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Review

Lac dye colours: A review of the origin, history and identification techniques in textiles

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ABSTRACT

Lac dye, the dyestuff derived from *Kerria* scale insects, has been valued for millennia by various civilizations, which have appreciated its deep red shades in textiles, paintings, and other cultural artefacts. The colour derived from lac dye is complex both in structure and history, and has been the topic of numerous discussions addressing its origin, history and multiple uses as a dyestuff, medicine or cosmetic. However, there is still a significant lack of cohesion between sources, and no publication to date has offered a comprehensive overview of lac dye. This review aims to fill this knowledge gap by exploring the biological sources from which lac dye derives; the historical importance in Asia and the Mediterranean area; and the variety of processing techniques according to technical written sources. Particular attention is given to the use of lac dye on textiles by comparing the existing dyeing manuals and identification in historical textiles by analytical methods such as high-performance liquid chromatography (HPLC) coupled to diode array (DAD) and mass spectrometry (MS) detectors or surface-enhanced Raman spectroscopy (SERS). The review also offers an updated overview on the taxonomy of *Kerria* lac insects, highlighting their geographical diversity and suggesting future perspective of research. The discussion provides new insights into the complexity of lac dye and its use in the dyeing traditions worldwide, by intersecting sources from history, science and art.

1. Introduction

For millennia, dyers and weavers from across the globe have used natural materials (plants and animals) to create colourful textiles [1,2].

Within the palette of Asian colouring sources, lac dye, the red dyestuff produced by parasitic scale insects of the genus *Kerria* (Hemiptera: Kerriidae) has a long history of local traditions and international trade [2]. Early references to its use as a textile dye can be found in ancient Vedic texts (4th century BC) [3]. Lac-dyed textiles from the 1st century AD have recently been unearthed in Mongolia [4]. In Asia and the Middle East lac dye has been mostly used on wool [5–9] and silk [10–15] for pink, purple, scarlet and crimson colours, while its identification on cotton is far more limited [16,17]. In the Far and Middle East the cultural and artistic value of this red dyestuff remained unaltered for millennia.

Further, in the Mediterranean world the practice of dyeing textiles with lac dye experienced periods of appreciation and prohibition. Nowadays, lac-dyed textiles retain a special resonance across Asian communities where they symbolize heroism and social ranking [18] or convey religious and cultural beliefs [19].

Lac dye has been appreciated as a colouring material in the West, as demonstrated by the number of written sources that, over a period of eight centuries (9th - 17th c.), describe how to extract lac dye from the raw material (sticklac) and how to process it into a lake pigment[1] or coloured ink [20–26]. This widespread techni-

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[1] Lake pigment is a precipitate of the dye onto an insoluble substrate (generally alum-$KAl(SO_4)_2{\cdot}12H_2O$) that once dried, is ground, mixed with a binder and used as a paint.

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cal knowledge has been corroborated by the identification of lac dye on painted objects, from a Hellenistic terracotta vase dated 3rd century AD (Italy) [27], to illuminated manuscripts [28–31], paintings [32–34] and polychrome artefacts [35,36]. However, a similar appreciation does not seem to have been reserved to lac dye in the context of the European textile dyeing industry, where its use is less documented. In fact, the earliest known example of a recipe for dyeing with lac dye is from the 16th-century Venetian manuscript *Plitcho* [37], written almost a century after the regulations that forbade the use of lac dye on silk in the city of Genoa [38].

The study of written documents is a valuable method to better understand the commercial and cultural value of lac dye over time. Dye books and technical manuals offer a unique insight into the dyeing techniques, materials and knowledge transfer among dye workshops. However, the practice of dyeing with lac dye in Europe is still understudied.

Before focusing on the historical importance of lac dye and the available literary sources with recipes for lac-dyeing, this review will provide an overview of the lac insects (genus *Kerria*), including morphology, life cycle, and distribution across Asia. In the context of cultural heritage disciplines *Kerria lacca* (Kerr, 1782) is largely addressed as the main source of lac dye. However, since its first scientific description in the 18th century [39], 28 other *Kerria* species capable of producing lac dye have been recorded across Asia [40]. To the extent of the authors' knowledge, only one study has tentatively associated *Kerria* specimens of known geographical origins with historical lac-dyed textiles [41]. To fill the knowledge gap on the variety of lac insects, this review provides an updated map of the 29 *Kerria* species found in India, Southeast Asia and South China.

In addition, this work intends to correlate the information gathered from the written sources with scientific evidence of the use of lac dye in archaeological and historical textiles. From an analytical point of view, the unambiguous characterisation of organic colourants from textile artefacts is a challenging endeavour [42,43] and lac dye, with its complex chemical composition, is no exception [44–47]. Nevertheless, when samples are available for dye analysis, high-performance liquid chromatography coupled to a diode array detector and mass spectrometry (HPLC-DAD-MS) has proven to be the most reliable technique for the unequivocal identification of lac dye in textiles, with evidence from archaeological sites in Asia [4,14,48] to modern European fabrics [49,50].

2. The lac insects and their geographical distribution

Scale insects of the family Kerriidae (Hemiptera: Coccomorpha) are commonly called lac insects [51]. The name derives from *Kerria lacca*, the best-known species renowned for its ability to secrete lac, a hard and brittle substance yielding shellac resin, dye and wax [52]. Although the word "lac" applies to all the family members, described into nine genera and 101 species, some of these insects do not produce profitable amounts of lac, as in the cases of the genus *Paratachardina* (Balachowsky, 1950) [41] and *Kerria* subgenus *Chamberliniella* (Varshney, 1987) [40,53]. The insects belonging to the genus *Kerria* are unanimously recognized as the main source of lac and lac dye [53].

2.1. Life cycle of lac insects

Currently, the genus *Kerria* Targioni Tozzetti, 1884, counts 29 species worldwide [40]. The taxonomy of lac insects is based on the morphology of adult females and is updated as new species are described [54–59]. Recently, K.K. Sharma (2020) edited an informative catalogue on the taxonomy of lac insects, which includes a complete bibliography of the relevant publications of the last 60 years [53].

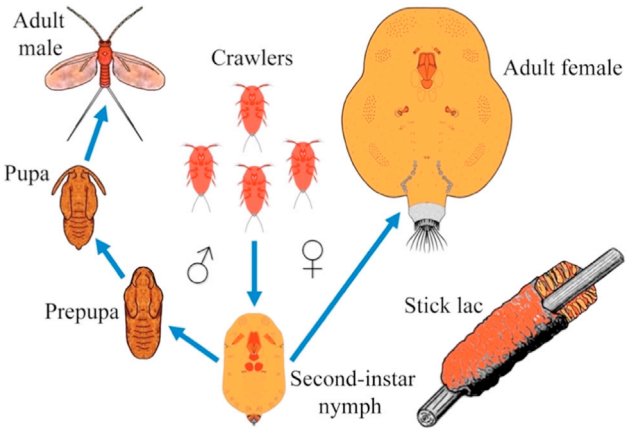

Fig. 1. General life cycle of Kerriidae from the first- and second- instar to the adult stage.
© Drawing by Takumasa Kondo.

Lac insects thrive on branches and twigs of host plants, extract water and nutrients from the plant sap and grow in number creating colonies of hundreds of thousands of individuals [60]. The females have two nymphal stages before reaching the wingless adult stage and the males go through two nymphal stages and a prepupal and pupal stage before reaching the winged adult stage [51] (Fig. 1). The life cycle of lac insects lasts about 6–8 months with up to 3 generations annually, including a summer and winter generation, varying in duration depending on the *Kerria* species [61,62]. Lac insects have a unique morphology compared to other scale insects, e.g., the presence of a dorsal spine, sclerotized brachial plates and a pair of large anterior spiracles placed on the body margin or dorsum [63]. The adult male is elongated, winged and mobile while the adult female has a pear-shape body (ca. 2.9–3.3 mm long and 2.6–2.8 mm wide), which becomes globular and bigger in size to host the growing number of eggs [51]. Females can lay up to 1000 bright red eggs, from which the first-instar nymphs (crawlers) of crimson-red colour emerge in a few hours [51]. The crimson-coloured fluid present in the body of adult females, crawlers and eggs is mainly composed of anthraquinone molecules and is the source of the lac dye colourant.

2.2. Lac insect distribution

Lac insects of the genus *Kerria* live wild and are cultivated across various regions of Asia: the highest biodiversity of *Kerria* spp. is in India (22) followed by South of China (12), Myanmar (8), Thailand (7), Pakistan and Nepal (5) and other tropical areas (Fig. 2) [40,53,64].

Kerria lacca, also called Indian lac insect, is the best-known and most widely cultivated *Kerria* species across Asia [53]. It is also reported in Azerbaijan, Georgia and Guyana [40]. The Indian *K. lacca* was described for the first time at the end of the 18th century by James Kerr, a medical officer at the India Company's Service, who published an informative report on the morphology and biology of this species [39]. Two strains of *K. lacca*, i.e. *kusmi* and *rangeeni*, are unique to the Indian territory and differ in life cycle, host plant preferences and quality and quantity of lac secreted. The *kusmi* strain is considered superior due to its higher productivity and light colour of the resin [65].

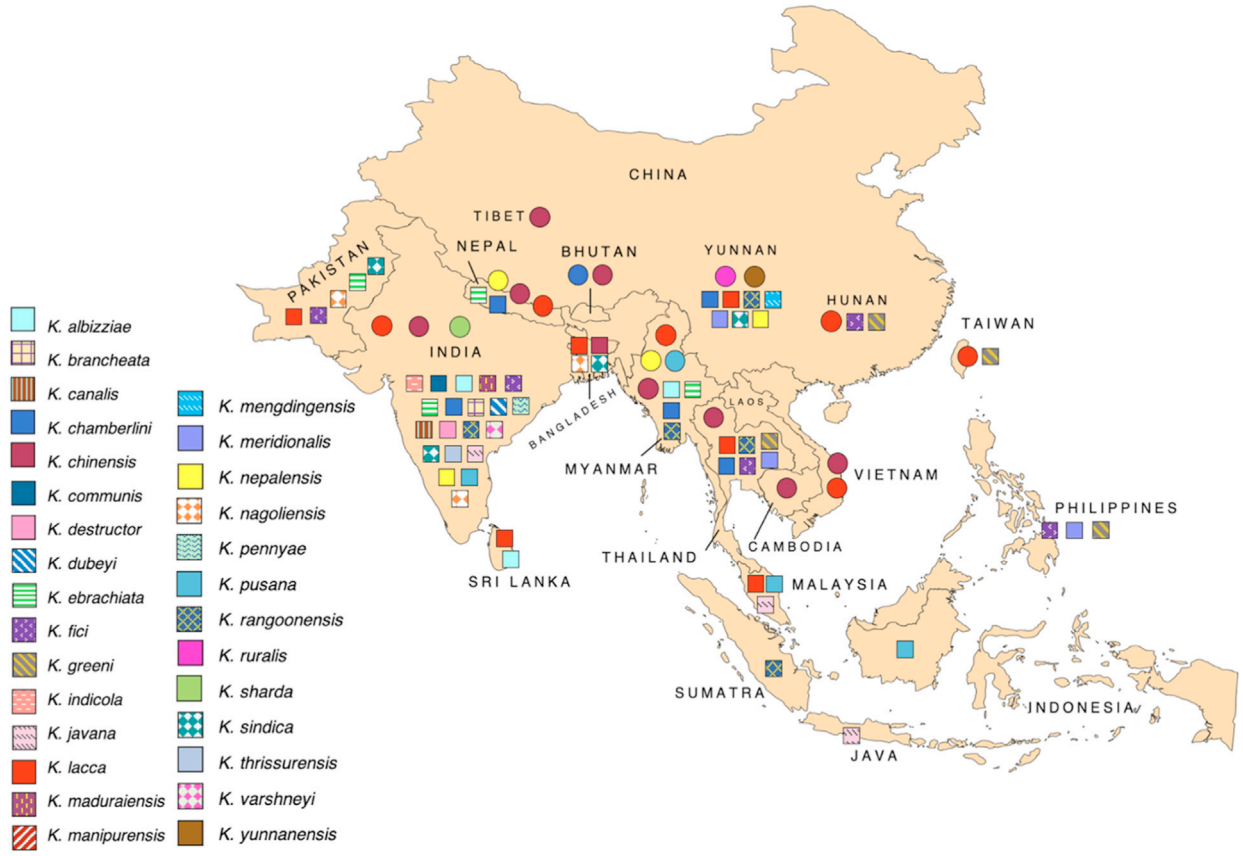

Fig. 2. Geographical distribution of the 29 *Kerria* species across tropical and subtropical regions of Asia. ○ - endemic species or species specifically recorded in the literature as commercially important for lac production; □ - cultivated species with no information available on their commercial importance. © Drawing by Mila Crippa.

Kerria sharda Mishra and Sushil, 2000 and *Kerria chinensis* (Mahdihassan, 1923)[2] are also cultivated in India, especially in North-eastern regions [53]. *Kerria chinensis* is the second most common species, being recorded in 10 countries, including Bhutan, Nepal, Cambodia, Myanmar, Vietnam and Thailand, where it is the main commercial species [53,62,66]. *Kerria (Kerria) ruralis* (Wang, Yao, Teui & Liang, 1982) and *Kerria yunnanensis* Ou & Hong, 1990 are two endemic species in China, with the latter being the main commercial source of lac in the country [66]. The biodiversity of the lac insect in China is such that 12 species have been recorded mostly from the Yunnan province, including *K. chinensis, Kerria (Chamberliniella) meridionalis* (Chamberlin, 1923), *Kerria sindica* (Mahdihassan, 1923) and *Kerria* (*Kerria*) *nepalensis* Varshney, 1977 [53,64].

Moreover, *Kerria (Kerria) pusana* (Misra, 1930) and *K. nepalensis* are widely used for lac production in Myanmar [66,67]. In India, new *Kerria* species has been identified by Ahman and co-workers (2013) [57,58] and Rajgopal, Mohanasundaram and Sharma (2021) recently recorded *Kerria canalis* in Rajgopal, 2021, Tamil Nadu [59].

Lac insects highly depend upon the host plants and bushes they colonise, and hundreds of plant species have been recorded as host plants [68]. *Kerria lacca* strain *kusmi* thrives on *kusum* tree (*Schleichera oleosa* (Lour) Oken.), whereas *rangeeni* insects prefer *dhak* (*Butea monosperma* (Lam.) Taub.) and *ber* (*Ziziphus mauritiana* Lam.) [2]. Other major lac host plants and bushes recorded in Asia are figs (*Ficus religiosa* L. and *Ficus altissima* Blume), acacias (*Acacia auriculiformis* A.Cunn. ex Benth.), litchi (*Litchi chinensis* Sonn.), raintree (*Samanea saman* (Jacq.) Merr.), the jujube tree (*Ziziphus jujuba* Mill. and *Z. mauritiana* Lam.), *Dalbergia* spp., *Cajanus cajan* (L.) Huth and *Vitis* spp. [53,64,66,69]. According to Sharma (2016), the insect species and host plant are among the factors which influence the quantity and quality of raw lac produced per female insect [65]. The quality of lac, in particular, depends on physiochemical properties, including the colour, which is estimated in terms of dye content. *K. lacca,* and *kusmi* strain in particular, secret lac of light colour which is nowadays the preferred type of lac for the production of shellac resin and the one with the higher price on the market [70]. Conversely, *Kerria chinensis, Kerria sharda* and Vietnamese *Kerria* spp. produce the darkest lac. In his study on *K. chinensis*, Mahdihassan (1948) attributed to this species the best yield of lac dye due to the high density of the insect colonies and the voluminous bodies of the females producing lac dye in relation to the relatively small amount of resinous secretion [71].

It is interesting to observe that the economic and cultural significance of lac dye and shellac changed over time. As described by Cardon (2007), for centuries raw lac has been valued for its colouring content and dyeing properties [2]. However, nowadays, shellac resin is the most sought-after product derived from lac, finding applications in various industries due to its non-toxic, eco-friendly and biodegradable nature [72].

3. Multitude of lac products and lac dye colours

3.1. From sticklac to lac dye

During the early to adult stage, female lac insects secrete through specific abdominal glands significant amounts of lac [51].

[2] In taxonomic nomenclature, parentheses enclosing the author's name and date are used to indicate that the species was originally described in a different genus. If no parentheses are present, the species was originally described in the current genus.

Fig. 3. Lac test embedding the female insect with crawlers surrounding the test (left); lac encrustations on a litchi tree (right). © Photos by Takumasa Kondo and Sunil Joshi.

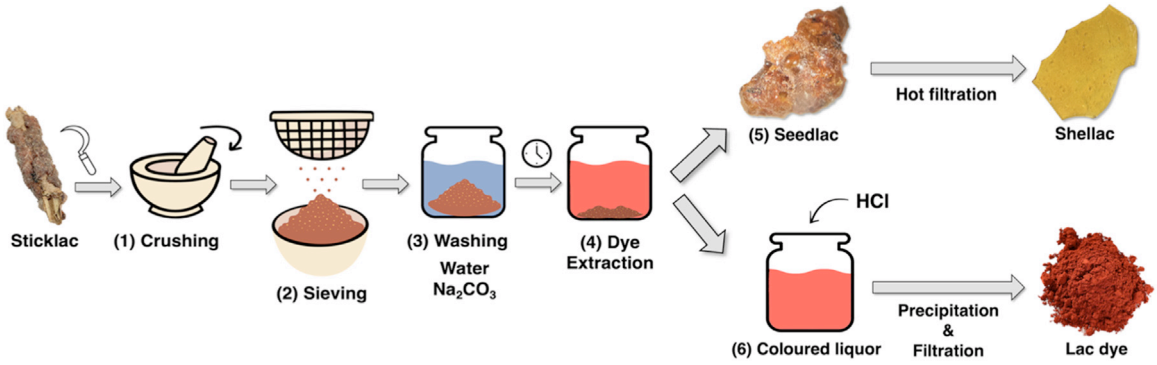

Fig. 4. Processing of sticklac to prepare shellac and lac dye colour.

As a result, each female insect becomes embedded in a round resinous test (Fig. 3, left), which protects both the insect's body and its eggs from predators. Because of the large number of lac insects living in close proximity on host plants, each lac test merges with the others creating reddish-brown encrustations around the trees' branches and twigs (Fig. 3, right) [70].

During the harvesting periods, the branches covered with resin are cut, laid out and left to dry. When sold in this form the raw lac is known as sticklac, a composite material which includes resin (68 %), lac dye from the insects (10 %), wax (6 %), and other impurities, such as wood debris and dust (16 %) [52].

To make it profitable, sticklac undergoes several processes of purification from which three main commercial products are isolated, i.e., shellac resin, lac dye and wax [70].

Porter (2019) described the stages of this process in use at the Indian Institute of Natural Resins and Gums (Ranchi, Jharkhand) (Fig. 4): (1) the lac encrustation is scraped from the twigs and crushed into small pieces, (2) sieved to remove sand, dust and wood debris and, (3) soaked in large baths containing water and sodium carbonate [73]. As a result of these steps (4), the red fluids present in the lac insect bodies get solubilised in water, while the crushed and semi-refined lac settles at the bottom of the vats. Once the washing is complete and the impurities removed, (5) the cleansed and lightly coloured lac, called seedlac, is taken out and processed with traditional or mechanical methods [70], such as hot filtration, to obtain shellac in the form of yellow-to-brown small flakes. The clean seedlac can be further purified from the remaining wax and yellow-orange colouring substances, in order to obtain decolourised lac or bleached lac, which is extensively used in the pharmaceutical, electronics and surface coating industry [72,74,75]. The red coloured solution (6) remaining from the washing process is then pumped into large tanks, where hydrochloric acid is added to the water. The precipitate that forms due to this process is collected, filtered, washed and finally laid out to dry until obtaining a crystallised lac dye (80–90 % dye content). As described by Sharma and co-workers (2020), the powdered lac dye can undergo further steps of purification until a bright red lac dye powder (99 % dye content) is obtained [52]. Known in the trade market as Natural Red 25 (CI 75450), this pure form of lac dye finds applications as a colouring material, dyestuff in the textile and leather manufacturing industries [76–78], food additive in China, Japan and Thailand [79,80] and also excipient in pharmaceutical products [81].

3.2. Chemical composition

Sticklac, the raw material from which lac dye is extracted, has a complex chemical composition. Several water-soluble anthraquinone molecules (laccaic acids) responsible for the red-to-carmine colour of lac dye are found along with other coloured components, such as erythrolaccin and deoxyerythrolaccin [52,82,83].

The latter two give the typical yellow-orange colour to shellac, which also contains colourless molecules, described in detail elsewhere [84]. The chemical structures of the colour-giving molecules present in lac dye and shellac are shown in Fig. 5.

Pioneering studies on the chemical composition of lac dye were conducted between the end of the 19th century and early 20th century by Schmidt, Dimroth and Goldschmidt, who named the identified molecules laccainic acids [2]. Further insights into the structure and molecular characterization of lac dye components was provided during the 1960s [85–90] and 1990s [91–93] by Indian, English and Japanese researchers.

Laccaic acids A and B are the main components and laccaic acids C, E, F and flavokermesic acid are present in various lower proportions. Flavokermesic acid is currently the most accepted terminology for laccaic acid D, a colourant molecule also present in other scale insect dyes [94,95]. Laccaic acid F, described for the first time by Hu and co-workers (1997) after being isolated from sticklac from Thailand [96], was recently detected in Coptic textiles [97]. Along with laccaic acid F, Lech (2025) confirmed also the

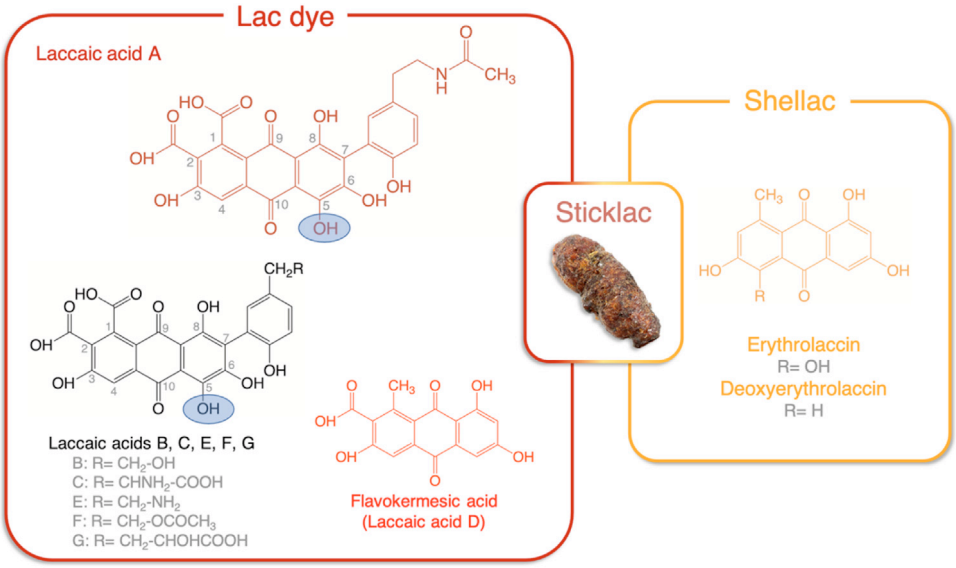

Fig. 5. Molecular structure of the colour-giving molecules present in lac dye: laccaic acid A (main red colourant molecule), laccaic acids B, C, E, F, G and flavokermesic acid (laccaic acid D). The hydroxyl group in C5 position, absent in xantholaccaic acids, is highlighted with a blue circle. Erythrolaccin and deoxyerythrolaccin are yellow colourant molecules found in shellac.

presence of another minor compound, identified as laccaic acid G [97]. Furthermore, the composition of lac dye includes other minor components named xantholaccaic acids, which derive from their laccaic acids counterparts upon loss of the hydroxyl group in C5 position [45–47,93,97,98].

3.3. Dye compositon according to lac insect genera

The number of studies that have taken into consideration genera of lac insects other than *Kerria* is limited. Cameron and co-workers (1978) compared *K. lacca* with *Austrotachardia acaciae* (Maskell, 1892) [99]; Wouters and Verhecken (1989b) used specimens of *Tachardiella larreae* (Comstock, 1882) from California [44]; and more recently Santos et al. (2015) compared lac dye from the genera *Kerria* and *Paratachardina* Balachowsky, 1950 [41]. These studies found that laccaic acid B is the compound that varies the most across the different samples. According to Santos et al. (2015), laccaic acid B is the main colour-giving molecule in *Paratachardina* sp., while it is absent in the sample of *T. larreae* studied by Wouters and Verhecken (1989b). Also, as stated by Cameron et al. (1978), *K. lacca* and *Austrotachardia acaciae* differ in the relative amount of xantholaccaic acid B.

A comprehensive table summarising the composition of lac dye according to studies on lac insect genera is presented in the Supporting Material (Table S1).

Within the published literature, the work conducted by Santos and co-workers (2015) appears as the most thorough attempt done so far to tackle the complexity of lac dye from different species of lac insects. For the first time, HPLC-DAD-MS analysis was used to show differences in the molecular profiles of lac dye from unknown *Kerria* and *Paratachardina* spp.

In addition, the application of multivariate data analysis, specifically principal component analysis (PCA), enabled groups of unknown *Kerria* spp. to be differentiated based on the relative proportion of laccaic acids and resinous compounds. Consequently, a historical lac-dyed textile was correlated with lac insect from Pakistan [100]. Although the researchers provided an accurate identification of the laccaic acids from the textile samples, they critically observed that it is not possible to refine the provenance of an historical textile based on the specific biological source without prior taxonomic investigations of the *Kerria* species. In the past decades, extensive work has been done on other scale insects, such as cochineals, with the aim to distinguish between different sources of carmine reds, including “Mexican cochineal”, *Dactylopius coccus* Costa, 1829, “Armenian cochineal”, *Porphyrophora hamelii* (Brandt, 1833) and “Polish cochineal”, *Porphyrophora polonica* (Linnaeus, 1758) [44,69,101–103]. However, no systematic work has been done on lac dyes extracted from verified *Kerria* species. As demonstrated elsewhere [10,46,104], disclosing the exact biological source used for dyeing a textile may enable a better understanding of the place of production, origin and trade of the raw material as well as knowledge transfer of the dyeing processes.

4. The historical importance of lac dye

Local communities across Asia developed since an early date successful ways to extract the red colourant from the lac insects and to use it as a medicine [105,106], skin cosmetic [3] and dyestuff for wool, silk and cotton [2,16].

In India, early references to the colouring potential of lac dye and lac-dyeing practice can be found in classic texts from the late Vedic period, such as the *Ashtadhyayi* (4th c. BC) and *Samyutta Nikkaya* (3rd-2nd c. BC) [3]. In the *Nayadhammakahao* (454 AD) the red dyestuff is extracted by crushing lumps of raw lac [2]. Later, in the 10th century, Ksemendra‘s *Samayamatrka* (10th-century) described boiling the raw material to obtain a coloured liquid, which was then cooled down and used as a dye bath [3]. In China, the birthplace of silk weaving, lac dye has been valued for dyeing textiles since the Han dynasty (206 BC-220 AD) [107]. Schafer (1957) reported that the Chinese author Chang Po described in his text *Wu Lu* (320 AD) a “red gum” used to dye scarlet red silk and produce a type of fabric called *Yichishu*, i.e., “red cloth from the ant gum” [108]. Cambodia and Annam (modern Vietnam) were also part of the trade networks. A historical account from the Tang period (618—906 AD) described Cambodia as the “land of true wax”, while according to the *Geographical Memoirs of Kiao Chou,* the province of Annam had to give regular tributes of lac to the court of the Chinese emperor [2]. In China, lac dye remained a primary source to dye scarlet silks for centuries, until American cochineal started to replace it [109]. Japan imported the tradition of soaking disc-shaped cotton in lac dye (*wata-enji*) for painting and dyeing from Central Asia and China [110].

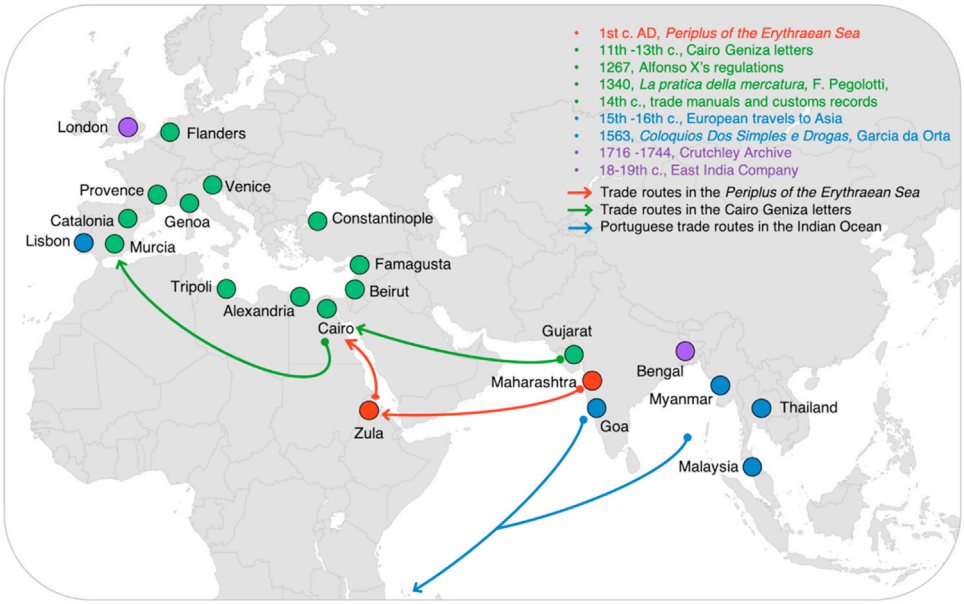

Fig. 6. Map showing some of the locations where raw lac was traded and sold as a dyeing material as recorded in historical sources from different periods of time. Locations, written sources and trade routes are indicated with different colours according to the centuries: 1st c. (red), 11th-14th c. (green), 15th-16th c. (blue); and 18th-19th c. (purple).

Like the Far East, the Middle East valued the colours obtained from lac over many centuries. According to Mahdihassan (1954), Persians and Arabs imported lac from Indonesia and Southeast Asia [107] and regularly used lac dye on wool and silk carpets [111]. In the Islamic world and China, lac dye was also appreciated for its affinity to leather and doe skin [2].

In the Mediterranean area, lac insects and lac dye had also been known since antiquity. Ktesias, in his text *Indika* (5th-century BC), described wild insects living on trees that were ground into a powder and used by Indian communities to dye garments a purple hue [111].

At the beginning of the Christian era, raw lac was traded to the West on sea routes (Fig. 6).

According to the *Periplus of the Erythraean Sea,* a 1st-century AD handbook written by an anonymous Greek merchant, lac was exported from Ariaké (modern-day Maharashtra, India) to the port of Adulis (modern-day Zula, Eritrea) [112].

After the Arab conquest of the 7th century, the circulation of lac across the eastern and western Mediterranean area increased progressively. This is evidenced by the extensive use of lac dye in Coptic textiles [97,113–116].

Pfister (1936) [117] and Forbes (1956) [118] attributed the widespread use of lac dye in Egypt to the interruption of trade with Armenia, Byzantium and the northen regions, which limited access to European cochineals and kermes. More recently, Gulmini and co-workers (2017) identified lac dye on Roman-Byzantine textiles, suggesting its use in Egypt as early as the 5th century AD [119]. That Egypt was an important centre for the circulation of raw lac is also attested by several documents in the Cairo Geniza, an archive found in the Ben Ezra synagogue in Old Cairo [120]. Lac was in fact one of the commodities regularly bought in Gujarat by Jewish traders from Egypt and Libya and imported into the Mediterranean via Yemen to Cairo [121]. Some Geniza letters dated 1138 AD show that Indian lac was among other goods traded to the Iberian Peninsula (Al-Andalus), where, according to Constable (1994), lac competed with kermes on the local markets [122].

In the Romanesque period lac dye was considered so valuable that in 1267 AD Alfonso X of Castile reserved its exclusive use for the royal dye works in Murcia, along with indigo, kermes and redwood [123].

The circulation of lac across European markets during the Middle Ages is also documented in trade manuals, cartularies and customs records [124,125]. In his handbook *La Pratica della Mercatura* (1340), Francesco Balducci Pegolotti recorded the presence of raw lac for sale in Venice [126]. The author described two types of lac: ripe (*matura*) and unripe (*acerba*), of which the former was highly prized. These two types of lac could be distinguished by hardness (more of less brittle) and colour, of which the ripe one was dark-red like blackberries, while the unripe lac was light-red. Dust and wood debris had to be discarded and, if the lac was of good quality, a deep red colour would appear when mixed with a bit of saliva [126]. Four centuries after Pegolotti's account, James Kerr (1781) observed that "the best lac is of a deep red colour. If it be pale, and pierced at the top, the value diminishes, because the insects have left their cells." [39]. Both accounts reflect the fact that for centuries raw lac had been highly valued when fairly concentrated in colourants and hence, mainly sought-after for its dyeing properties. By the 14th century, Venice and Genoa were major trading centres for the circulation of raw lac in the Mediterranean [124]. Lac was purchased in Constantinople, Alexandria, Famagusta and Beirut along with other expensive commodities like saffron [30].

According to Harsch (2020), lac was then re-exported to Provence, Seville, Catalonia and Flanders as recorded by Genoese custom registers dated 1376–1377 [124]. Despite this flourishing trade networks, in 1466 the Genoese silk guild *Arte della Seta* imposed strict limitations on the circulation and use of lac dye. In the section titled "De laca nemo tingat" of the *Reformationes*, the guild prohibited the use of lac dye on silk and also the commerce of lac-dyed fabrics, with severe sanctions for the offenders, including heavy fines, the expulsion from the guild and the public destruction of the cloths [38].

It has been proposed that a possible reason to this prohibition might be due to the resin present in the raw lac, which, once in the warm dye bath, would melt and damage the delicate and expensive silks [2].

During the 15th and 16th centuries, international trades of commodities continued to flourish. European travellers such as

Garcia da Orta, Vasco da Gama, Duarte Barbosa and Andrea Corsali recorded that high-quality lac was primarily sourced from Myanmar, northen Malaysia and Thailand before being imported to the West [2,127].

The use of lac dye in Europe appears to have become more regular from the 18th century onwards [128]. In England, lac dye was employed for large-scale dyeing of broadcloth wool from the early 1700s. This practice is documented in several recipes preserved in the Crutchley Archive, a unique collection of dye books compiled by the Crutchley family of dyers who operated in Southwark, London [129].

In southern France, lac dye was also used in important production centres including Carcassonne, Cuxac and Montolieu. Unpublished documents held in the Archives départementales de l'Hérault in Montpellier show that lac dye was imported by sea from India, Myanmar, and Thailand, and used in combination with cochineal to dye scarlet wool [130]. However, from the mid-18th century, its use became limited due to regulations introduced to control the dye industry [128].

In 1741 the French master-dyer Antoine Janot was accused of violating the regulations that prohibited the use of lac dye at the manufactures of Saint-Chinian. The scarlet cloth, initially claimed to be dyed with lac dye, was seized and Janot was denied from continuing his career. Interestingly, recent molecular analyses conducted by Jing Han and Anita Quye revealed that Janot was not guilty, in fact, the investigation demonstrated that the confiscated cloth contained other dyestuffs, but notably lacked lac dye [130].

Between the late 18th and early 19th centuries, the value of lac dye increased under the influence of the East India Company (EIC), which sought a cheaper alternative to American cochineal for dyeing scarlet broadcloths [131]. Among the chemists and dyers consulted by the EIC were David Turnbull and Edward Bancroft, who contributed to developing a powdered form of lac dye, suitable for export to Britain and easily used by the Company's dyers [131,132]. In this form, lac dye entered Western markets and was adopted by European dyers [49].

The importance of lac dye gradually declined over the following centuries with the introduction of synthetic dyes in the textile industry. At the same time, the demand shifted towards shellac, which became a key material for producing gramophone discs, wood-finishing varnish and adhesives [70,133,134].

This reversal in value was noted in 1883 by Hugh McCann in his report on the dyeing industry in Bengal, one of the main lac-growing area ruled by the British goverment [135]. According to this account, the value of lac dye dropped sharply in less than a decade, with exports falling from 1120 to 250 tons, while shellac exports remained steady at around 5000 tons [135].

Nowadays, raw lac is still primarily harvested for shellac production [136,137]. Nevertheless, the practice of dyeing with lac dye continues in parts of India and Southeast Asia [16,19,136].

In recent decades, social enterprises, non-profit organisations and fashion designers have partnerted with artisans from rural areas to create high-quality textiles [138–141]. The use of natural materials, local weaving techniques and patterns is a common feature of these modern arts, which aim at keeping ancient traditions alive while creating livelihood opportunities.

5. Lac dye in technical written sources

5.1. Terminology

Ancient documentary sources provide a unique insight into the history and technology of lac-dyeing and lac lake pigment making [128]. However, their interpretation and meaning can be troublesome. Recipe books and treatises, for instance, often use the same term ubiquitously to refer to any animal- or plant-based dye source in a lake pigment form [142].

In the case of lac dye, tracing the linguistic origin and history of a colouring material that was used for centuries by different cultures is a challenging endeavour. Table 1 gives an overview of the rich vocabulary used in European written sources to address both the raw material and the dyestuff.

The English word *lac* seems to derive from the Sanskrit *lākṣhā*, which, according to different authors, is a later form of the Cambodian *le-ak* [107] or the Sanskrit *raksha*, from *raga* and *ranj*, meaning dye or "bright dye" [3]. In the Indian numbering system one *lakh* corresponds to one hundred thousand, a word which might have been chosen in early times to describe the dense colonies of lac insects providing valuable products [18]. In fact, in ancient Indian texts, namely the *Atharvaveda* (1500 BC) and *Ashtadhyayi* (4th c. BC), the term *lākṣhā* refers to the lac insect and its by-products, resin and dyestuff, both extracted for medicinal and dyeing purposes [2,158].

When the raw material became a commodity and found a way along the trade routes from Asia to the Middle East and ultimately Western Europe, the terminology changed according to certain linguistic and cultural influences, specifying the material that was sought for (dyestuff or resin). One early evidence of lac dye imported from India into the Mediterranean is the travel account *Periplus of the Erythraean Sea* (1st century AD) [112]. *Lakkos chromatinos* is listed here among other goods and identified by McCrindle (1879) as a cloth dyed with lac dye [112] or by Casson (2012) as the red dyestuff [159]. Similar records appear centuries later in various sources to address lac-dyed leathers and skins: *al-lakk* (like lac) in Abu Anifa Al-Dinawari's *Kitab al-Nabat* (9th c. AD, Persia) [2] and *in color de laccha* (with the colour of lac) in Rosetti's *Plitcho* (16th century, Venice) [37].

In medieval texts of Arabo-Islamic tradition, *lakk* (لك) is the term regularly present to identify the raw material. As such, it is present in several documents in the Cairo Geniza dating from the 11th and 13th centuries [120]. When *lakk* is used for the production of paints and inks, a specific vocabulary identifies the colours obtained from it, for instance ruby (ياقوتي) in *al-Muʿizz Ibn Bādīs's Umdat al-kuttāb wa-ʿuddat ḍawī al-albāb* ("The staff of the scribes and the implement of the wise men", 11th c.) [22,143] or fine scarlet (*nobre karmen*) in the 13th-century Judeo-Portuguese treatise *Libro de komo se fazen as kores* [23]. It is interesting to note that the word *laki* is still used nowadays in the Persian language (Farsi) to define a dark red colour typically associated to carpets' production.

While the vocabulary in the Muslim culture seems to remain constant across time, transformations are instead seen in the medieval Latin culture. It seems that in western European medieval sources the Latin *lacca* and vernacular terms *lacha, lache* or *laccha* became synonyms of the colour itself, i.e., red. In written sources for painting and illumination, the term *lacca* (and later the English *lake*) became synonym of the colours obtained with lac dye, but also any dye precipitated onto a substrate, leading to further confusion ever since [128,142].

On the other hand, a rich vocabulary related to the raw material began to circulate across merchant and trade documents. Raw lac, for instance, could be associated with specific centres of import. As reported by Harsch (2020), the Catalan manual (*Libre de conexenses,* 1385) mentions *laqua de Tripoll* (from Tripoli), *laqua de Laxandria* (from Alexandia), *laqua de Armínia* (from Armenia) and *laqua de Romania* (from the Byzantine Empire) [124].

Within the technical literature for pigment making, *lache crude* (unrefined lac), *gumma lace* and *gomma de lacca cruda* are the most recurring terms for sticklac [24,25]. The only known exceptions are the *Libro de komo se fazen as kores* and the early 15th-century

Table 1
List of lac dye terminology, including tentative date and area of origin/language of the written sources and indication of the typology of material production, i.e. dyestuff, lake pigment or commodity.

Historical s ource	Recipe number	Date (AD)	Probable area of produc-tion/Language	Type	Name for raw material	Name for colour	References
Periplus of the Erythraean Sea	Chapter 6	1st c.	Greek	Commodity	–	*Lakkos chromatinus*	[112]
***Kitab al Nabat*, Abu Anifa Al-Dinawari**	–	**9th**	**Arabo-Islamic**	**Dyestuff for leather**	**–**	***Al-lakka***	[2]
Mappae Clavicula	253	9th-12th	Miscellanea/Latin	Lake pigment	*Lacca*	*Lacca*	[20,21]
Umdat al-kuttāb wa-ʿuddat ḍawī al-albāb, al-Muʿizz Ibn Bādīs	–	1025 c.	Tunisia/Arabo-Islamic	Free-lac paint/Ink	*Lakk*	*Yaghoti* (ruby)	[22,143]
Cairo Genizah	–	early 11th-12th	Egypt	Commodity	*Lakk*	–	[120]
Giovanni Scriba's notarial notebook	-	1156	Italy, Genoa	Commodity	*Lacca*	–	[124]
Document issued by Alfonso X	-	1267	Portugal	Commodity	*Lacca*	–	[123]
Tuḥaf al-ḥawāṣṣ fī ṭuraf al-ḥawāṣṣ, Abū Bakr Muḥammad Al-Qalalūsī	Q IV.11	13th c.	Al-Andalus/Arabo-Islamic	Lake pigment/Ink	*Lakk* لك	–	[144]
Kitāb al-azhār fī ʿamal al-aḥbār, Muḥammad Ibn Maymūn al-Marrākušī al-Ḥimyarī	MḤ III.2.c	mid-13th c.	Baghdad/ Arabo-Islamic	Lake pigment/Ink		Red/ruby	[145]
	MḤ III.3						
	MḤ VI.4.d						
Al-muḥtaraʿ fī funūn min *al-ṣunaʿ*, *al*-Malik al-Muẓaffar Yūsuf al-Ġassānī	MM III.16	late-13th c.	Yemen/Arabo-Islamic	Lake pigment/Ink		–	
	MM III.17						
O Libro de Komo Se Fazen As Kores	Chapter 13	13th c.	Iberian Peninsula	Free-lac paint	*Laka*	*Nobre karmen*	[23]
La pratica della mercatura, Francesco Balducci Pegolotti	-	1340	Italy, Florence	Commodity	*Lacca acerba, lacca matura*	-	[126]
Libre de conexenses	-	1385	Spain	Commodity	*Laqua*	-	[124]
Francesco di Marco Datini's Archives	-	1394	Italy	Commodity	*Laccha*	–	[125]
		1401			*Laccha acerba, laccha matura*		
Trattato dell'Arte della Lana	**–**	**1418–1421**	**Italy, Florence**	**Dyestuff for leather**	***Ghoma di lacha***	***Lacha***	[124]
De diversis coloribus, Ms. Jehan le Begue	309	14th	Italy - France/ French and Latin Northern Europe	Lake pigment	*Laque*	*Laque*	[24]
Experimenta de coloribus, Ms. Jehan le Begue	36	1431			*Lache crude*	*Lacham*	
	37			Lake pigment	*Gumam lache*	*Lacham*	
Liber diversarum arcium, Ms. Montpellier	Chapter 9	14th-15th		Lake pigment	*Lacha cruda or lacha or gummi*	*Lache*	[25]
Ms. Strasbourg	31	early 15th	Germany	Lake pigment	*Lagga*	*Paris rot*	[26]
Ms. Bolognese	129	15th	Italy	Lake pigment	*Gomma de lacca cruda*	*Lacha*	[24]
	130				*Gummam lacce*	*Laccha*	
	131				*Gumma lacce*	*Laccha*	
	B.137				*Laccha cruda*	*Lacha*	
	B.140				*Gomma laquale*	*Lacha*	
Genoese regulations	-	1466	Italy, Genoa	Commodity/Dyestuff for silk	*Laca, lacha*	–	[38]
William Watkyn's stock of painting materials	–	1544–45	London	Commodity	Gomlak	–	[146]
***Plitcho*, Gioanventura Rosetti**	**-**	**1548**	**Italy, Venice**	**Dyestuff for silk**	***Gita de laccha***	***Laccha***	[37]
				Dyestuff for leather	***Gomma de laccha***	***Laccha***	

(*continued on next page*)

Table 1 (*continued*)

Historical s ource	Recipe number	Date (AD)	Probable area of production/Language	Type	Name for raw material	Name for colour	References
Coloquios dos simples, e Drogas, Garcia de Orta	–	1563	Portugal/India	Commodity	*Lacre; lacre em canudo* (processed maybe shellac)	–	[127]
Ricette per far ogni sorte di colori, Ms. Paduan	90 113	16th-17th c.	Italy	Free-lac paint	*Gomma lacca* *Lacca*	– *Lacca*	[24]
De Secreti Universali di Don Timoteo Rosselli	**–**	**1644**	**Italy, