

NATURAL DYES, ULOS WEAVING, AND SUSTAINABLE LIVELIHOODS IN MEAT VILLAGE, INDONESIA

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Abstract

Natural dye utilisation in ulos weaving is increasingly positioned as a practical pathway to align cultural heritage with sustainability-oriented rural development. This study investigates the direct influence of natural dye utilisation (X1) on (i) socio-economic sustainability and local biodiversity conservation (Y) and (ii) product–village reputation as a cultural destination (Z) in Meat Village, Lake Toba Geopark, Indonesia. The research applies a mixed-method design, combining participatory observation, in-depth interviews, and a structured survey of 61 weavers across three artisan groups. Quantitative analysis is conducted using a restricted PLS-SEM model that tests only two direct relationships: $X1 \rightarrow Y$ and $X1 \rightarrow Z$. The findings indicate that natural dye utilisation is strongly and positively associated with socio-economic sustainability and biodiversity conservation, and is also positively associated with destination reputation. Qualitative evidence suggests that natural dyes strengthen perceived authenticity, reinforce cultural narratives, and encourage stewardship of dye-plant resources, which together support livelihood resilience. The study highlights natural dye practice not merely as a technical substitution for synthetic dyes, but as a value mechanism connecting ecological responsibility, product differentiation, and community-based tourism readiness. The results support targeted interventions such as sustainable dye-plant management, skills upgrading, and eco-labelling to scale adoption while safeguarding local cultural and ecological assets.

Keywords: natural dyes; ulos weaving; sustainability; cultural tourism; rural livelihoods.

1. INTRODUCTION

Sustainability-oriented tourism increasingly rewards destinations that can demonstrate credible links between cultural heritage, local livelihoods, and environmental stewardship. In this policy climate, craft-based economies are not merely “cultural assets”; they become operational instruments through which communities can embed responsible production while strengthening place identity. The global SDG agenda explicitly frames responsible consumption and production as a pathway for reducing toxic outputs and resource intensity, making artisanal supply chains a legitimate sustainability arena rather than an aesthetic add-on (United Nations, 2015). Yet, for academic and policy utility, the linkage must be specified as a mechanism: which craft practice, through what pathway, generates measurable socio-economic and reputational outcomes?

Within the UNESCO Global Geoparks framework, destination quality is assessed not only by visitation and branding, but by whether local development coheres with conservation, education, and sustainable development logic. UNESCO states that geoparks undergo revalidation every four years, and that failure to address

deficiencies after a “yellow card” can lead to loss of status (“red card”) (UNESCO, 2026a; UNESCO, 2026b). This governance structure pushes destinations beyond narrative claims and toward auditable evidence of “working sustainability” at community level. Consequently, empirical studies that connect specific livelihood practices to sustainability indicators become part of the knowledge infrastructure needed for geopark credibility (UNESCO, 2026b).

Lake Toba Caldera has faced this governance moment directly, having received a UNESCO “yellow card” warning in September 2023 and subsequently mobilising improvement programs to regain “green card” status. National reporting notes that the warning was associated with management and infrastructure concerns, prompting coordinated follow-up between tourism authorities and geopark managers (ANTARA News, 2025). In practical terms, such a warning creates pressure to demonstrate that sustainability is embedded in everyday economic practice rather than restricted to policy documents. Therefore, culturally grounded production systems that are both market-facing and conservation-aligned become strategically valuable for demonstrating functional sustainability (UNESCO, 2026b).

Textile dyeing is one of the most sensitive junctions between craft economies and environmental performance because dyes and auxiliaries can generate toxicity and persistent pollution when effluents are not adequately managed. A major review in *Environmental Science and Pollution Research* documents how textile dyes can degrade water quality and create risks to ecosystems and human health, and it synthesises treatment pathways required to mitigate these impacts (T. Islam et al., 2023). Complementary evidence from recent open-access review work further emphasises ecotoxicity and health risks from dye-containing wastewater, highlighting the policy and remediation burden associated with conventional dye systems (M. M. Islam et al., 2025). This establishes why dye choice and handling are not “technical details” but sustainability determinants.

For craft destinations, the implication is direct: a shift in dye practice can operate as a sustainability lever with downstream effects on perceived product responsibility and place credibility. However, adoption of natural dyes is not costless—scalability, reproducibility, and colour fastness remain material constraints that must be acknowledged, not obscured by “green” storytelling. A recent critical review in *Nano-Structures & Nano-Objects* synthesises these technical and sustainability trade-offs, explicitly discussing how extraction methods, biomordants, and process control influence feasibility for wider use (Pranta & Rahaman, 2024). Thus, empirical research should treat natural dye utilisation as a measurable practice whose benefits must be demonstrated with disciplined evidence rather than assumed.

