valuable resource capable of generating new product lines and enhancing local economic vitality.

Recent research highlights the adaptability of Circular Economy (CE) techniques across many sectors. At the

micro-business level, the integration of waste valorization with digitization improves sustainable resilience and competitiveness [13]. In urban food manufacturing, circular economy approaches for byproduct management efficiently integrate safety, environmental sustainability, and value

creation [14]. Nonetheless, significant disparity remains regarding the systematic implementation of circular economy principles within historical crafts such as Xiangyunsha, which are inherently connected to cultural identity and ecological wisdom.

This knowledge vacuum underscores the necessity of investigating how the revalorization of *Dioscorea* byproducts through new material applications—such as sheets, composites, and pigments—can establish Xiangyunsha as a paradigm for cyclical heritage industries. This method transcends basic environmental conservation to include cultural sustainability and global competitiveness, seamlessly merging traditional ecological knowledge with innovative design. Current research on Xiangyunsha has mostly concentrated on its historical evolution, cultural importance, and artisanal techniques as an embodiment of a living heritage [15-17]. This research validates the craft's reliance on ecological elements—such as sunlight, river silt, and *Dioscorea* yam extracts—establishing it as a model of traditional sustainable practices [18]. Xiangyunsha illustrates that Intangible Cultural Heritage (ICH) is intrinsically connected to natural ecosystems and local resource utilization, highlighting the importance of ecological understanding for cultural preservation [19,33].

Situating circularity within heritage and craft

In recent decades, researchers have recognized the resurgence of intangible cultural heritage (ICH) within global cultural and fashion industries, placing heritage-based crafts as drivers of sustainable development and cultural diplomacy [20-22]. This is consistent with UNESCO policy, which underscores the integration of ICH with contemporary enterprises to bolster cultural vitality and economic resilience [23].

Complementary literature in environmental science and circular economy highlights the dual dilemma of

organic waste—its potential for pollution (soil/water) and its possibilities for valorization through biotechnological innovations [24-26]. Studies on plant-based waste valorization demonstrate the effective transformation of residues into usable products (e.g., bio-composites, pigments) utilizing technology associated with Food Industry 4.0 [25]. These techniques embody Niesenbaum's (2019) ecological integration paradigm, emphasizing biodiversity and sustainability. The results indicate that cultural companies like Xiangyunsha can effectively include waste valorization into their production methods, thus aligning ecological preservation, artisanal identity, and market innovation.

Comprehensive Circularity and Craft Sector Evolution
The adaptive reuse of built heritage is a parallel option that enhances material longevity and aligns conservation with overarching sustainability objectives [27-29]. This "coevolutionary" strategy integrates heritage management with circular resource flows, preserving cultural identity while reducing environmental effects. It endorses academic appeals to reassess cultural development initiatives and site management strategies within UNESCO guidelines [21].

The craft sector is continually evolving in response to environmental demands. European roadmaps emphasize the importance of eco-certification, service design, collaboration, and digitization to improve competitiveness while maintaining cultural identity [30]. Moreover, sustainable craft methods increasingly incorporate product-service systems with cultural continuity, allowing artists to adjust to global trends while preserving local heritage values [31]. This evolution positions crafts as both custodians of traditional knowledge and integral contributors to the green and circular economy.

Despite the growing recognition of Xiangyunsha's cultural importance, a significant deficiency in academic attention persists in the systematic reassessment and management of its production byproducts. The current study prioritizes historical and cultural viewpoints while predominantly overlooking the environmental repercussions of *Dioscorea* residues and liquid waste management.

There is a lack of empirical research in the following four domains:

1. Quantification of Waste Flows: Data regarding the exact volume, composition, and seasonal fluctuations of *Dioscorea* residues, process liquids, and biological weeds produced in the Shunde Xiangyunsha industry is scarce.
2. Environmental Risk Assessment: The ecological threats presented by the unprocessed release of tannins and organic matter—such as soil compaction, microbial inhibition, and aquatic eutrophication—are insufficiently defined.
3. Resource Valorization Pathways: Few empirical studies exist on effective methods for transforming these intricate waste streams into high-value secondary materials (e.g., natural pigments, sustainable sheet materials, or biocomposites).
4. Integration with Cultural and Economic Strategy: Current academic research inadequately investigates how the repurposing of production byproducts might bolster environmental goals, preserve cultural identity, and enhance the economic sustainability of the Xiangyunsha artisan industry.

This study aims to address the highlighted knowledge gaps by investigating creative ways for the valorization of Xiangyunsha byproducts. The precise objectives of the research are to:

1. Characterize Waste Streams: Conduct a quantitative analysis of the volume, composition, and seasonal variation of the principal byproducts from Xiangyunsha production, particularly *Dioscorea* residues, process liquids, and biological weeds.
2. Evaluate Environmental Risk: Conduct an empirical assessment of the ecological risks linked to contemporary disposal methods for these byproducts.
3. Establish Valorization Pathways: Execute material conversion operations to transform the specified waste streams into high-value functional materials, including sustainable sheet materials, clay composites, and natural pigments, appropriate for new product development.
4. Model Cultural-Ecological Integration: Illustrate how byproduct reutilization bolsters the tenets of the circular economy while concurrently enhancing the cultural authenticity and legacy significance of the Xiangyunsha craft.
5. Propose a Sustainable Framework: Outline a thorough approach for sustainable use that combines traditional craft methodologies with modern environmental science and circular economy principles.

Methods

Research design

This study employed an interdisciplinary mixed-methods approach, combining quantitative analysis, laboratory experiments, and qualitative research. The methodology integrated environmental science, materials science, and cultural heritage studies to comprehensively assess waste creation, evaluate ecological concerns, and investigate valorization options for Xiangyunsha byproducts.

Data collection

Quantification of byproduct streams

Site-specific measurements were performed at the Xiangyunsha industrial facility in Shunde. Seasonal sampling (spring, summer, autumn, and winter) was utilized to document temporal variations. The data collection involved measuring the weight of *Dioscorea* leftovers after extraction, recording the quantities of discarded *Dioscorea* liquid, and estimating the biomass of weeds produced by the upkeep of drying fields.

Environmental risk assessment

The environmental risks linked to unrefined waste were evaluated by laboratory and field analyses. Chemical Analysis: *Dioscorea* residues and liquids were examined for essential chemical parameters, including pH, tannin concentration, organic matter content, nitrogen, and phosphorus levels.

For ecological Impact, soil samples subjected to trash were assessed for alterations in fertility, microbial activity, and acid-based balance. The potential for eutrophication in water quality was assessed using measurements of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), dissolved oxygen, and nitrate/nitrite levels. Field observations recorded related problems like odor generation and insect infestation.

Material valorization experiments

Laboratory research aimed at transforming waste streams into lucrative resources:

Composite development: Dioscorea residues and weeds were subjected to chemical pretreatment (e.g., sodium hydroxide, oxidizing agents) and amalgamated with viscous binders to produce sheet and clay composites. The materials were evaluated for mechanical strength, colorfastness, texture, and morphology.

Pigment extraction: Natural pigments were extracted from Dioscorea liquid with various mordants (e.g., lime, alum, and vitriol). The resultant pigments were developed for application in various mediums (watercolor, oil, and traditional Chinese painting) and evaluated for durability, adhesion, and efficacy.

Prototyping: Prototype items (e.g., artisanal paper, packaging, lighting, paints) were created to illustrate the functional efficacy and practical utility of the valorized materials.

Cultural-heritage contextualization

The technical findings were situated within a wider socio-cultural framework through semi-structured interviews with local artisans, designers, and other stakeholders. Thematic content was collected regarding perceptions and the feasibility of trash reutilization in the Xiangyunsha sector. This was augmented by an examination of pertinent literature regarding cultural heritage policy and sustainable craft methods.

Data analysis

Descriptive statistics were utilized on the quantitative data to ascertain mean volumes,

seasonal patterns, and environmental risk thresholds. Laboratory data were juxtaposed with defined national requirements for soil and water quality. The composite and pigment material qualities were assessed by standardized physical and visual evaluations. Thematic coding was employed to evaluate qualitative interview transcripts and discern fundamental cultural and heritage viewpoints on byproduct valorization.

Validation

The results were validated by a professional review team consisting of environmental scientists, materials engineers, and cultural heritage experts. The market and functional feasibility of the product prototypes were evaluated by external designers and prospective end-users.

Ethical and safety considerations

All field and laboratory activities complied with established environmental safety regulations, and trash produced during the study was managed in accordance with local norms. Informed agreement was obtained from all interview participants, and meticulous adherence to ethical principles regarding the non-appropriation of traditional knowledge was observed.

Results

Waste quantification

In response to RQ1 (What types and amounts of byproducts are produced during Xiangyunsha dyeing and finishing, and how do they fluctuate seasonally and throughout production stages?), field surveys in Shunde revealed substantial byproduct generation during Xiangyunsha production. For a factory operating on 100 Chinese mu of land in 2024, 288 tons of Dioscorea tubers yielded 159 tons of waste residues (55.4% of weight). Extrapolated to the regional scale, Shunde produced 3,191 tons of Dioscorea residue annually.

Waste liquid showed strong seasonal variation. During the rainy season, production interruptions led to the direct disposal of approximately 13,564.8 kg/year of Dioscorea liquid. By contrast, more stable weather periods allowed reuse or mixing of old and new liquid

batches, reducing discharge volumes.

Lawn maintenance from fabric drying fields generated 47.5 tons of weeds per year, reflecting the continuous need to manage vegetation under Shunde's subtropical monsoon climate.

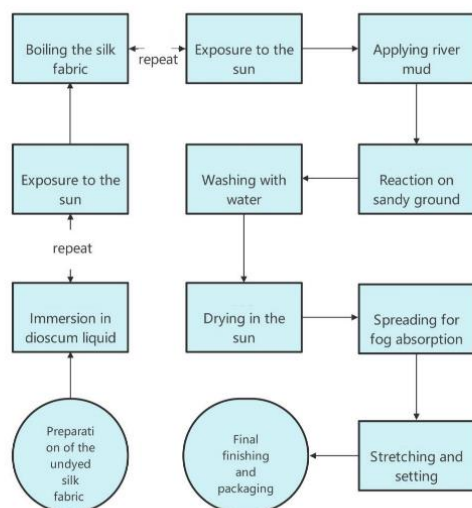


Figure 1. Traditional xiangyunsha processflow chart illustrating stages of production where waste is produced (created by the author)

Environment risk assessment

The results of RQ2 (What ecological and health hazards are linked to the existing disposal methods

of these byproducts, especially regarding soil, water, and microbial equilibrium?), laboratory and field analyses confirmed significant environmental risks associated with the unprocessed Xiangyunsha byproducts:

Dioscorea residues and liquids

The analysis of Dioscorea residues indicated high concentrations of tannins, which resulted in the inhibition of indigenous microbial activity and consequently prolonged composting and degradation cycles. Leachate from these residues, when released into aquatic environments, poses a substantial risk of eutrophication and nutrient imbalance.

Dioscorea liquid was determined to be acidic (low pH), leading to a detrimental effect on soil health by reducing fertility and disrupting microbial equilibrium. Furthermore, the colloidal substances present in the liquid contributed to the hardening of soil aggregates, thereby reducing essential air and water permeability. The residual organic matter and tannins also inadvertently created favorable breeding environments for various pests, including nematodes, mosquitoes, and flies.

Improperly dried weeds were found to be susceptible to the formation of mold and mycotoxins. When these were discarded into local ponds, their rapid decomposition significantly consumed dissolved oxygen, leading directly to fish mortality, disease outbreaks, and the acidification of bottom sediment.



Figure 2. Location, drying field environment, and Xiangyunsha clothing samples contextualizing the relationship between production environment and waste generation (captured by the author)



Figure 3. The image depicting several operational scenes in the traditional Xiangyunsha process (captured by the author)

Material revalorization

The results of RQ3 (What methods can be employed to convert *Dioscorea* residues, waste liquids, and weeds into novel materials, and what are their functional and aesthetic characteristics?), the experimental investigations successfully demonstrated the conversion of *Dioscorea* residues and weeds into stable, aesthetically unique sheet and clay-based composites.

