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Sialkoti paper used by Pahari artists: raw materials and fibre analysis

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Abstract

This study aims to characterise the so-called Sialkoti paper used to produce Pahari drawings preserved today in the Wereldmuseum in Leiden (Netherlands) (WML). These works originate from the Punjab Hills in India (today Himachal Pradesh) and are commonly known as 'Pahari miniature paintings'. The paper upon which these drawings are executed is said to have been produced in Sialkot during the eighteenth and nineteenth centuries when papermaking was an integral part of an overall regional economy correlated with other sectors such as agriculture and the textile industry. Although the term Sialkoti refers to identified papermills in Sialkot (now Pakistan), the paper from this region is yet to be subjected to a systematic study. This article therefore explores the paper(s) in question through macro- and microscopic observations of structure, pulp and fibres. The study of historical sources, complemented by the analysis of paper samples and fibre identification, has revealed that the pulp would have been prepared from a variety of manufactured products using different technologies, such as rags, cloth, mats, rope and other plant-based materials made from local bast fibres which, once tattered, were recycled to prepare the pulp. Microscopic study reveals that a variety of fibre combinations under different conditions and processing steps were used, in particular sunn hemp fibre (*Crotalaria juncea L.),* a plant species that has until now rarely been identified in historical paper. In addition, the presence of kenaf and jute fibres, as well as a significant quantity of cotton fibres, have also been demonstrated. To overcome the lack of comparative materials, our work was supported by a comparative study of several materials made from sunn hemp now held in the Ethnobotany Collection at Kew Gardens. Samples were taken from these materials and provided useful reference micrographs for the identification of the WML samples. The quality of the paper used by Pahari artists, as well as the raw materials available and their processing, are discussed in detail. Putting all the data, including technical and historical information into perspective, we conclude that the Pahari artists used a paper of inferior quality compared to other types of paper used for other purposes such as the creation of illuminated manuscripts in the Punjab plains. This study therefore provides useful analytical and material evidence that complements previous historical, technical and anthropological studies.

Keywords Sialkoti paper, Pahari drawings, Indian handmade paper, Sunn hemp, Fibre identification, Microscopy

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Introduction

A conservation and research project on a collection of 134 Pahari drawings and paintings dating from the eighteenth and nineteenth centuries, produced in the Punjab hills of northwest India and currently housed at the Wereldmuseum in Leiden (WML), has made it possible to study the paper used to create these works.[1] The term *Pahari*, derived from the word *Pahar* in Hindi which means 'from the hills', commonly refers to the lower Western foothills of the Himalayas (today Himachal Pradesh). The region consisted of a series of small states ruled by Rajas. Most were Hindus and Vaishnavas, meaning that they worshipped Vishnu and his avatars, such as Rama and Krishna. Consequently, the painted images reflect a preference for scenes borrowed from vaishnava literature such as the *Bhagavata Purana, Bhagavad Gita, Ramayana, Gita Govinda*, as well as Hindu narratives (*Ballad of Amir Hath, Vikramaditya, Karata-Arjuna*, among others) (Fig. 1). The collection covers a large variety of themes: portraits of gods and goddesses (Fig. 2), personifications of musical modes and poetry (*Ragamalas*) (Fig. 3), heroines (*Nakiya*), and portraits of rulers and historical figures (Fig. 4). The works were collected by Jean-Philippe Vogel (1871–1958), a Dutch Sanskriti and epigraphist, who was first Superintendent and then General-Director of the Northern Circle of the Archaeological Survey of India from 1900 to 1912 [1].

Fig. 2 The goddess Sarasvati, charcoal, inks and white paint on handmade paper © Collection Nationaal Museum van Wereldculturen, RV-3025-37

Fig. 1 Episode of the Ramayana, the sleep of the giant Kumbhakarna, charcoal, inks and white paint on handmade paper © Collection Nationaal Museum van Wereldculturen, RV-3025-1

Fig. 3 Virahini Nayika welcoming the rain, black ink, white paint and traces of stylus on handmade paper © Collection Nationaal Museum van Wereldculturen, RV-3025-57 recto

[1] The acquisition numbers of these works are RV-3025–1 to RV-3025–134. The whole collection is available online in high resolution – https://collectie.wereldculturen.nl/ (keyword: Kangra). For a comprehensive overview and additional information on the project, watch the recording of the online talk 'Pahari Collection of Drawings and Paintings' given on January 26, 2023 at the Gurmani Centre for Languages and Literature of the Lahore University of Management Sciences. https://www.gcll.lums.edu.pk/post/pahari-collection-of-drawings-and-paintings.

Fig. 4 Portrait of Raja Isvari Sen of Mandi, colours, gold paint, black ink and white paint on handmade paper © Collection Nationaal Museum van Wereldculturen, RV-3025-77

The scholarly community has claimed that Sialkoti paper (a colloquial term used for paper made in Sialkot) was used by Pahari artists ([2]: 14).[2] However, this claim has yet to be backed up by scientific evidence or analysis. Our aim was, therefore, to examine scientifically the paper used by the Pahari artists and ascertain the materials used to make the painting supports in question, and whether the paper used was actually made in Sialkot. While pigments in South Asian paintings have already been analysed, paper from this region has until now been little studied and poorly understood. Following numerous discussions with custodians of South Asian collections, it became clear that many people in the field had little or no knowledge of papermaking and the materials used.[3] The research project therefore aimed not only to understand South Asian paper from a scientific point of view and correct assertions, misconceptions and preconceptions, but also to generate interest and develop knowledge within the community.

V.C. Ohri, curator at the Bhuri Singh Museum, Chamba and at the Himachal State Museum, Shimla in the 1960s and 1970s, wrote that two types of paper, differing in thicknesses and quality (with the thinner being the better), were traded in the Punjab hills and used by Pahari artists. Only the thicker paper was used for painting, as it was sufficiently strong to be used to prepare the laminated painting support called *vasli*, made by superimposing two sheets of paper ([3]: 43–45). This information is, however, rather vague and fails to give a precise idea of the type of paper available in the Punjab hills. It should also be noted that most of the historical sources cited in this article, whether written by engineers, civil servants or travellers, date from after 1850 and therefore post-date the production of Pahari works, which began to decline once the Sikhs took control of the regions.[4] Most of them also refer to papers produced in prisons. Faced with the growing need for paper for the administration and the development of printing, from 1860 onward, the British began to produce paper in prisons, taking advantage of and exploiting a free labour force. Sialkot was one of the most important paper-manufacturing prisons in South Asia ([4]: 123). These references remain, however, valid because paper technology changed very little during the nineteenth century and we may therefore assume that the techniques used by inmates were substantially the same as those previously used by traditional papermakers [5]. It should also be noted that some of these references are often difficult to understand, as it is unclear whether the processes described were observed directly by the authors, reported by word of mouth or copied from earlier sources. This is all the more reason to carry out specific research on existing material culture (Pahari drawings preserved in the WML), as it provides us with detailed and genuine information regarding the raw materials and techniques used in the manufacture of Sialkoti paper through the eighteenth century until the early nineteenth century. This new material evidence should be considered tantamount to primary sources, as it complements the written historical sources and greatly contributes to an improved understanding of the development of local paper technology in Punjab. In order to be able to place our results of material analyses in context, we also refer to the written secondary sources, such as the reports of travellers or literature concerned with the technology of papermaking in the Punjab region.

Sialkot, located in the Punjab plains of today's Pakistan, was probably the second town to produce handmade

[2] Wall texts in Indian museums, such as the Bhuri Singh Museum in Chamba and Kangra Art Museum in Dharamsala (Himachal Pradesh) visited by A. Couvrat Desvergnes in October 2022 also refer to Sialkoti paper.

[3] An informal survey of museum staff during study trips, conferences and courses revealed that silk, wool, cotton, rice, bamboo, hemp and linen, among others, were used in papermaking in South Asia.

[4] The year 1809 symbolically marked the fate of the princely states of the Punjab hills, invaded by the armies of the Gurkhas and then Maharaja Ranjit Singh, but for several decades Pahari artists continued to practice their art for the new Sikh elite.

