

Aal Root Dyeing Tradition of Odisha: A Review on Cultural Heritage, Natural Dyes, and Sustainable Textile Practices

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Abstract

Kotpad textiles are well known for their cultural and traditional value. Many studies have explored their history, symbolism, and role in tribal communities. However, less attention has been given to the science behind the dyeing process. Limited research is available on dye chemistry, mordant–fibre interactions, and their role in sustainable textile production. Therefore, this review combines traditional knowledge with modern textile science. It examines both the cultural heritage and the scientific aspects of Kotpad dyeing. The study suggested that the purity of the samples of the Aal root and the differences in the regions of mordanting techniques resulted in the inconsistency of morindone yield and color reproducibility. Literature related to studies suggest that mordanting and dye extraction processes may improve wash fastness and shade stability in Morinda-based natural dyes. This study relates dying heritage of the local people and modern science, thereby highlighting its efficacy for the production of eco-friendly textiles with commercial viability, which are still based on traditional wisdom.

Keywords: Kotpad textiles; Aal dye; Natural dyeing; Mordant interaction; Anthraquinone pigments; Sustainable textile processing

Introduction

Dyes extracted from plants have gained renewed attention for their biodegradability, cultural significance, and low environmental impact (Aggarwal, 2021; Balachandran & Sabumon, 2023; Samanta & Singhee, 2023). Kotpad weaving, practiced by Mirgan tribal Community in the Koraput district of Odisha, is India's one of the rich tribal textile traditions and has been survived across several generations. Coarse hand-spun cotton is mostly used by the weavers, and the roots of the Aal plant are used for dyeing. The plant grows naturally in the Koraput region and gives powerful earthy red, maroon, and brown colors (Kannan et al., 2020; Samanta & Singhee, 2023). The fabrics are woven with beautiful geometric motifs using extra weft insertion techniques. The motifs symbolise harmony with nature. It includes crabs, tortoises, and trees, which stand for fertility and prosperity (Pandey, 2024; Dutta & Maulik, 2021). In the past, these textiles were made for the weavers' family and the community, and were mostly given as gifts at marriage and sacred ceremonies, thus, becoming the manifestations of social identity and spirituality (Pandey, 2024). Kotpad textiles are the artistic heritage of the area, resulting in the grant of the Geographical Indication (GI) tag to them in 2005. The weaving customs struggled to survive modernization as they are dependent on raw materials obtained from

natural resources - handspun cotton fibers, looms made of wood, and vegetable dyes which are manually extracted (Dutta & Maulik, 2021). The fabric is a perfect example of the environmentally friendly design from times before the industrial dyeing era (Sankari et al., 2024). Although the importance of the symbolism and the aesthetics of the weaving have been mainly documented in history, the chemical mechanisms of the interaction between the dye and mordant and fibre have been given comparatively limited scientific attention (Samanta & Singhee, 2023; Kannan et al., 2020). This study is based on botanical, chemical and material study on the aal dye, its reaction with metallic mordants, and the mechanism of bonding with the natural fibres like cotton (Sabatini et al., 2020). It also focusses on the socio-ecological systems that keep the Kotpad weaving tradition alive and discusses how the artisans deal with all the natural resources, communal labor and design innovation (Pandey, 2024; Das, 2024). The Kotpad tradition is re-branded to be a heritage art as well as scientifically applicable ecological practice by combining scientific validation with cultural knowledge.

Methodology for Literature Review

For the present study, literature was collected from published studies related to Kotpad textiles. The relevant selected literature was analysed and organised under sub sections such as origin, cultural context, traditional symbolism, dye interaction with fabric etc. The findings were analysed meticulously to understand the science behind the weaving tradition of Mirgan community of Kotpad.

Conceptual Framework

This review is based on the idea that Kotpad dyeing is more than a textile-making process. It is a combination of traditional knowledge, natural resources, and sustainable practices that have been preserved by the Mirgan weaving community over generations. The framework shows how the use of Aal root as a natural dye is connected to dye extraction, mordanting, and fibre bonding processes. These factors influence the colour, durability, and quality of the fabric.

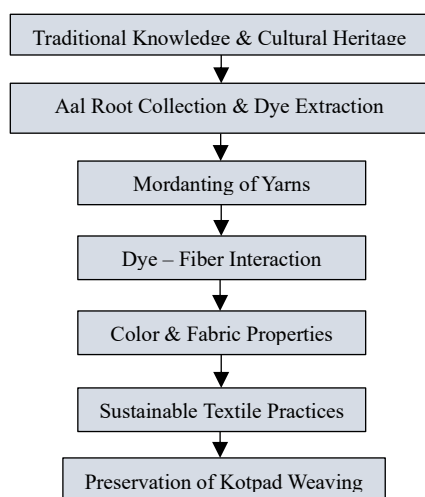


Figure 1. Conceptual Framework

Origin and Cultural Context of Kotpad Weaving

The preservation of Kotpad handloom weaving requires an interdisciplinary approach that integrates ethnographic knowledge with scientific investigation. Mirgan weaver community of Odisha has an intergenerational history where weaving is a form of livelihood and culture. Their themes, which represent fertility, nature and social harmony, encode ecological knowledge by using natural dyes extracted from Aal roots. The ethnographic knowledge with the chemical analysis can aid in the process of deciphering the material properties of such dyes and optimizing in the process of mordanting without disturbing the cultural aspects. Scientific studies can support the preservation of traditional dyeing practices by improving understanding of dye chemistry while respecting indigenous knowledge systems. Through such forms of collaborative practices, the Kotpad culture can be

transformed into an environmentally friendly model of eco-textile innovation, in which chemical refinement will support the cultural survival, and, in turn, indigenous creativity will train the existing scientific strategy, which will ensure continuity and moral regeneration of Odisha's textile culture (Patra, 2021; Pandey, 2024).