Sheet composites: The mesh size of the processed residues was a critical factor, directly influencing the final product's fineness and color uniformity. Increasing the proportion of *Dioscorea* powder deepened the resulting sheet hues, achieving a range of desirable natural browns and reds characteristic of the traditional dyeing process.

Clay composites: Stability and structural integrity were achieved by optimizing the binder ratios. The resulting surface textures exhibited variability directly correlated with the concentration of *Dioscorea* content.

These material outcomes showcase the potential for upcycling these organic byproducts into sustainable inputs for the design sector (Figures 4–9 illustrate preparation methods and material outcomes).

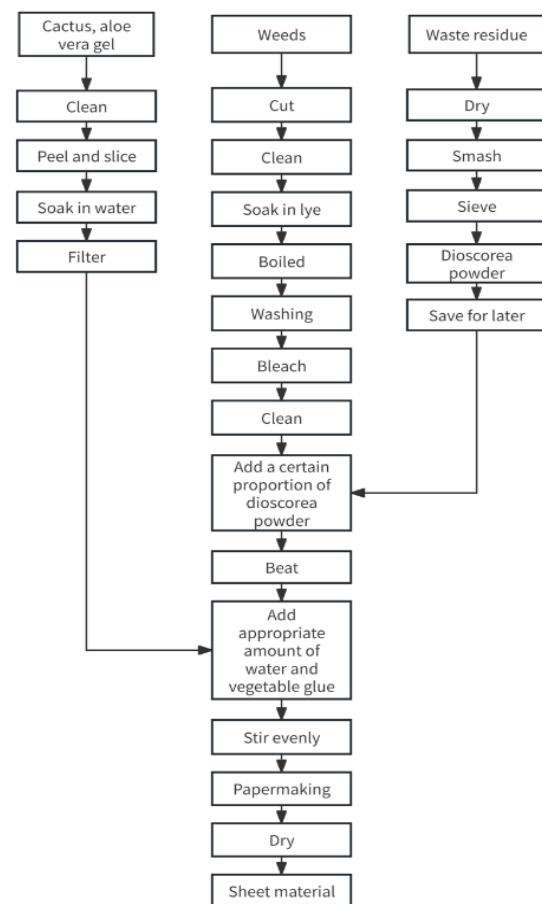


Figure 4. Procedure for fabricating sheet materials from *dioscorea cirrhosa* byproducts and weeds (created by the author)

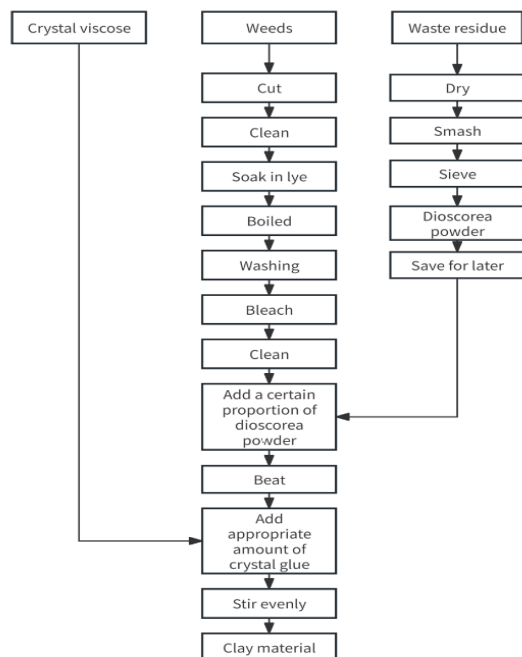


Figure 5. Procedure for fabricating clay materials with dioscorea cirrhosa wastes and weeds (created by the author)

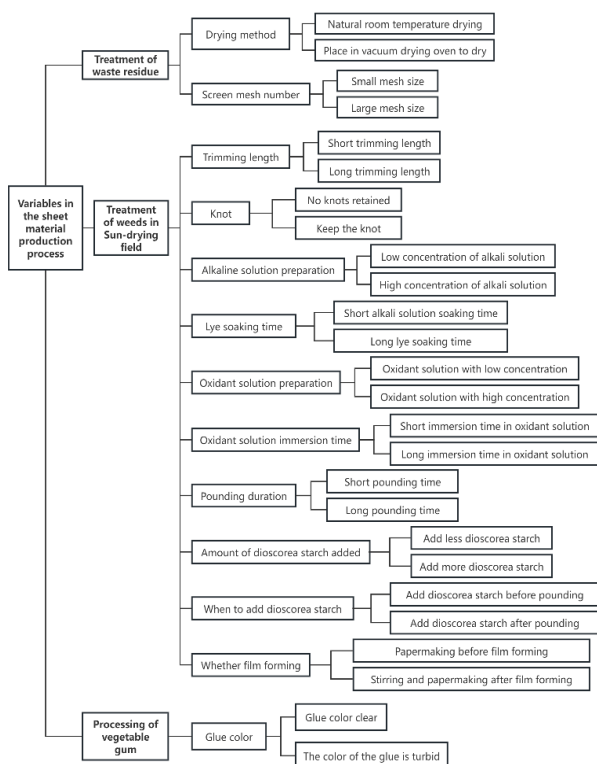


Figure 6. Quantitative variables in the preparation of sheet materials from waste dioscorea residues and weeds (illustration by the author)



Figure 7. Impact of including Dioscorea powder on the coloration of the sheet material (photographed by the author)



Figure 8. Collection of images illustrating various textures on the surface of sheet materials (photographed by the author)

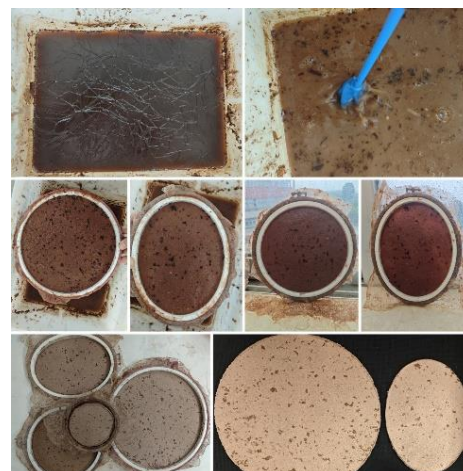


Figure 9. Images depicting sheet material exhibiting uneven patterns resulting from the operations of film formation, crushing, and papermaking (photographed by the author)

Pigments from dioscorea liquid

Pigments were successfully extracted using alum, lime, and vitriol mordants. These produced color ranges from yellow brown to deep black, depending on mordant type and ratio. Medium formulations extended applications: gum Arabic pigments suited watercolor, linseed oil pigments suited oil painting, and gelatin-based pigments were especially effective on silk for Chinese painting. Stability tests confirmed stronger adherence to silk compared with paper. Figures 10–11 document pigment preparation and resulting hues.

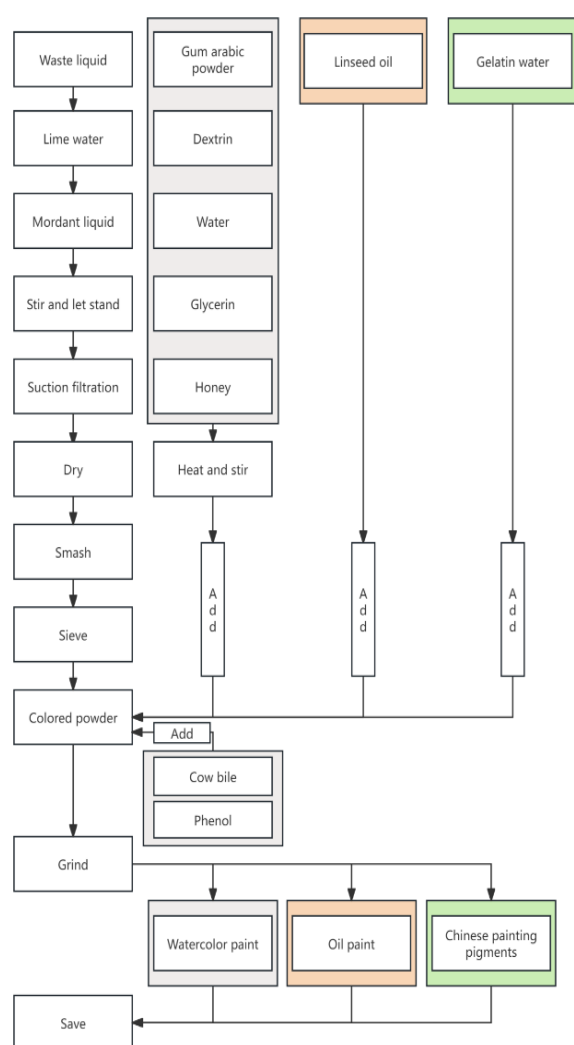


Figure 10. Technique for synthesizing pigments from Dioscorea liquid (shown by the author)



Figure 11. Image depicting a segment of the procedure for producing pigment materials from dioscorea liquid (captured by the author)

Cultural and heritage integration

Regarding RQ4 (How can the revaluation of Xiangyunsha byproducts enhance cultural identity and local handicraft while adhering to circular economic principles?), prototypes were developed from revalorized materials, including handmade writing paper, notebooks, packaging, desk calendars, clay lamps, pulp sculptures, and portable boxed paints. These products combined functional utility with natural aesthetic qualities derived from

Dioscorea residues and pigments.

The results suggest that revalorization extends the ecological philosophy of Xiangyunsha—“taking from nature and returning to nature”—into new domains. By incorporating waste reuse into cultural-creative industries, the craft reinforces its identity as both a heritage practice and a model for sustainable innovation. Creative product development methods summarizing the transformation from waste to applied products are present in Table 1.

Table 1. Creative product development methods summarizing the transformation from waste to applied products

Forms of the product	Materials and tools	Production method
Folding packaging design	String, perforator, sheet materials	Utilize folding technology to create diverse packing configurations.
Textured artisanal writing paper items	Rulers, utility knives, and sheet materials	Adjust materials to the specified dimensions and shapes by cutting and trimming them.
Artisan-crafted notebooks	Hollow molding plate, molding powder, bowl, scraper, phosphorous liquid, high-temperature pot, plants, alum, green alum, blue alum, beaker, glass rod, linen, plastic wrap, scissors, hole punch, C-shaped bent needle, hemp rope, clips, small wooden sticks, sheet materials.	The paste dyeing procedure, plant heat transfer printing technique, and punching and threading binding method are all distinct processes.
Artisan-crafted desk calendar	Ruler, utility knife, scissors, thread, hole punch, loose-leaf split ring, a little wooden dowel, and sheet materials	Decorate the sheet material with paint. After cutting, utilize a hole punch and a loose-leaf ring for assembly, and then position it into a stationary frame made of wooden sticks and hemp rope.
Artisan-crafted lamps	Wooden chopsticks, hemp rope, light strings, and sheet materials	Assemble the frame using wooden chopsticks, adorn the sheet material with paint, cut it to fit the back frame, affix it securely, and then attach the light string and hemp rope.
Sculptures crafted with paper pulp	Pencils, wastepaper bins, scissors, pureed substances, and Dioscorea powder	Integrate clay substances with Dioscorea powder, segment waste cartons to form the structure, stratify the materials, and apply surface protection as required after drying.
Portable packaged paint products	Spatula, mobile paint container	Utilize a spatula to transfer paint into the paint container.

Some of the developed products are shown in Figure 12.



Figure 12. Image illustrating various development approaches for innovative items derived from waste materials

Toward a sustainable Xiangyunsha model

In synthesizing the data for RQ5 (What framework or model can be provided to incorporate trash revaluation into Xiangyunsha production, ensuring a balance among ecological sustainability, economic viability, and the preservation of cultural heritage?), a sustainable development paradigm arises wherein waste quantification (RQ1) informs management, environmental risk awareness (RQ2) propels action, material revalorization (RQ3) facilitates practical innovation, and cultural integration (RQ4) guarantees continuity. Drawn upon the synthesized data, a sustainable Xiangyunsha model is proposed as shown in figure 13.

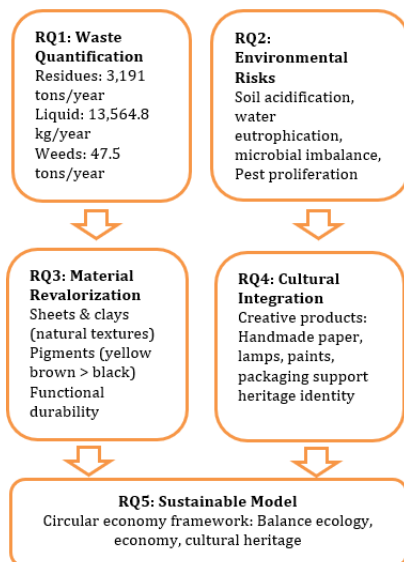


Figure 13. A proposed sustainable Xiangyunsha model

In the proposed sustainable Xiangyunsha model, the upper layer (RQ1–RQ2) identifies waste volumes and associated risks; the middle layer (RQ3–RQ4) demonstrates revalorization methods and cultural integration; the final layer (RQ5) consolidates findings into a sustainable Xiangyunsha production model balancing ecology, economy, and cultural heritage.

The proposed framework establishes Xiangyunsha as a heritage-oriented circular economy model that harmonizes ecological sustainability, economic viability, and cultural preservation. This change reduces environmental risks and generates new revenue streams for local enterprises, thereby improving resilience and long-term sustainability.

Discussion

From traditional craft to environmental challenge

The data confirm that Xiangyunsha, while regarded as a unique cultural heritage activity, generates significant quantities of organic waste. Annually, this firm generates 3,191 tons of *Dioscorea* residues, 13,564.8 kg of liquid waste, and 47.5 tons of weeds, illustrating the significant environmental burden it imposes [32]. Historically, remnants and undesirable plants were either composted or naturally reintegrated into the ecology, consistent with long-standing eco-textile practices and place-based knowledge in Xiangyunsha communities [15–17,34].

However, modern production intensities and variable meteorological circumstances (precipitation, typhoons, humidity) have disrupted this balance, leading to soil acidification, water eutrophication, and heightened dangers from insect multiplication—patterns consistent with broader textile-effluent literature and soil-system responses to organic loading and amendments [6–10]. These findings demonstrate the paradox of heritage industries: while they embody ecological knowledge, they can produce unsustainable waste streams when scaled to meet contemporary demand [18–20, 23]. Consequently, addressing the ecological ramifications of Xiangyunsha manufacturing is crucial for both environmental preservation and the sustained sustainability and cultural integrity of this traditional art.

Waste as a resource: aligning with circular economy

The experimental results demonstrate the feasibility of transforming waste into sheet materials, clay composites, and pigments. This complies with circular-economy concepts by closing material loops and generating new product streams without synthetic additives [11, 12]. The discovery that *Dioscorea* tannins offer natural pigmentation, resilience, and antimicrobial properties is consistent with the wider *Dioscorea* processing and biorefinery literature and with efforts to extract value from yam/cassava chains while addressing safety and process efficiency [2–5]. Compared with conventional paper and pigment manufacturing that depend on chemical dyes and stabilizers, *Dioscorea*-derived products provide multifunctionality while minimizing environmental effects, aligning with evidence that valorization of organic waste can jointly support ecological conservation and economic growth [24–26,35]. Such valorization resonates with recent sectoral applications where circular strategies translate byproducts into inputs for new product streams [13, 14]. Collectively, these findings underscore the promise of Xiangyunsha waste revalorization as a technological innovation and a scalable approach for bio-based material manufacturing within circular economy paradigms.

Cultural continuity and innovation

Crucially, waste revalorization here is not only environmental or technological; it enacts Xiangyunsha's ecological philosophy—"extracting from and restoring to nature"—embedded in the craft's historic material culture and techniques [15–17]. Operationalizing this philosophy through handmade paper, pulp sculptures, and natural pigments sustains traditional integrity while embracing contemporary innovation in cultural and design industries [20, 31]. This stance accords with policy and scholarly arguments that ICH should integrate sustainable development logics and contemporary market linkages without eroding cultural identity [19, 21–23]. In short, reusing byproducts in historical crafts is a creative re-articulation of core principles that strengthens both symbolic and economic value in present-day cultural and fashion economies [20–23, 31]. Ultimately, these methods demonstrate how heritage-driven

innovation may preserve cultural authenticity, stimulate design creativity, and promote sustainable futures.

Multidisciplinary implications

The results of this study are significant across various domains. From an environmental science viewpoint, they tackle the pollution-utilization contradiction by demonstrating how tannin-rich byproducts—usually harmful to soils, waterways, and microbial communities—can be repurposed as beneficial materials for material production [6–10, 18, 25]. In economic and sustainability research, these byproducts acquire new significance through cultural and creative enterprises, redefining ecological costs as catalysts for innovation and harmonizing with circular-economy principles and entrepreneurial strategies across various sectors and scales [11–14, 24–26]. From the perspective of cultural heritage studies, waste revalorization illustrates the adaptability of traditional crafts in response to ecological and cultural pressures while preserving their relevance and community importance, thereby reflecting current discussions on intangible cultural heritage, sustainability, and site management practices [19–23]. Collectively, these viewpoints highlight Xiangyunsha's potential as a paradigm for harmonizing ecological conservation, economic rejuvenation, and cultural perpetuation within a cohesive sustainability framework.

Toward a sustainable model for Xiangyunsha production

The findings demonstrate that a systematic framework is essential for the sustainable exploitation of byproducts in Xiangyunsha production. A comprehensive framework must encompass the quantification and monitoring of waste to preempt seasonal challenges stemming from hydro-meteorological fluctuations and production surges; the on-site treatment and conversion of residues, liquids, and vegetation via circular-economy process strategies and bioresource valorization pathways; and collaboration with designers and creative industries to convert revalorized materials into commercially viable products and services, leveraging craft-sector service design and sustainability frameworks. Policy and community participation are equally vital to assure

alignment with cultural heritage preservation and environmental standards, in accordance with UNESCO-informed governance frameworks, cultural advancement initiatives, and heritage management practices [19–23]. Integrating waste revalorization into Xiangyunsha can transform the industry from a potential pollutant to a circular-economy while also aligning with built-heritage strategies—such as adaptive reuse and eco-efficient retrofitting—that enhance place-based cultural and environmental outcomes at a territorial scale. In this manner, the sector safeguards Shunde's ecological systems while simultaneously rejuvenating local industry through culturally rooted, new economic prospects [13, 14, 27–31]. This sustainable model illustrates how Xiangyunsha can transform from a precarious legacy practice into a global benchmark for the successful integration of ecological preservation, cultural continuity, and economic innovation within circular-heritage enterprises.

Conclusion

This study investigated the reevaluation of leftovers from Xiangyunsha dyeing and finishing, concentrating on *Dioscorea* residues, waste liquids, and weeds. The findings indicate that these byproducts, if not well controlled, provide significant environmental hazards, including soil acidification, water eutrophication, and biological imbalance. Experimental trials, however, revealed the viability of revalorizing these wastes into sheets, clay composites, and pigments, which were effectively converted into cultural-creative products.

The findings underscore the dual potential of waste revalorization: environmentally, it alleviates pollution and diminishes ecological pressure, while commercially, it cultivates new product lines with feasible market prospects. Cultural continuity is preserved by integrating Xiangyunsha's ecological philosophy of "taking from nature and returning to nature" into contemporary sustainable methods, thus establishing the craft as a global model of circular heritage industries.

Coordinated policies among industry, politicians, and researchers are necessary for sustainable growth in Xiangyunsha. Waste management technology, policy incentives, and interdisciplinary research can facilitate ecological preservation while fostering

innovation and cultural continuity. Xiangyunsha exemplifies the evolution of ancient crafts into paradigms of circular economy, merging ecological responsibility, economic resilience, and cultural sustainability.

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