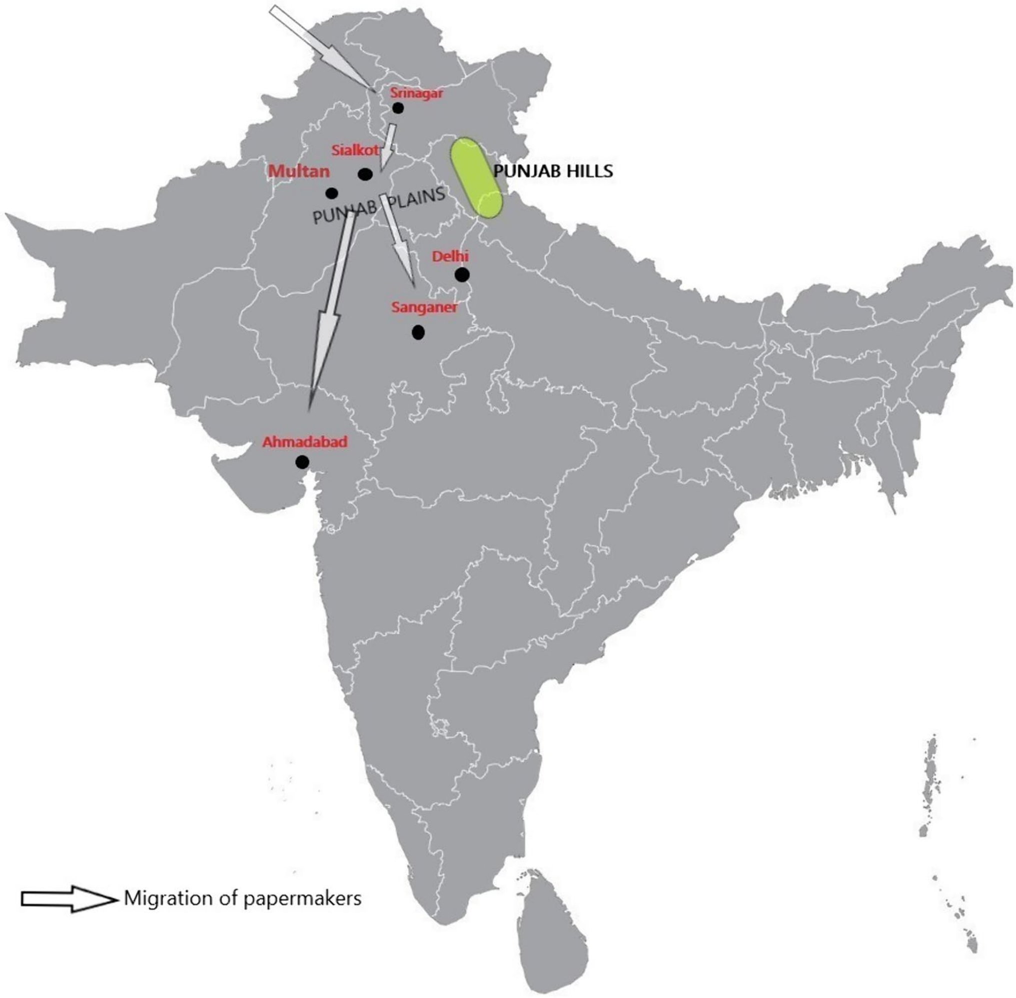

Fig. 5 Map of some of the major paper production centres in northern and western India

paper in South Asia. It is commonly acknowledged that the first papermills were erected in the middle of the fifteenth century in Srinagar (today India Kashmir) when Sultan Zainu'l- 'Abidin of Kashmir (1417–1467) invited Muslim artisans, descendants of papermakers from Samarqand and Bukhara, to develop trades and crafts ([4]: 29–31).

During the reign of the first Mughal emperor Akbar (1556–1605), Kashmiri papermakers migrated to Sialkot, Punjab, and set up papermills in the surrounding villages of Rangpur, Nakapura and Hirapura, where the paper industry could flourish thanks to the abundant flow of the river Aik (Fig. 5) ([6]: 41).

From the seventeenth to the nineteenth century, several sources in Persian and Urdu mention the unrivalled whiteness of Sialkoti paper and report the production of a variety of qualities. During Jahangir's reign (1605–1627), 'Mān Singhī, Khasā-i Jahāngīrī and Nim Harīrī papers were known to be white, clean and stout ([4]: 7, 8, 61–99); [7]: 255; [8]:265]. [5] Khasā-i Jahāngīrī paper was probably named after the Mughal emperor Jahangir, who reigned between 1605 and 1627, and ordered it for his personal use ([7]). It was white, fine, clean, durable and well-burnished. The property of whiteness seems to have been attributed to the fact that the pulp was washed in the river Aik, recognised as clean and pure ([4]:7, 62,

[5] Rahman mentions that 'Mān Singhī paper probably refers to Raja Mān Singh (1550–1614), the Rajput Raja of Amber, who was the most trusted general of Emperor Akbar and governor of Kabul; and Nim Harīrī paper, as the name suggests, refers to silk because of its glossy and soft texture. (Al-harir الحرير meaning silk in Arabic).

256).[6] Shāh-Jahāngīrī paper was then produced and was also thin, light and of a bluish hue. In the middle of the nineteenth century, Baden-Powell reported that "It is the most expensive, and lighter in weight than other descriptions of native papers. It is chiefly used in manuscripts of the *Kuran*, the *pothis* of the Hindus, and for *sanads*" [9]:78. He also mentioned the manufacture of an inferior quality paper, rough and thick, used to make accounting registers, as well as other varieties of utilitarian paper.

The traditional papermaking process was reported by Gray [5], Baden-Powell [9], Emerson [10] and later by Hunter [11],[7] then summarised by Konishi ([4]: 101) and recently re-articulated by one of the authors [12]. As a reminder, paper technology in South Asia was first introduced and perform in very similar to that used by the Arabs in two main aspects. The first aspect is the use of a mould made in two parts: a rigid wooden frame (*sacha),* composed of four bars of wood mortised in the corners and crossbars or ribs and a movable screen or mate (*chapri)* made of stems of plants, grasses or often reeds (*mir* or *munj)*, laced together at intervals by horsehairs to hold them in position. In the 1930s, Dard Hunter collected a paper mould in Sialkot that illustrates the characteristics described ([11]:18; 12). The second aspect, which will be discussed throughout this article, is the recycling of fibrous materials in the preparation of the pulp. After collection, these materials underwent a repetitive sequence of beating, washing and retting in a vat with the addition of an alkaline lye made from crude sodium carbonate or soda ash and lime. Once the pulp was ready, the papermakers moved on to sheet production. Once dried, the sheets were coated with starch and stone-burnished.

Methods

We have based our study and argument on macro- and microscopic analysis because, until now, there have been no other reliable methods developed to assess pulp quality, identify paper raw materials and thereby comprehend papermaking technology in the Punjab regions. While archaeometry and heritage science today favour non-destructive methods, particularly for the analysis of pigments and dyes, these methods have their limits when it comes to identifying the raw materials used in handmade papers. Fibre analysis relies primarily on the visual identification of anatomical features, which cannot be achieved with any of the current analytical techniques.

To support our choice, recent studies have shown that microscopic analysis using a polarising microscope, although destructive, is a relevant and simple method for characterising pulp and identifying paper fibres [13, 14], particularly for papers from Central and Southeast Asia [15–17].

Therefore, a study protocol was developed and implemented to examine the papers used by Pahari artists [18]. It included both a macroscopic examination of specific visual and structural components, and a microscopic analysis using a polarising microscope to identify the plant fibres used in the preparation of the pulp.[8]

Macroscopic observation

A group of 112 items was selected for the macroscopic study, the others were excluded because they were too deteriorated or did not fit into the geographical, temporal and material framework of this study. A protocol was drawn up using an Excel spreadsheet to document and record the physical characteristics of the paper: its morphology, thickness, texture, colour, fibre distribution, quality and impression of the papermaking mould sieve (the visibility, arrangement, distribution and count of laid and chain lines), traces of manufacture (brush, burnisher) and papermakers' flaws, as well as the presence of extraneous materials [13]. The above-mentioned fields were assessed visually or measured using equipment such as a digital micrometre, digital glossmetre, light box, Dino-Lite® and Munsell Soil Color cards®.[9]

Microscopic examination

The Wereldmuseum kindly permitted sampling in order to perform fibre analyses and therefore to improve our understanding of the paper technology in Sialkot. The 81 micro-samples processed into separate fibres were mounted on permanent mount slides prepared with Canada balsam [18]. The selection of samples was designed to be as exhaustive as possible in order to be representative, so for certain works composed of several pieces of paper, a sample was taken from each piece. The slides were analysed using the polarising microscope Olympus BX51 (at the CSMC, University of Hamburg) and with the Zeiss AxioLab.A1 (at the Research and Conservation Centre of the Rijksmuseum in Amsterdam). Examination of the samples at low magnification (5× and 10×) provided useful information on pulp characteristics (fibre placing), while magnification at 20× and higher enabled plant species to be identified by anatomical features of fibres and associated cells found in the pulps.

6 Naviq got this information from the *Ibrātnamāh* written by Khair-ud Dīn.

7 Dard Hunter visited the Sialkot papermill in the 1930s and reported on his trip in Papermaking by Hand in India, New York 1939.

8 For this study no microchemical spot tests were carried out.

9 https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-soil-color-charts/.

Fig. 6 **a** Example of paper with a visible network of laid and chain lines, RV-3025-106, **b** Example of cloudy type of paper with no papermaking sieve print structure visible, RV-3025-110. Photographs taken on a light box

Results and discussion

Macroscopic observations

It is worth highlighting that the papers in the collection are generally in good physical condition. They show no signs of mechanical and chemical damages, other than that caused by poor handling, storage conditions as well as by insects and rodents [12]. The average thickness of all the papers in the collection is 0.22 mm. The observation of backlit items revealed that the majority of the paper has a cloudy look-through, i.e. uneven pulp distribution, making it more or less difficult to discern the marks left by the paper mould screen, such as the network of laid lines left by the reeds and the chain lines left by the horsehairs. [12] While 1% of samples has uniform look-through, 13% showed low cloudy structure, 35% moderate cloudy structure and 33% high cloudy structure. (Fig. 1) (S.1). The combination of aspects such as the reed and hair thickness, the mat condition and the amount of pulp scooped by the papermaker are crucial factors in the final appearance of the sheet. However, the

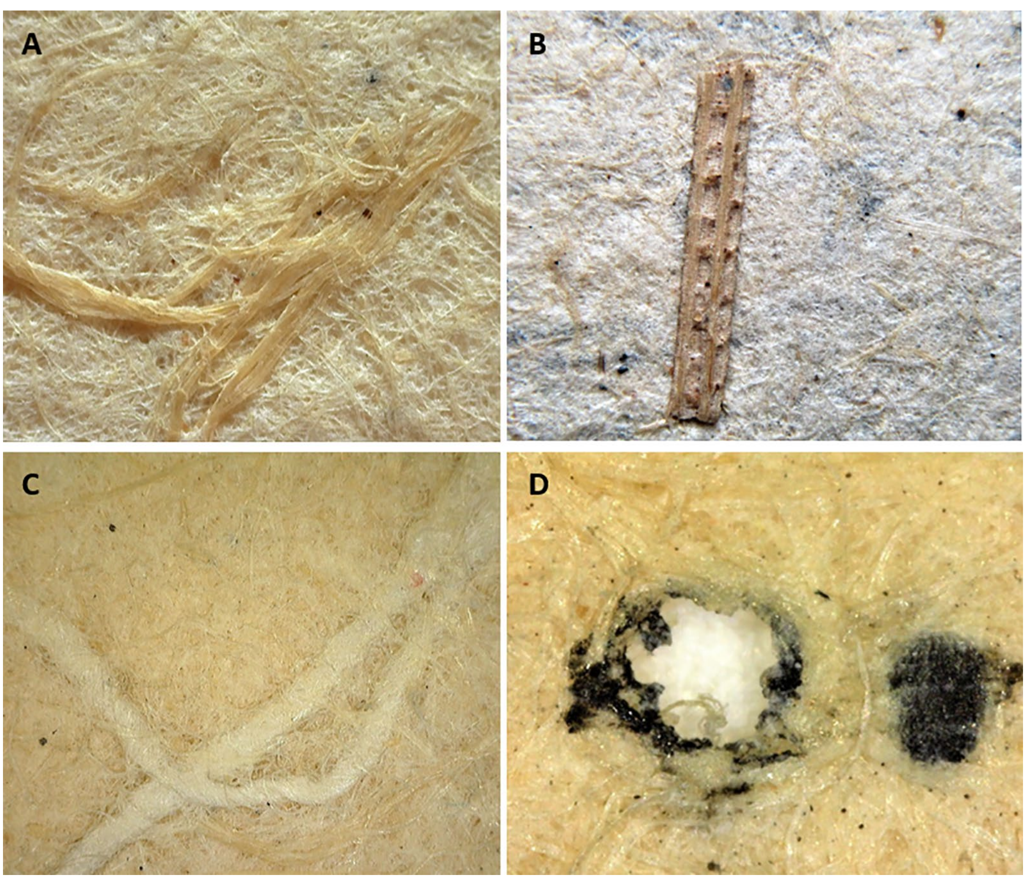

Fig. 7 **a** Prominent bundles of fibres at the surface, **b** piece of shive, **c** fragment of uncoloured strands, **d** black particles (Images by Dino-lite® 55X)

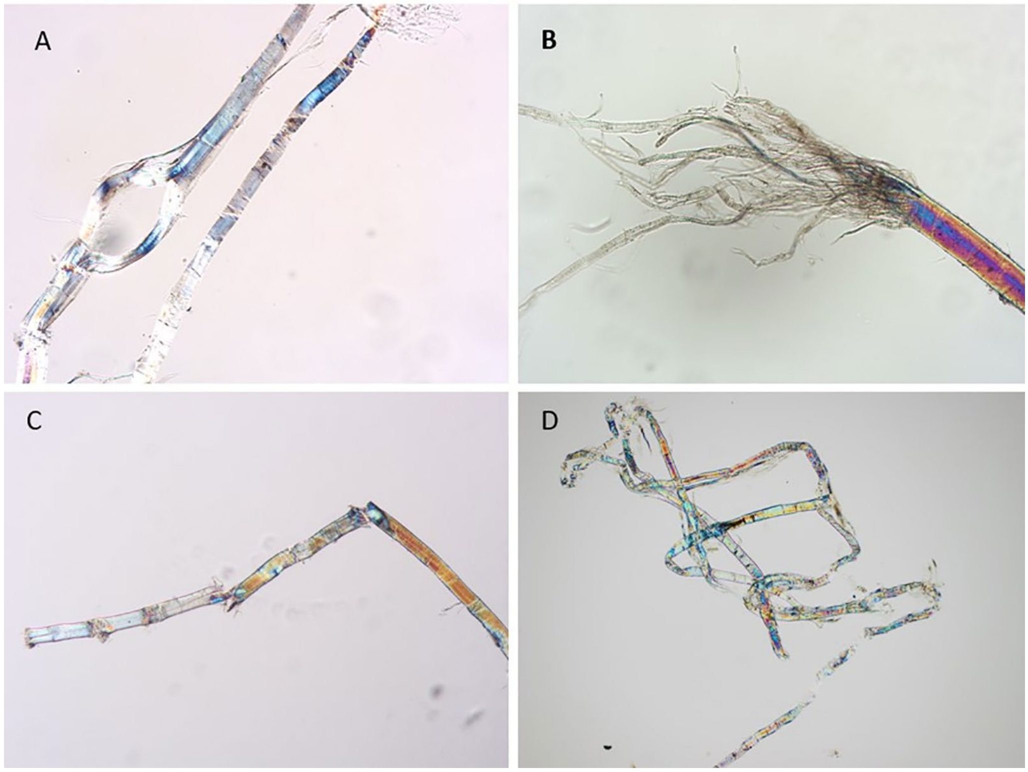

Fig. 8 **a** Burst fibre, sample 63, 10×, RV-3025–77, **b** highly fibrillated fibre, sample 73, 20×, RV-3025-82, **c** broken fibre, sample 75, 20×, RV-3025–82, **d** twisted fibres, sample 66, 10×, RV-3025-75

degree of pulp refinement is one of the most important factors as a poorly beaten pulp is less likely to allow the visibility of the mould marks. In our case, 4% of the works examined had clearly visible laid lines, while 5% had visible chain lines. (Fig. 6a, b) (S. 2, 3).

Close inspection of the surface with raking light highlights that the papers also contain a good deal of extraneous materials, such as various particles, clumps, prominent bundles of fibres raised at the surface, small pieces of shive (bark), small black particles and fragments of strands, coloured or not (Fig. 7a, b, c and d) (S. 4, 5, 6 and 7).

Under a magnifying lens, the black material look like tiny charcoal particles that have been crushed, probably during the burnishing of the sheet, leaving a characteristic trail. As described in a previous article, charcoal particles are interpreted as sodium carbonate residues from the combustion of certain saltworts used during the retting process to improve and accelerate the disintegration of recycled materials and the separation of fibres to produce a homogeneous pulp [12].

Microscopic observations

The observation with the polarising microscope reveals that 11% of samples has good-quality fibres, 43% medium-quality and 46% poor-quality (S. 8). Deteriorated fibres are burst with swollen parts, broken and show extremely defibrillated ends (Fig. 8a, b, c). Many samples also feature flaccid, twisted fibres that have lost their rigidity following a long maceration process. (Fig. 8d).

Furthermore, 50% of samples contained short, highly fibrillated fibres, while 41% showed medium fibrillation and 9% low fibrillation (S. 9). In addition, 67% showed a significant amount of insubstantial tissue (S. 10). As for the pulp feature, 90% of samples had a mixture of fibres in varying conditions and lengths, either isolated or associated in clumps or compact bundles. The remaining 10% of samples revealed that 5% contained only long fibres, 4% medium fibres and 1% short fibres. (Fig. 9a, b) (S. 11).

The lack of reference material for fibre analysis from the Himachal Pradesh region meant that, during the course of the project, it became essential to obtain relevant reference images that might be used in the case of severely damaged or recycled fibres. The description and characterisation of plant fibres have been studied in two major publications, but these refer to native or textile fibres rather than to processed fibres used in paper manufacturing. In addition, both publications provide only black-and-white illustrations which in our case proved to be

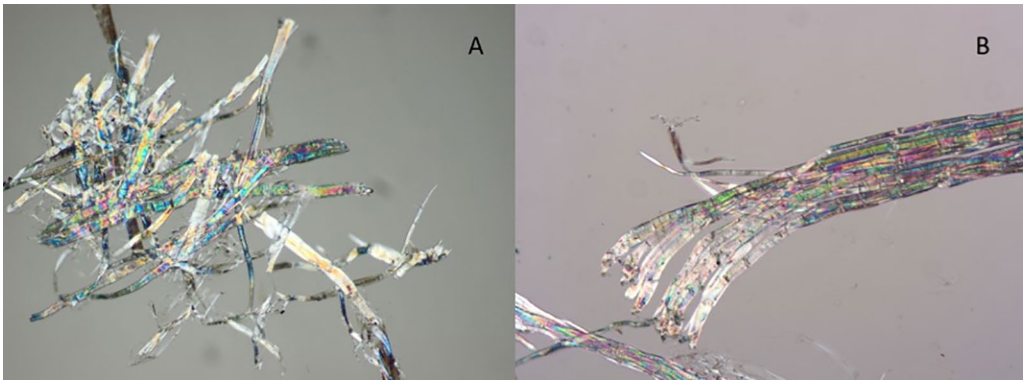

Fig. 9 **a** Short and fibrillated fibres assembled in clump, 10×, sample 9, RV-3025-110, **b** bundle of sunn hemp fibres, 10×, sample 94, RV-3025–36

Fig. 10 **a** Bundle of sunn hemp fibres of the Campowre variety, extracted after 5 days of retting, inv.n.60204, **b** cake of dry pulp made from sunn hemp, inv.n.60190, **c** twine from Sindh made from sunn hemp fibres, inv.n.60917, **d** mat of sunn hemp, Jubbulpore, inv.n.68916, **e** bag with tassels, inv.n.73226. Kew Gardens Ethnobotany Collection. Photo: Amélie Couvrat Desvergnes

insufficient tools [19, 20]. Since bast fibres are extremely difficult to differentiate and identify with precision when they are fibrillated and damaged, comparison with materials from the Kew Gardens Ethnobotany Collection has proved invaluable in interpreting microscopic images and understanding pulp composition. Samples were taken from known raw fibres, processed fibres extracted from intermediate papermaking stages such as half-pulp and dry pulp cakes made from sunn hemp and other fibres (Fig. 10a, b) as well as manufactured products such as cordage, sacking and mat, made from sunn hemp, jute and other local species (Fig. 10c, d, e).[10] The results of the analysis were particularly useful in obtaining reference images of the anatomical characteristics of the sunn hemp (*Crotalaria juncea L.*).