Socioeconomic Status of the Mirgan Weaver Community

Dutta and Maulik (2021) stress that the Kotpad weavers of Odisha plays one of the most important roles in the tradition of handlooms of India. The research shows that Kotpad textiles, which are deeply rooted in the traditional style, may be diversified with the help of natural dye applications, block printing, and batik without losing their authenticity. The study suggested that these strategies and innovative application would help to increase the revenue and help Kotpad weavers to practice their trade in international markets. This socioeconomic strategy may empower the restoration of the local livelihoods.

Another study on Sambalpuri weavers provides information on the economic hardships of tribes that practice weaving, like the Mirgans (Das, 2021). The research concludes that in spite being the products have high prices in the market, maximum percentage of money is managed by the middlemen at the expense of the weavers who are poorly paid. It was identified that due to systemic marketing inequities, the growth of weavers is hindered. The study highlights the need to have collaborative formations and state-oriented interventions to provide equitable wealth sharing and livelihood sustainability to the tribal weavers in Odisha.

Mishra (2020), in his study suggested the concept of digitalization to change the economic conditions of weavers in the rural Odisha. The study focusses e-commerce as a viable marketing channel that is sustainable to remove mediators and conduct direct interaction between artisans and clients. He also suggested that by imparting digital literacy to weavers, they will not only be able to retain their traditional aesthetics, but receive justified pay. This digital inclusion assists in reducing the divide between the rural and urban areas as it modernizes the indigenous economies without destroying their cultural entities.

Patra (2021) studied the impact of e-marketing that has transformed the conventional markets of handlooms by bridging the gap between weavers and the world through the use of social media. In the case of Kotpad textiles, this exposure can help to popularize their symbolic motifs. It has been observed that digital marketing platforms may facilitate wider dissemination of the cultural significance. Therefore, the digital platforms do not simply facilitate trade but they also act as storytellers who keep intangible cultural symbols.

Samanta and Singhee (2023) give the scientific premise in which fabrics are dyed using natural dyes. They describe that the red color is also a result of morindin and morindone based on anthraquinone, which on mordanting produces metal-chelate complexes, resulting in permanent shades. Authors also observe the antimicrobial and UV-protective qualities of these dyes, which contributes scientific significance to the symbolic tribal motives. Their discussion revealed that chemistry and cultural symbolism can exist simultaneously.

Intergenerational Transmission of Indigenous Knowledge

The socio economic and ethical transformations of indigenous weavers in Odisha especially in Nuapatna and Maniabandha were further discussed in another study (Pandey (2024). The paper highlights the dangers of corporatization and market driven policies to the oral traditions and apprenticeship systems. Similar to other traditional weaving communities, Kotpad artisans rely heavily on intergenerational transmission of knowledge. There is a need to change policies and the production models to make sure that there is no commodification of traditional knowledge rather it is kept under the control of various communities. Das (2024) presents bio-design as a new model of combining the traditional craft and modern biotechnology through Kotpad as a case study. However, it is emphasised that scientific intervention must not overshadow the indigenous knowledge. Such combination of traditional knowledge and contemporary science can strengthen the future of Kotpad dyeing. It helps preserving the cultural heritage while improving understanding of dyeing mechanism.

Extraction & hydrolysis (morindin → morindone)

The process of getting the dye mainly from the roots of Aal which is the base of the Kotpad handloom textiles is very complicated and this is the reason why maroon-colored textiles by Kotpad handloom are very famous (Kannan et al. 2020). It involves the separation of anthraquinone glycoside morindin ($C_{26}H_{28}O_{14}$) from several of its units which by hydrolysis turns into morindone ($C_{15}H_{10}O_5$).

- **Harvesting and preparation:** Mature roots are harvested, cleaned, and dried prior to extraction. After that, they are washed and are left for drying.
- **Boiling:** The roots which had been dried in the shade are boiled in water to get the dye liquid.
- **Pre-treatment:** To get more dye and more color from the root, pre-treatment such as castor oil soaking or any alkaline solution (e.g., wood ash or lime) is used. These steps can sometimes also involve fermentation.

- **Concentration:** The dye is concentrated by repeating the cycles of boiling and drying.

- **Chemical Hydrolysis Reaction:** During hydrolysis, morindin is converted to morindone through cleavage of glycosidic bonds. This transformation may occur through thermal, acidic, or enzymatic processes.

- **Alkaline Pre-treatment:** The application of lime or wood ash helps to deprotonate phenolic groups in morindin, thus making the complexation with metal mordants more efficient (Sankari et al. 2024).

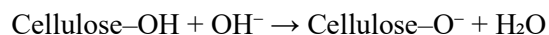
The use of heat under controlled conditions leads to the cleavage of glycoside, thus forming the very red morindone. Among the factors affecting color and fastness in Kotpad dyeing, the release and hydrolysis of morindin to morindone take the lead. Knowledge of these chemical reactions enables one to refine dyeing process which in turn helps to keep and even elevate the value of the traditional Kotpad fabric.

Mechanisms of Dye Fixation on Cellulosic Fibres

Cotton consists primarily of cellulose; a polysaccharide composed of β -(1→4)-linked glucose units containing numerous hydroxyl groups capable of participating in intermolecular interactions. These –OH groups serve as hydrogen bond donors and acceptors but hardly interact with planar hydrophobic anthraquinone dyes like morindone ($C_{15}H_{10}O_5$). Hence, the direct adsorption of morindone on cellulose is very low, resulting in low washing and light fastness (Bechtold & Mussak, 2009; Samanta & Agarwal, 2009). The use of metal ions such as Al^{3+} or Fe^{3+} in mordanting is necessary to produce stable, insoluble complexes that are fixed within the fiber matrix, thus, the dye is not released during washing or when exposed to light (Cardon, 2007; Natural Dye, 2025). The metal-bridge model is considered one of the principal mechanisms explaining mordant-assisted fixation of anthraquinone dyes on cellulosic fibres. According to this model, the metal ion (e.g., Al^{3+}) binds with a metal ion to form a chelate complex in which the deprotonated morindone ligand coordinates with a metal ion (e.g., Al^{3+}) and at the same time interacts with cellulose hydroxyl groups. With this bridge operation the metal ion can be considered as a linker that connects the dye and the fiber, whereas the steric bulk and the charge help to stabilize the attachment. The other mechanism is that the dye-metal complexes are physically entrapped. Several chelated units combine to form colloidal lake particles which insert into the amorphous regions of cellulose. Within the fiber microstructure, these lakes are present; thus, they are physically confined and their wash fastness is improved. The modulation of the fiber surface through pre-treatments is very important. Conventional Kotpad method relies on an oil and alkaline pretreatment (lime

or wood ash) to open up fibers, also remove fats by saponification. This will release more hydroxyl groups. This allows deeper penetration of dye-metal complexes at repeated immersion/drying cycles.

Alkaline fiber swelling:



Sequential cycles of complexation and drying gradually build up densely bound, colorfast layers. The metal bridging, physical entrapment, and surface modulation by pre-treatment—account for the fabrics to acquire intense, lasting red-maroon colors. At the same time, the fabrics remain structurally strong and visually authentic from a traditional point of view.

Dye Uptake and Fiber Affinity

Morindone fixation efficiency depends largely on the cotton pre-treatment. The traditional Kotpad method, in essence, uses oil and alkaline treatments (wood ash or lime) that expand the fiber matrix, saponify leftover fats, and reveal more hydroxyl groups of cellulose. This chemical and physical change of fiber surfaces makes them more accessible for dye-metal complexes and thus, hydrogen bonding and van der Waals interactions get stronger. Besides, pre-treatment makes the fibers more porous so that colloidal lakes of metal-mordanted morindone can go even deeper into the amorphous regions of cellulose. Moreover, sequential immersion–dry cycles not only increase color intensity, but they also create multilayered, tightly bound complexes, thus, fastness is enhanced and shade development becomes uniform. Chemical preparation and empirical knowledge, this is the interaction that the Mirgan weaving tradition to be thus embodied by this method.

Multicycle Dyeing for Stabilization of Shade

Weavers primarily depend on the back-and-forth dipping and drying operations to get the typical maroon and rust colors. With every operation the deposition of morindone-metal complexes is reinforced thus slowly forming a dense layer of colloidal lakes in the fiber structure (Cardon, 2007; Samanta & Agarwal, 2009). This gradual buildup not only deepens the color and makes it more durable but also helps in even color distribution. Repeated dyeing cycles may facilitate progressive formation and stabilization of dye–metal complexes within the fibre matrix. The method is such that the dye is tightly bound even under washing, UV exposure, and friction, thus being a perfect marriage of chemical principles and artisanal practice.

Conclusion

Kotpad dyeing represents a unique blend of traditional knowledge, cultural heritage, and environmentally sustainable textile practices. The reviewed studies suggest that the quality of the final colour largely

depends on the type of mordant used and the method of its application. Mordants such as alum and iron have been reported to improve dye fixation and shade stability in anthraquinone based natural dyeing. The literature highlights that Kotpad dyeing is not only culturally significant but also supported by important dye–mordant interactions that influence textile performance. However, scientific research on dye composition, colour fastness, and fibre–dye bonding under traditional dyeing conditions remains limited. Further studies are needed to better understand these processes and to support the preservation and sustainable development of this indigenous textile tradition.

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