Natural dyes are widely characterised as renewable and potentially lower-toxicity alternatives, derived from plants and other biological resources with culturally meaningful provenance. Reviews in environmental science literature highlight the emergence of biomordants as a sustainability strategy to replace conventional metallic

mordants, aiming to reduce ecological damage while maintaining textile performance (Gürel, 2024). This literature matters for tourism-oriented craft because sustainability claims are increasingly scrutinised; credibility depends on whether ecological narratives align with feasible production routines and verifiable practices (Pranta & Rahaman, 2024). In this framing, natural dye utilisation becomes an institutional signal of responsible production and local resource governance rather than merely a stylistic preference.

Ulos, as a Batak woven textile tradition, is repeatedly documented as a carrier of symbolic meaning and socio-ritual value, positioning it as a high-density cultural product capable of representing place identity. A proceedings-based study on ulos pattern heritage explains ulos as Batak traditional woven cloth with cultural and ritual significance, while also discussing how innovation can elevate visibility and tourism-facing relevance in the Toba highland context (Barus et al., 2016). This matters because a culturally saturated product tends to carry stronger authenticity cues in destination narratives. Accordingly, changes in production attributes—such as dye type—can plausibly alter not only product value but also perceived cultural legitimacy (Barus et al., 2016).

From a destination-development perspective, ulos also fits within the logic of creative tourism, where textiles are staged as experiential learning, demonstration, and heritage engagement rather than merely retail. A bibliometric synthesis in *Administrative Sciences* clarifies that “creative tourism” has evolved as a destination strategy connected to creative industries and experience-based value formation, making craft practices central to tourism competitiveness (Benhaida et al., 2024). In this sense, natural dye utilisation can be interpreted as an experience-enhancing attribute: it supports storytelling about authenticity, ecological responsibility, and cultural continuity, which are key to reputation formation in cultural destinations (Benhaida et al., 2024). However, branding value alone is analytically insufficient unless it is tied to measurable outcomes.

This paper therefore adopts a deliberately restricted explanatory design: it isolates natural dye utilisation (X1) as the single antecedent variable and tests only two direct relationships— $X1 \rightarrow Y$ (socio-economic sustainability and local biodiversity conservation) and $X1 \rightarrow Z$ (product–village reputation as a cultural destination). This restriction is methodological and strategic: it yields a clean, modular contribution that can be extended in separate papers without conflating mechanisms. Such single-lever modelling is consistent with geopark governance needs, which often require actionable interventions that can be monitored and reported (UNESCO, 2026a). To keep the research focus auditable, the constructs and hypotheses are summarised in Table 1.

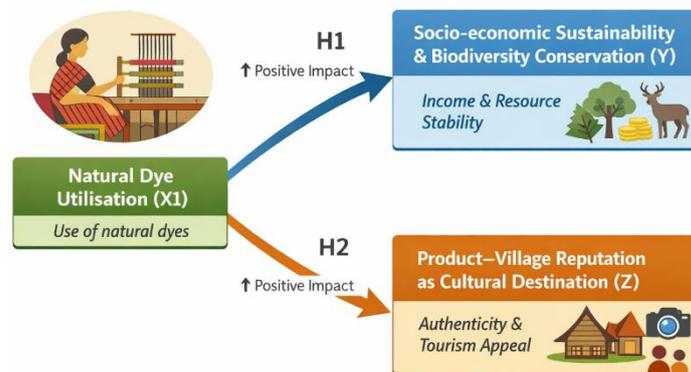
Table 1. Constructs and hypotheses (restricted model)

Code	Construct	Role in model	Hypothesis
X1	Natural Dye Utilisation	Exogenous predictor	—
Y	Socio-economic Sustainability & Local Biodiversity Conservation	Endogenous outcome	H1: $X1 \rightarrow Y$ (positive)
Z	Product–Village Reputation as Cultural Destination	Endogenous outcome	H2: $X1 \rightarrow Z$ (positive)

Finally, the core argument advanced here is that natural dye utilisation plausibly strengthens sustainability outcomes through two complementary pathways: an internal pathway (livelihood resilience and resource stewardship) and an external pathway (reputation formation via authenticity and ecological credibility). Under UNESCO’s revalidation regime, such mechanisms are not merely academic; they map onto accountability structures that determine whether geopark destinations retain status and legitimacy over time (UNESCO, 2026b). The Lake Toba “yellow card” episode reinforces the urgency of demonstrating community-level sustainability mechanisms that are visible, measurable, and defensible in governance terms (ANTARA News, 2025). Accordingly, this study positions natural dye utilisation as a concrete intervention point for sustaining culture-based livelihoods while strengthening destination reputation.

Figure 1 conceptual model

Restricted Conceptual Model (Direct Effects Only)



2. METHODOLOGY

2.1 Study design

This study used a mixed-method design. Qualitative data (participatory observation, in-depth interviews, and photo documentation) were collected to document natural dye practices and local meanings in ulos weaving. Quantitative data were collected through a structured questionnaire to test a restricted model with only two direct relationships: $X1 \rightarrow Y$ and $X1 \rightarrow Z$.

2.2 Study area and participants

The study was conducted in Meat Village, Tampahan District, Toba Regency, North Sumatra, Indonesia (Lake Toba Geopark area). Respondents were 61 weavers from three weaving groups (Mandiri, Bintang, and Marsada Roha). The unit of analysis was the individual weaver.

2.3 Variables and hypotheses (restricted model)

This paper focuses on one independent variable and two dependent variables:

- X1: Natural Dye Utilisation
- Y: Socio-economic Sustainability & Local Biodiversity Conservation
- Z: Product–Village Reputation as a Cultural Destination

Two hypotheses were tested:

- H1: X1 positively influences Y.
- H2: X1 positively influences Z.

2.4 Data analysis

Quantitative analysis used PLS-SEM (SmartPLS) to estimate the direct effects of X1 on Y and Z. The reflective measurement model was assessed using indicator loadings, Cronbach's alpha, composite reliability, and AVE. Hypotheses were tested using bootstrapping to obtain path coefficients (β), t-statistics, and p-values, with a 5% significance threshold.

3. FINDINGS AND DISCUSSION

The Findings and Discussion section presents the empirical results and interprets them in relation to the research objectives and hypotheses. Following the restricted model adopted in this paper, the discussion focuses exclusively on the direct effects of natural dye utilisation (X1) on socio-economic sustainability and local biodiversity conservation (Y) and on product–village reputation as a cultural destination (Z). Quantitative findings are complemented by qualitative insights to strengthen contextual interpretation and policy relevance.

3.1 Profile of Ulos Weaving Production and Natural Dye Adoption

This subsection presents the baseline characteristics of ulos weaving activities in Meat Village, which form the empirical context for interpreting the structural relationships tested in this study. Establishing production scale and adoption patterns is essential to ensure that statistical results are grounded in observable economic practice rather than abstract perceptions.

The three weaving groups in Meat Village collectively produce **49 pieces of ulos per week**, equivalent to **190 pieces per month** or **2,280 pieces annually**. Product prices range from **IDR 700,000 to IDR 3,000,000 per piece**, depending on motif complexity, craftsmanship, and dyeing method. Importantly, approximately **30% of total production uses natural dyes**, indicating that natural dye utilisation is already embedded in the local production system but has not yet reached dominance.

This production profile confirms that ulos weaving in Meat Village functions as an active livelihood system rather than a symbolic cultural activity alone. The partial adoption of natural dyes suggests sufficient variation in X1 to explain differences in

sustainability outcomes and destination reputation, which is a prerequisite for meaningful statistical testing.

Table 2. Ulos weaving production profile in Meat Village

Weaving group	Active weavers	Weekly output (pcs)	Monthly output (pcs)	Annual output (pcs)	Price range (IDR)	Natural-dyed share (%)
Mandiri	22	18	70	840	700,000–3,000,000	30
Bintang	19	15	60	720	700,000–3,000,000	30
Marsada Roha	20	16	60	720	700,000–3,000,000	30
Total	61	49	190	2,280	—	30

Source: Primary data processed (2025)

3.2 Measurement Model Evaluation

Before analysing the structural relationships, the reliability and validity of the measurement model were assessed to ensure that the constructs used in this study were statistically sound. All constructs were specified as reflective, meaning that observed indicators were assumed to reflect underlying latent variables.

The construct Natural Dye Utilisation (X1) demonstrated strong internal consistency, with Cronbach's alpha and composite reliability values exceeding the commonly accepted threshold of 0.70. Convergent validity was confirmed through average variance extracted (AVE) values above 0.50, indicating that the indicators adequately captured the underlying construct.

Similarly, the constructs Socio-economic Sustainability and Local Biodiversity Conservation (Y) and Product–Village Reputation as a Cultural Destination (Z) met reliability and convergent validity criteria. These results indicate that respondents' perceptions regarding income stability, ecological stewardship, and destination reputation were measured consistently and coherently. Consequently, the measurement model was deemed suitable for subsequent structural analysis.

3.3 Effect of Natural Dye Utilisation on Socio-economic Sustainability and Biodiversity Conservation (X1→Y)

The first hypothesis (H1) tested whether natural dye utilisation positively influences socio-economic sustainability and local biodiversity conservation. The structural model results show a **strong positive and statistically significant relationship** between X1 and Y, with a path coefficient of $\beta = 0.747$ and $p < 0.001$.

This finding indicates that higher levels of natural dye utilisation are associated with improved livelihood stability, stronger conservation orientation, and greater awareness of sustainable resource use among weavers. Qualitative observations support this result, as artisans reported that natural dye production encourages careful management of dye plants, longer production cycles, and stronger valuation of product quality over quantity.

From an economic perspective, naturally dyed ulos tend to occupy higher price segments, contributing to income resilience rather than volume-driven earnings. From an ecological perspective, reliance on plant-based dyes reinforces the importance of maintaining local vegetation and discourages environmentally harmful chemical inputs. Together, these mechanisms explain why natural dye utilisation functions as a powerful driver of socio-economic sustainability at the community level.

3.4 Effect of Natural Dye Utilisation on Product–Village Reputation as a Cultural Destination (X1→Z)

The second hypothesis (H2) examined the influence of natural dye utilisation on the reputation of Meat Village as a cultural destination. The analysis reveals a positive and statistically significant relationship, with a path coefficient of $\beta = 0.339$ and $p < 0.001$.

This result suggests that natural dye utilisation contributes meaningfully to how the village and its products are perceived by visitors, buyers, and external stakeholders. Natural dyes enhance perceived authenticity through visible colour characteristics and through narratives of environmental responsibility and cultural continuity. These attributes are increasingly valued in cultural and experiential tourism markets.

Field observations indicate that weaving demonstrations involving natural dyes are particularly effective in attracting visitor interest and engagement. Thus, natural dye utilisation does not merely enhance product quality but also strengthens the symbolic and experiential dimensions that underpin destination reputation.

3.5 Integrated Discussion: Natural Dye Utilisation as a Strategic Development Lever

Taken together, the findings demonstrate that natural dye utilisation operates as a **dual-impact mechanism**. Internally, it strengthens socio-economic sustainability and biodiversity conservation by promoting responsible production and livelihood resilience. Externally, it enhances the reputation of the village as a credible cultural destination by reinforcing authenticity and sustainability narratives.

The strategic implication is clear: promoting natural dye utilisation represents a feasible, low-regret intervention for destinations seeking to align cultural heritage, sustainability goals, and tourism development. Rather than relying on abstract policy commitments, local governments and geopark managers can support tangible practices that are observable, marketable, and measurable.

4. CONCLUSION

This study examined the role of natural dye utilisation in the ulos weaving industry of Meat Village by applying a deliberately restricted model that tested only two direct relationships. The findings demonstrate that natural dye utilisation has a strong and positive influence on socio-economic sustainability and local biodiversity conservation, indicating that environmentally responsible dyeing practices contribute to income stability, livelihood resilience, and increased awareness of resource stewardship among weavers. At the same time, natural dye utilisation was found to have a positive and significant effect on product–village reputation as a cultural destination, strengthening perceptions of authenticity and enhancing the village’s appeal within cultural and experiential tourism contexts.

By isolating natural dye utilisation as a single explanatory variable, this paper provides clear evidence that sustainability-oriented craft practices can function as a practical development lever rather than a symbolic intervention. The results suggest that supporting natural dye adoption can simultaneously address economic,

ecological, and reputational objectives within geopark-linked rural tourism development. From a policy perspective, targeted interventions such as sustainable dye-plant management, technical training, and eco-labelling schemes are likely to amplify these benefits. Future studies may extend this framework by incorporating tourism management quality, governance factors, or mediation mechanisms to further explain how cultural production systems contribute to long-term destination sustainability.

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