Analysis of the paper samples from the WML drawings showed that 60% of the samples have only one fibre type (S. 13) and more precisely 94% of them contained hemp as the only fibre type used in pulp preparation, while 5% and 1% contained kenaf and jute respectively (S. 12). 28% of samples contained a mixture of different types of fibre, including sunn hemp combined with kenaf (16%) or jute

[10] We are indebted to Mark Nesbitt, curator of the Economic Botany Collection at Kew Gardens, for allowing us to take samples and analyse them.

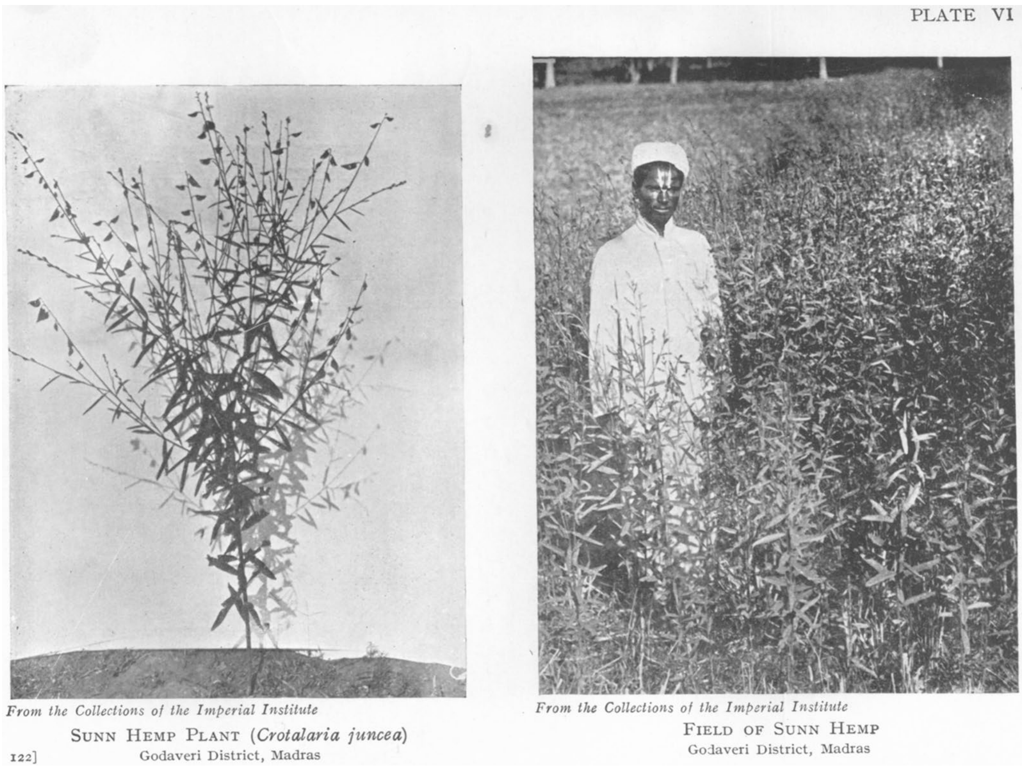

Fig. 11 Sunn hemp plant and field of sunn hemp in the Godavari district (Madras). Source: Goulding E., Imperial Institute Handbooks Cotton and other Vegetable fibres: their production and utilisation, London: John Murray, 1919, pp. 122–23, plate VI

(12%) (S. 13). We consider the presence of grass, flax, hemp and softwoods to be incidental, as they were not used in the composition of pulp at that time and in that geographical area. For example, grass could have been preserved in agricultural products such as ropes and sacks because of their function, and therefore be present in paper pulp.

Bast fibres contain characteristic associated cells that allow more precise identification of the species. In the case of our project, only 36% of the samples contained associated cells such as pitted vessels, spiral thickenings, parenchyma and epidermal cells, which in some cases proved invaluable not only for the identification of the fibre themselves.

As mentioned previously, Sunn hemp is mainly present in WML papers. The plant and its associated cells remain incorrectly referenced for microscopy applied to paper-making fibres. Sunn or san hemp, also known as Indian or brown hemp, is different from true hemp (*Cannabis sativa L.).* It draws its name from *san* in Sanskrit and is found in ancient sources. The plant also bears numerous vernacular names, such as *sanni, senkokra*, *sanai*, *tag.* The botanical term *juncea* was given by Linnaeus (rushy *Crotalaria*) because of its similarity to *Spartium junceum* ([21]: 431). It has always been widespread throughout South Asia and its versatility as a source of fibre makes it an essential product for the economy and industry throughout the country (Fig. 11).

The inner bark is used to make all kinds of agricultural and domestic products because the fibre is extremely robust, durable and water resistant ([22]: 430–437; 23: 270–288). In 1801, Roxburgh proposed that it might be a promising substitute for Russian hemp because of its rapid growth, affordability, flexibility, strength and durability ([24]: 343, 345–418.).[11] In Sialkot sunn hemp was widely produced and used. Its fibres have some characteristics common to *Cannabis* hemp, although its lumen is usually wider and more uneven, and the thickness of its fibre wall may greatly vary along the whole fibre length, depending on the age of the plant. The same sample may also contain a large range of variations in the width of the fibres. The fibre also shows numerous cross-markings, pronounced dislocations and longitudinal striations (Fig. 12a) ([19]: 340; [20]: 24–29). Sunn hemp is also evidenced by the presence of thin-walled fibres which feature slit like, axial pits (Fig. 12b) ([20]: 28).

[11] Roxburgh, who was the superintendent of the company's botanical garden in Calcutta, conducted numerous strength tests on native fibres.

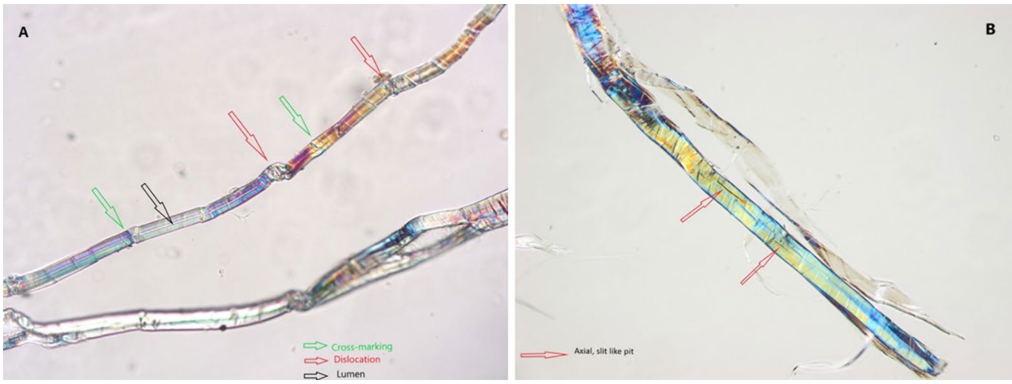

Fig. 12 **a** Sunn hemp fibre, sample 94, 10×, RV-3025–36, **b** thin walled cell with axial slits, sample 33, 20×, RV-3025–87

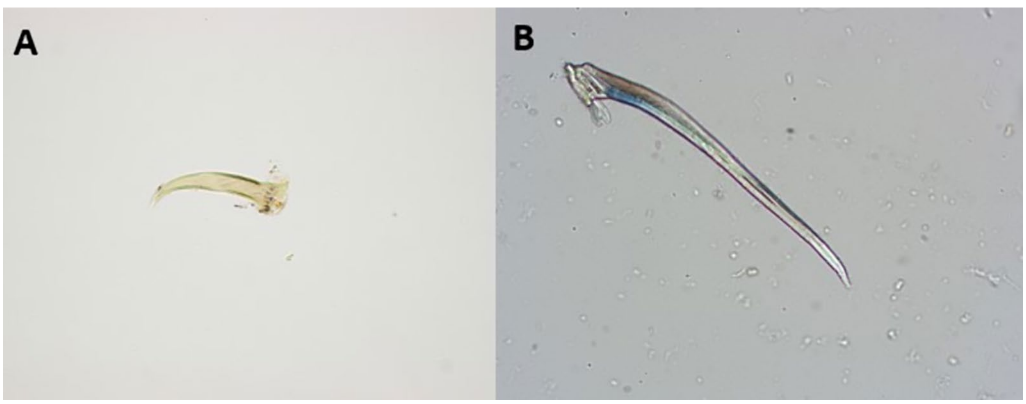

Fig. 13 **a** Short pricked hair, 20×, sample 50, RV-3025–132, **b** long hair with epidermal cell, 20×, sample K7, Kew Gardens inv. n. 68916

Natural ends are rarely seen since fibres in paper pulp are too processed to retain their ends. Similarly, associated cells are rarely found in pulp, since they disappear during retting, maceration and beating. Analysis of Kew Gardens materials, made from minimally processed fibres, has, however, provided relevant images of these associated cells, which are extremely diverse and are often confused with cells found in other bast fibres. Epidermal hair is the most characteristic associated cell in Sunn hemp ([19]: 341; [20]: plate 37a).[12] The two-celled hair is curved and consists of a small basal cell and an elongated pointed distal cell or apex. While a sample taken from a Pahari drawing shows a short pricked hair attached to an epidermal cell (Fig. 13a), a sample of rope from Kew Gardens highlighted the presence of long hairs attached to epidermal cells (Fig. 13b).

Epidermis cells show a brick arrangement which sometimes contains stomata (Fig. 14a).[13] Other associated cells from the xylem may also be found, such as narrow and long pitted vessels, and spiral thickenings (Fig. 14c, d).[14] The parenchyma cells have various shapes and sizes depending on whether they originate from the phloem or the xylem (Fig. 14b) [25]

Jute was also found in 12% of the samples and always in combination with Sunn hemp (i.e. in 10 works: RV-3025-126, RV-3025-83 a, RV-3025-86, RV-3025-68, RV-3025-56, RV-3025-74, RV-3025-44, RV-3025-38, RV-3025-68, RV-3025-11). There is only one case where jute was found on its own (or 1%), in drawing RV-3025-49, but the unusual arrangement of long, clean, low-fibrillated and good quality fibres suggests that the sample was taken from an area of paper containing very little-processed

[12] The hairs or trichomes are outgrowths of the epidermis and protect the plants against UV, insects, transpiration, and frost, and the parenchyma cells are food storage tissues responsible for metabolism and the vessels or tracheids are fluid conduction tissues.

[13] Stomata or guard cells attached to the epidermis are the chief external opening of the epidermis and are responsible for gas exchanges.

[14] Vessel elements and spiral thickenings contain lignin deposits responsible for the rigidity of the plant.

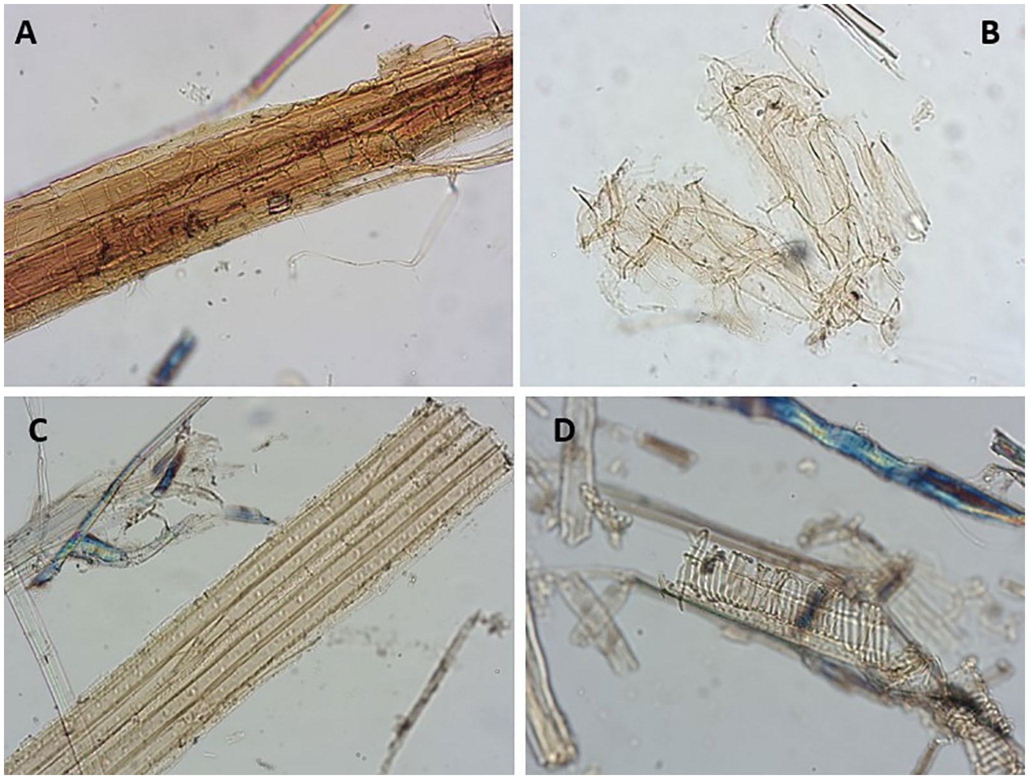

Fig. 14 **a** Epidermis cells show a brick arrangement, 20×, sample K13, Kew Gardens inv. n. 60194 a, **b** cluster of short and large parenchyma cells 20×, sample K22, Kew Gardens, inv. n. 60200.42, **c** long and narrow pitted vessels, 20×, sample K4, Kew Gardens, inv. n. 60204, **d** spiral thickenings, 20×, sample K22, Kew Gardens, inv. n. 60200

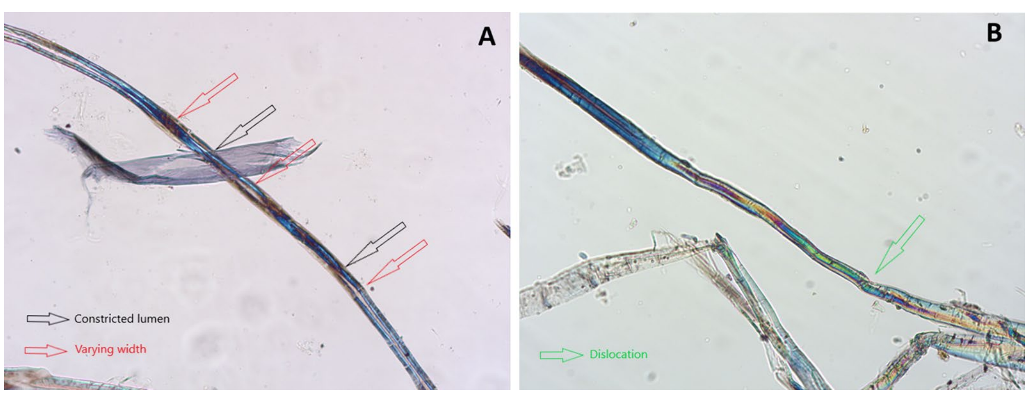

Fig. 15 **a** Jute fibre, 20×, sample 63, RV-3025–77, **b** jute fibre, 20×, sample 98, RV-3025–44

recycled material made from jute. Two species of jute are found in South Asia: brown jute (*Corchorus capsularis L.)* and *tossa* jute (*Corchorus olitorius L.).* The jute plant is called *putta, júta, jata in* Sanskrit and *pát, jhut, jhóto* and *jhuto* in vernacular languages. The fibre is called *pát* and *koshta*. The sackcloth is called *tát* and the bags made from it are *goni* or *choti*. Nevertheless, the term *goni* from which derives the word gunny was also employed for sacking made from other bast fibres ([21]: 405–410; [22]: 242). Watt and Royle mainly described the cultivation and use of the plant in East and North Bengal, which were the main producing regions in South Asia ([22]: 244). Jute cultivation began to spread at the beginning of the nineteenth century under the impetus of the British, who wanted to find a substitute for Russian hemp in the manufacture of ropes and cloth in England. It was not

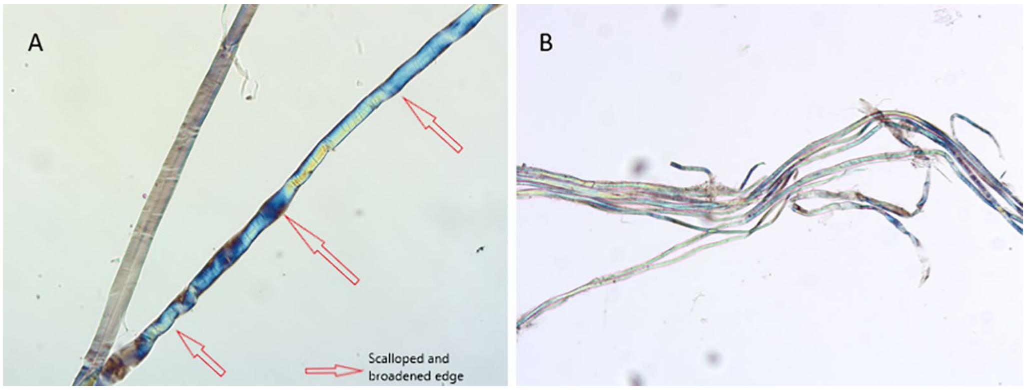

Fig. 16 **a** Kenaf fibres, 20×, Sample 148, RV-3025–49, **b** bundle of kenaf fibres, 10×, sample 70, RV-3025–76

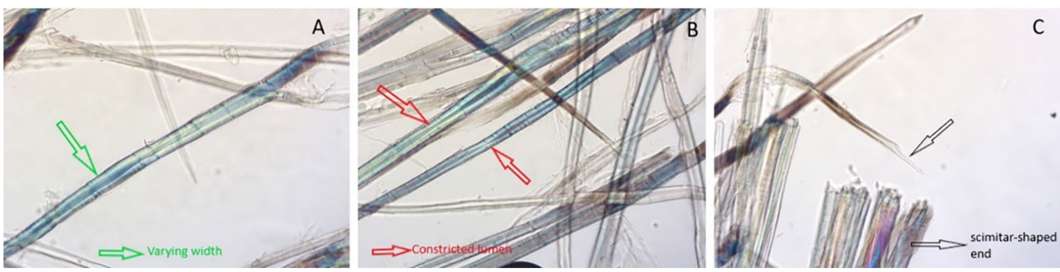

Fig. 17 **a** and **b** Kenaf fibres, 20× (fibre for hamster nesting), **c** scimitar-like end of a kenaf fibre, 20× (fibre for hamster nesting)

until the second quarter of the nineteenth century, however, that the plant was produced on a larger scale. That is why jute fibres were sporadically found in our samples dating from the first half of the nineteenth century. Watt who recounted in great detail the whole process of tillage, weeding, fertilising, harvesting, retting, fibre separation, batching and spinning, reported that the retting and separation operations were simple, inexpensive and speedy, making jute a cost-effective source of fibre for the manufacture of bags, fabrics, ropes, mats and carpets of various qualities ([22]: 414–422). Royle, however, mentioned that the plant required a much longer steeping process than Sunn hemp ([23]: 244]). In his monograph on fibre manufacturers in Punjab, nonetheless, Gee neglected to mention it, which may indicate that the plant was too insignificant in western India to be mentioned [26]. Nor does it appear in any of the other sources mentioned as cultivated in the western provinces. Jute articles, however, were traded within the borders of the country and abroad and thus imported into Punjab, Sindh and Kutch from Bengal [21]. This is certainly the reason it is only found in a small number of samples. In the specimens, the characteristic features are narrow and clear lumens, thick fibre walls, as well as the varying width and constrictions of the lumen along the fibre length (Fig. 15a, b).

In some parts, the lumen is almost closed by constriction. The dislocations and cross-markings are faint ([19]: 40; [20]: 169–172).The usual straight nature of the fibre is imperceptible, perhaps because the fibres have macerated for a long time and have lost their native strength. No associated cells were identified in the samples; however, such cells are rarely present ([19]: 41).

Kenaf fibres have been identified in 16% of the samples in combination with Sunn hemp (or 13 samples: RV-3025-3, RV-3025-17, RV-3025-46, RV-3025-47, RV-3025-48, RV-3025-49, RV-3025-61, RV-3025-63, RV-3025-66, RV-3025-76, RV-3025-81, RV-3025-82, RV-3025-103. However, it was also found as a standalone fibre only in four samples i.e. 5% of all samples (RV-3025-11, RV-3025-46, RV-3025-66, RV-3025-77). However, kenaf fibres are difficult to identify, as they are often confused with those of jute for the fibre anatomy and sunn hemp for the associated cells which are similar. Kenaf (*Hibiscus cannabinus L.)* is also named Deccan hemp because it was largely cultivated in the Western regions particularly in the Bombay Presidency as a crop and hedge plant. It grew in strips around cotton and sugarcane crops to protect them from livestock ([21]: 430–437; 630–631; [22]: 257; [25]: 3). The plant is also called *sankokra*, *patsan*, *ambári* in the western regions, and

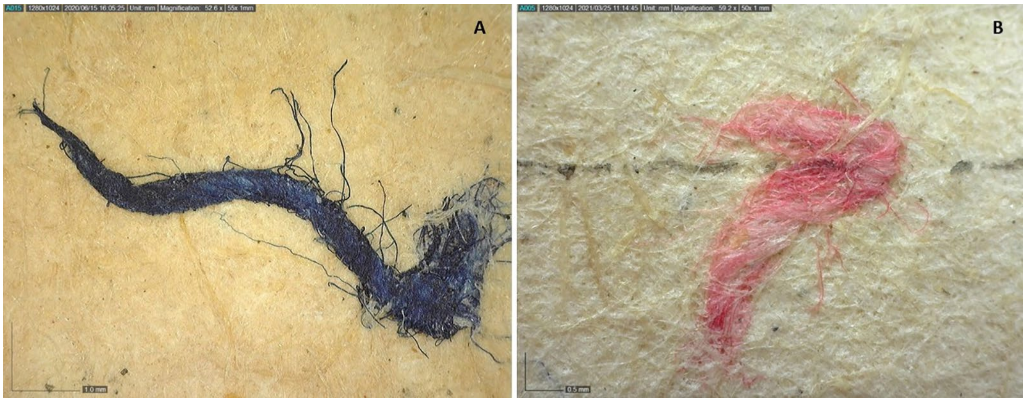

Fig. 18 **a** Strand of blue fibre, RV-3025–66, **b** strand of red fibre, RV-3025–24. Images by Dino-lite® 55×

Fig. 19 Blue bast fibre, sample 102, 20×, RV-3025–18

Fig. 20 Rope made with Sunn hemp (*Crotalaria juncea*), Sindh, 1864, Kew Gardens, inv.n. 60,199

kanoff, (or *kanaf* كنف in Persian) hence the word kenaf ([21]: 630). Like the aforementioned plants, kenaf fibres are used to make cordage, fishing nets and canvas. In his monograph, Gee barely mentioned this, which raises the question of its presence and uses around Sialkot and in Punjab. Royle and Baden Powell suggested that the fibres were weak compared to those of Sunn hemp ([21]: 508). Like jute, the lumen of a kenaf fibre is constricted and varies in width, but the walls of kenaf fibres are scalloped and broadened due to the variation in the width of the lumen, with thin or thick walls (Fig. 16a, b) ([19]: 44).

The walls are usually much smoother and more regular than those of Sunn hemp. The kenaf fibres used by hamsters to make their nests and purchased on the market allow us to see the characteristics of the native fibre unaltered by any treatment. Dislocations are rare, cross-markings are faint (Fig. 17a, b) and the fibre often ends with a scimitar-shaped end (Fig. 17c) ([19]: 342).

It is worth mentioning the presence of fragments of blue strand or fibre visible to the naked eye in the substrate of a significant amount of works (Fig. 18a). While 33% of the papers contained no pieces of thread, 38% contained one fragment of blue thread, 24% two fragments and 5% three or more fragments. For instance, the works RV-3025-121, RV-3025-66, RV-3025-87, RV-3025-40, RV-3025-41, RV-3025-49 contain visible pieces of

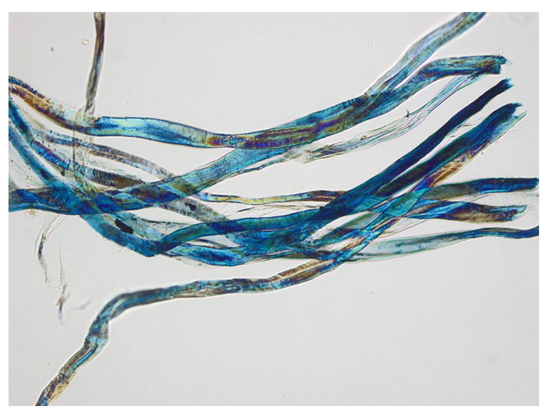

Fig. 21 Blue cotton fibres, 20×, sample 51, RV-3025–81

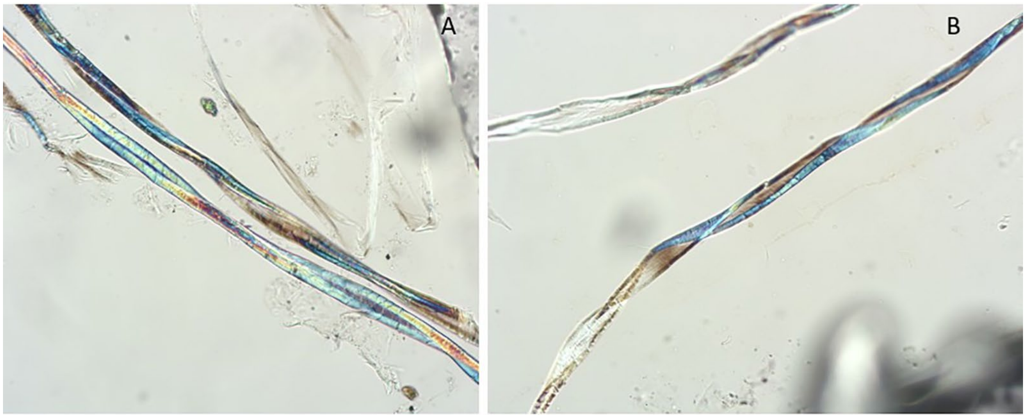

Fig. 22 **a** Well-rounded cotton fibre with smooth edges showing a well-defined arrangement of cross marking, Sample 42, 20×, RV-3025-83a, **b** long ribbon-like cotton fibre with shallow twists of large amplitude, Sample 42, 20×, RV-3025-83a

blue strands imbedded into their substrate. Very few objects such as the drawing RV-3025-24 and the painting RV-3025-82 contain small fragments of red strands (Fig. 18b).

Microscopic observation revealed the presence of blue-dyed bast fibres in 11% of the sample (Fig. 19). This aspect demonstrates that dyed fibres were also used for utilitarian products that were reused in paper pulp. A rope, today in Kew Gardens, collected in 1864 in Sindh, for example, contains a piece of blue yarn. (Fig. 20).

Cotton fibres were also identified in 30% of the samples. Among these, 18% are blue and 12% are of natural colour (Fig. 21). Cotton fibres were found in RV-3025-2, RV-3025-11, RV-3025-18, RV-3025-31, RV-3025-33, RV-3025-35, RV-3025-36, RV-3025-38, RV-3025-48, RV-3025-55, RV-3025-57, RV-3025-64, RV-3025-77, RV-3025-68, RV-3025-74, RV-3025-80, RV-3025-81, RV-3025-82, RV-3025-83a, RV-3025-86, RV-3025-125, RV-3025-128, RV-3025-132. Large bundles of cotton blue fibres were found in RV-3025-81, RV-3025-66, RV-3025-127, RV-3025-128.

Indian cotton, *Gossypium herbaceum L.*, tends to produce short-fibred, coarse cotton cloth [27]. *Gossypium herbaceum* L. generates two types of fibre: a long ribbon-like fibre with shallow twists of large amplitude and thickening of the edges and a well-rounded fibre with smooth edges showing a well-defined arrangement of cross marking [27]. Both types are seen in the samples (Fig. 22a, b). These reveal the presence of either cotton materials which, once tattered, were reused in paper making or cotton waste from the processing of the cotton bolls ([22]: 264).

Cotton was widely cultivated in Punjab, Rawalpindi and Amritsar being the largest areas of cultivation ([21]: 479). Baden-Powell provided a comprehensive list of all the categories of goods woven with cotton, from the coarsest canvas to the finest muslin ([9]: 1–23). The class of utilitarian cotton products included yarn and thread, plain, patterned and dyed cloth, rope for tents, horse nets and fringes, carpet and *newár*, a coarse ribbon used to weave charpoy bedding, large coloured tents and smaller ones made of white and red cotton as well as boat sails used on the traffic boats that sailed the rivers of Punjab ([9]: 253). Tangible examples of cotton-based materials are present in our collections today. For example, between 1855 and 1857 the Schlagintweit brothers participated in the great magnetic survey of the Indian subcontinent and, during their grand tour, collected samples of cloth and paper among other specimens of natural history [28]. These samples are now in the British Library, mounted in volumes.[15] The circumstances of the collection are unknown, and the captions at the bottom of the samples relate more to the places (city and region) of purchase than to those of actual manufacture. It is therefore impossible to ascertain whether the specimens were produced locally or imported. Volume IV on Wools and Cottons from Punjab, however, presents several samples of coarse cotton fabric used for utilitarian purposes. For example, the number 20 shows a piece of raw cotton fabric with three rows woven by hand with blue threads. The caption at the bottom reads '*Cotton with differently coloured threads*'.[16]

To conclude on the reuse of cotton in paper pulp, Dard Hunter wrote the following ([11]: 17):

[15] Hermann (1826–82), Adolf (1829–57) and Robert (1833–85) Schlagintweit, Alpine glaciologists from Germany, were invited by the East India Company in 1854 to complete the Magnetic Survey of the Indian subcontinent on the recommendation of Alexander von Humboldt.

[16] British Library, Collection Schlagintweit, Technical Objects from India and High Asia, Asia, Pacific & Africa X 366.

> *Discarded cotton cloth has never found much use as an Indian papermaking substance for the reason that every rag and tatter has always been in demand to conceal the nakedness of the poor; the most fragmentary scrap of woven cotton materials finds it humble use and when it is finally discarded it is so filthy, worn, and threadbare that is would not yield even a few usable fibres to the destitute papermakers […] It is not uncommon in India to see beggars whose emaciated bodies are covered only with shredded pieces of filth-encrusted gunny tied about the middle with frayed ropes […] In India, there are no professional rag-pickers, for when an old bedraggled rag is at last thrown out by its owner, it is at once seized by a less fortunate individual who stitches the rags to other tatters of woven cotton scrap to make the only garment of India's millions.*

It is not easy to say whether this empathetic account accurately describes the situation, but it does help to justify the small amount of cotton fibre found in the samples. The cotton from the above-mentioned woven products likely ended up in the papermill at some point. Recycling cotton textiles was a domestic activity that had been practiced at both industrial and household levels since antiquity. The collection of cotton waste took place at several points in the chain: at the beginning, after ginning and spinning; in the middle, in weaving, hosiery and sewing workshops; and at the end, after years of use, when textiles, rags and fabrics were too damaged to fulfil their original function. Today, most village industries, such as the Sri Aurobindo Ashram's paper production unit in Pondicherry, use white cotton rag scraps as raw materials to make paper [29].

It is interesting to note the absence of flax (*Linum usitatissimum L.)* and hemp (*Cannabis sativa L.)* fibres in the samples. This absence is explained in several sources. Flax called *alsi, ulsi* or *tesi,* was mainly cultivated for its seeds used as fodder and for the production of linseed oil. In Punjab, flax fibres were harvested in small quantities by the natives for their own purposes. They were twisted into twines to weave charpoys ([21]: 192; [26]: 3). The reasons for this were that the climate was unsuitable for large-scale flax cultivation and the processing of the stalks was more tedious than that of sunn hemp and jute ([21]: 169; 193–201). According to Watt, the seeds mature after the plant has matured, so that the stem is completely destroyed once the seeds are harvested ([22]: 722). In Punjab, the use of the plant as a source of fibre only began with the British occupation.[17] The Indian Flax Company only began operations in Sialkot in 1860 and focused mainly on the production of fibre for export to Europe ([26]: 522). A few years after its creation, however, the company had to close down. As for the true hemp, its use was localised in the Himalayan regions and by the local population of the hills for narcotic purposes. The dried leaves are used with other ingredients to make a drink called *bhang*, the flower tops with their resin were called *ganja* and the resin from the seeds *churrus* ([22]: 292). The people of the Himalayas and hence of the Punjab hills used the fibres to make ropes, fishing and bird nets, shoes, bags and coarse textiles for clothing, but these products were mainly for local consumption and were hardly exported to the plains ([21]: 255; [22]: 320–327; [26]: 2). In Punjab, it grew wild and continues to do so today, especially on the banks of the Jhelum River, and it was used as a mild narcotic. The stems were little used, except for burning and domestic purposes ([21]: 254). Watt also mentioned that several attempts were made at cultivation in eastern India, but all failed. In 1871 experiments were still in progress. Attempts were also carried out in the western Himalayas (Kumaon, Shimla, Kashmir) and Nepal.

[17] The occupation of the region took place much later than the other provinces, in 1849, when the Punjab was taken over by the British Raj after the Second Anglo-Sikh War.

Fig. 23 The story of Kāmarūp and Kāmalatā, dated 1250H/1834–1835, Bibliothèque Nationale de France, Département des manuscrits, Suppl. Persan 929. F. 4v. Kāmarūp's birth, F.5r. Photo: Amélie Couvrat Desvergnes

Discussion

A lower grade of paper

None of the macroscopic observations described above match the fineness, softness and whiteness of Jahāngīrī paper as described in historical sources such as Baden-Powell's. High-quality Sialkoti paper tended to be used for luxury manuscripts and important correspondence. The richly illustrated manuscript that tells the story of Kāmarūp and Kāmalatā, completed between 1834 and

Fig. 24 The mat and rope maker and his wife, Album of Kashmiri Trades and Occupations, 1850–1860, © British Library Board (OR. 1689, F.26r)

1835 and now preserved in the Bibliothèque nationale de France, for example, may have been prepared on the finest Sialkoti paper. The book copied in Amritsar or Lahore, not far from Sialkot, for Claude-August Court (1793–1880), a French general serving in the army of Maharaja Ranjit Singh illustrates the continuity of fine paper manufacture in the second quarter of the nineteenth century (Fig. 23). The light cream paper is evenly thick, strong, clean and has very few impurities.

In contrast, the paper used by the Pahari artists may correspond to a lower quality used for more common purposes. Paper was an expensive commodity that was kept and re-used sparingly, and it seems plausible that their economic and geographical situation meant that the Punjab Hills could only source material of inferior quality [12]. This is further illustrated by the way in which Pahari artists treated this precious material: each sheet of paper was filled to avoid wastage [30].

Recycling severely damaged manufactured products

As mentioned above, the microscopic study has shown that Sunn hemp and other fibres found in the samples are rather damaged and fibrillated. These aspects reflect, on a microscopic scale, the advanced extent of the deterioration of the recycled products that were re-used in the preparation of the pulp that underwent long maceration and retting processes. Nineteenth century sources from European travellers, officials and engineers mentioned old rags, cloth (*tát*), cordage, sacking, and mats being repurposed in paper pulp. These products were widely used in rural areas in agriculture and for all sorts of domestic purposes. Maritime articles, e.g. fishing nets and sails, were also included in the pulp, these being widely used by boatmen and fishermen in Punjab, known as the land of the five rivers (Sutlej, Beas, Ravi, Chenab and Jhelum), as well as those of the Indus and the Sindh ([21]: 775, 923; [22]: 19; [23]: 10). Baden-Powell also provided an interesting description of a rope-twister or *rassi-bat* including diagrams and vocabulary ([9]: 303). An interesting painted folio from the British Library shows the work of the rope and mat maker in Kashmir and highlights the use of stems and grasses to manufacture these items (Fig. 24).

Strong, durable plant fibres were and continue to be used today to produce these articles of fibre: Sunn hemp (*Crotalaria juncea*), jute (*Corchorus capsularis and C. olitorius),* kenaf *(Hibiscus cannabinus L)* and many other local species. In Punjab, the chief articles made from Sunn hemp were twine (*bán*), all sorts of cordages, matting (*trangar*), nets (*chinkás* or *chikka*) and sacking. *Bán* was used to produce the string bed called charpoy, as well as sides of carts (*pakhulís*) and seats for bullock carts [26]. In brief, the raw stems were steeped and retted in water for several days to facilitate the process of fibre separation. The inner bark would then be stripped by whipping the bundles on the surface of the water and beating them on a stone with a hammer; then the inner fibres would then be dried and sun-bleached ([20]: 434). When these articles were too worn and could no longer fulfil their original purpose, they were sent to the papermill to be recycled into pulp. In 1939 Hunter wrote ([11]: 17):

> *While the weaver of cloth and nets and the maker of ropes must rely upon the newly-harvested fibres for enduring strength and sufficient length, the papermaker must be satisfied with these commodities long after they have served the purpose for which they were originally fabricated; the disreputable condition of the material and the length of the fibres cause little concern to the maker of paper. […] The greater part of the cloth and rope comes from the cities of India and is usually in a deplorable condition, little short of decayed. The fishing nets, gathered along the rivers and streams, are not discarded by the fishermen until almost every mesh has been patched over and over and the nets are literally falling to bits.*

Although Hunter's testimony post-dates the production of the Pahari drawings from the Wereldmuseum by a century, when the state of the paper industry was in great despair, this quotation nevertheless provides us with an observation of the condition of some of the fibres found in the samples analysed.

None of the nineteenth century sources mention the cooking of recycled materials. Instead, they would undergo a repetitive sequence of three operations: maceration/retting with the addition of alkaline agents, washing and beating. In Sialkot, pulping would be done in the summer months, while the winter months would be devoted to sheet making. Recycled materials to which alkaline agents such as crude soda ash or wood ash along with lime were added would be left to ferment outside ([1]; [9]: 86). As Gray mentioned, the retting process could take from a few days to three or six months, depending on the method and the quality of the paper. Boiling, on the other hand, took only 24 h [5]. He pointed out, however, that the combined action of heat, sunlight and air was more effective in breaking up the material than the boiling process. The operation also had the dual effect of separating the strands, yarns and bundles, while bleaching the slurry. Gray also argued that the boiling process was only introduced after 1850, but his observations referred to jail paper. While examining the paper produced at Sialkot jail in the 1860s, Baden-Powell mentioned ([9]: 81):

> *The paper turned out was indeed of great strength, but was full of flaws and bits of black looking fibres. Very fair paper was made by mixing tat-pati & ect, or old paper with it. To make really good paper, the fibres require boiling with alkaline lye: this I observe is always done in Nepal […].*

In 1908 Emerson, who observed both native manufacturers and jail production, wrote that in Sialkot's native papermills, the ropes were allowed to macerate in alkaline lye for a month and then the usual process was carried out without boiling the material ([10]: 16). All this to say that this long maceration process could be one of the reasons the fibres in the samples are so fibrillated and damaged and the reason so much insubstantial tissue is present.

Conclusion

Throughout their history, the Sialkot paper mills have produced many varieties of paper, from the finest quality used for manuscripts and official documents to the lowest grade. The results of macroscopic and microscopic examinations and comparisons with works and manuscripts produced in the Punjab hills for major patrons, have made it possible to characterise Sialkoti paper used by Pahari artists for artistic creation, and have revealed that the paper was precisely not of the highest grade, but rather corresponded to a second or third-rate quality. There are several reasons for this. Firstly, the hill chiefs of the Punjab, who ruled over small and modest territories, had limited financial resources, which prevented them from purchasing and exporting quality materials to these remote Himalayan regions. It should not be forgotten that trade, which took place on the backs of mules, ponies, goats or light oxen, was often hampered by the vagaries of the weather, the topographical difficulties of the terrain, the crossing of tumultuous rivers and high mountain passes, steep trails, as well as by wars and abusive customs taxes. Secondly, it is plausible to think that the appearance and quality of the paper did not really matter to the artists in the end. Their objective was the execution of a finished painting that included coverage of the entire surface with several applications of thick, opaque watercolour. It was therefore not important for the painters to work on coarse, porous paper.

The study of historical sources, supplemented by the analysis of paper samples and the identification of fibres, has highlighted that the pulp would have been prepared from various manufactured products involving different technologies, such as rags, cloth, mats, ropes, and other plant-based materials made from local bast fibres which, once in tatters, were recycled to prepare the pulp. In this respect, papermaking was an essential part of Punjab's economy, forming the final link in the production and recycling chain. The Sialkoti paper used in the Pahari hills was, however, mainly made from sunn hemp fibres, although kenaf and jute were also used but to a lesser extent. The reason is simple: sunn hemp plant grows in abundance in the region and the majority of agricultural and household products are made from this plant. However, cotton fibres were also found in the pulp. These probably came not only from utilitarian products, but also from clothing rags.

Supplementary Information

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Supplementary material 1.

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Author contributions

Conceptualisation: Amélie Couvrat Desvergnes and Agnieszka Helman-Ważny. Funding acquisition: Amélie Couvrat Desvergnes was the leader of the project which was funded by Metamorfoze Netherlands. Fibre analyses were conducted in collaboration with the RFA 6 project at the CSMC led by Agnieszka Helman-Ważny. Investigation and data analysis: Amélie Couvrat Desvergnes carried out the historical and technical background research as well as the macroscopic observations of the corpus. Agnieszka Helman-Ważny served as consultant and supervisor of fibre analyses. Methodology: Amélie Couvrat Desvergnes and Agnieszka Helman-Ważny. Writing original draft: Amélie Couvrat Desvergnes. Editing: Agnieszka Helman-Ważny.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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References

1. Couvrat Desvergnes A. Jean-Philippe Vogel: superintendent of the Archaeological Survey of India and collector of Pahari artworks. Aziatisch Kunst, Jaargang. 54, nr.1, maart 2024: 3–16.
2. Seyller J, Mittal J. Pahari Drawings in the Jagdish and Kamla Mittal Museum of Indian Art. Hyderabad: Jagdish and Kamla Mittal Museum of Indian Art; 2013.
3. Ohri VC. The technique of Pahari Painting: An Inquiry Into Aspects of Materials, Methods and History (Based Upon Observation and Fieldwork). Shimla: Indian Institute of Advanced Study Rashtrapati Nivas; 2001.
4. Konishi MA. Hath-Kaghaz: History of Handmade Paper in South Asia. New Delhi: Aryan Books International; 2013.
5. Gray R. Note on the manufacture of paper in the Jails of the Punjab, appendix IV, in Gee WH. Monograph on Fibrous Manufacturers in the Punjab, in Monograph on Punjab Industries; Monograph on Woollen Manufactures of the Punjab in 1884–85, Lahore: Published by the Authority.
6. Souteriou A. The gift of the conquerors: hand paper-making in India. Ahmedabad: Mapin Publishing; 1999.
7. Naqvi HK. Urban centres and industries in upper India 1556–1803. Bombay: Asia Publishing House; 1928.
8. Rahman A. Indian science, technology and culture AD 1000–1800, Vol. III, Part I. New-Delhi: Oxford University Press; 1999.
9. Baden-Powell BH. Hand-book of the Manufactures and Arts of the Punjab Vol. II, with a Combined Glossary and Index of Vernacular Trades & Technical Terms, etc. Lahore: Punjab Printing Company; 1872.
10. Emerson HW. Monograph on paper making and Papier Mâché in Punjab. Lahore: Civil and Military Press Gazette; 1908.
11. Hunter D. Papermaking by hand in India. New York: Pynson Printers; 1939.
12. Couvrat Desvergnes A. Sialkoti paper used for the production of Pahari drawings and paintings in northwest India. In: Banou P, Boudalis G, Engel P, Hill R, Schirò J, Vodopivec Tomažič J, editors. Artists' paper a case in paper history. Horn: Verlag Berger; 2023. p. 299–334.
13. van Velzen STJ. The universe between felt and wire: A new look into the typology of Western made paper. PhD dissertation, University of Amsterdam. 2018.
14. Lukesova H, Holst B. Identifying plant fibres in cultural heritage with optical and electron microscopy: how to present results and avoid pitfalls. Heritage Sci. 2024;12:12.
15. Helman-Ważny A, et al. The techniques and materials used in making lao and tai paper manuscripts, manuscripts. Cultures. 2020;15:133–62.
16. Helman-Ważny A, Van Schaik S. Witnesses for Tibetan Craftsmanship: bringing together paper analysis, palaeography and codicology in the examination of the earliest tibetan manuscripts. Archaeometry. 2013;55(4):707–41.
17. Helman-Ważny A. More than meets the eye: fibre and paper analysis of the chinese manuscripts from the silk roads. STAR Sci Technol Archaeol Res. 2016;2(2):127–40.
18. Couvrat Desvergnes A. Protocol for the characterisation of non-watermarked handmade paper. 2023. https://www.metamorfoze.nl/sites/default/files/documents/PROTOC~1.PDF. Online resource, last visited 01/05/2024.
19. Ilvessalo-Pfäffli MS. Fibre Atlas: identification of papermaking fibres (Springer Series in Wood Science). Berlin: Springer; 1995.
20. Catling D, Grayson J. Identification of vegetable fibres. London: Chapman and Hall; 1982.
21. Baden-Powell BH. Hand-book of the manufactures and arts of the punjab with a combined glossary and index of vernacular trades & technical terms, etc. Vol. I, Economic Raw Produce. Roorkee: Thomason Civil Engineering College Press; 1868.
22. Watt G. The commercial products of India: being an abridgement of the Dictionary of the Economic Products of India. London: J. Murray; 1908.
23. Royle JF. The fibrous plants of India fitted for cordage, clothing and papers, with an account of the cultivation and preparation of flax, hemp, and their substitutes. London: Smith, Elder & Co; 1855.
24. Brickwood J, Allan W, Hunter P, Green J, Roxburgh W, Anderson A. Papers in Colonies and Trades, in Transactions of the Society, Instituted at London, for the Encouragement of Arts, Manufactures, and Commerce Vol. 22; 1804.
25. Kumar DS, Banji D, Prashanthi GP, Harani A. Pharmacognostical evaluation study on *Crotalaria juncea Linn*. Am Eurasian J Sci Res. 2011;6(3):139–45.
26. Gee WH. Monograph on Fibrous Manufacturers in the Punjab, in Monograph on Punjab Industries; Monograph on Woollen Manufactures of the Punjab in 1884–85, Lahore: Published by the Authority.
27. Collings T, Milner D. The nature and identification of cotton paper making fibres in papers. Pap Conserv. 1984;8:59–71.
28. Sarkar O. Science, surveying and scientific authority: the brothers Schlagintweit. In India and High Asia, 1854–57. South Asia J South Asian Stud. 2017;40(3):544–65.
29. Teygeler, R. Handmade paper from India. Kagaj: yesterday, today and tomorrow. In IPH Congress Book, 1998, 12. International Association of Paper Historians, Marburg; 2002: 185-194.
30. Couvrat Desvergnes A. Indian drawings from the Rijksmuseum: an insight into their production, their purpose and their significance, in ICON Conference post-prints, 3–5 October 2018, ed. A. Bainbridge. 2020.

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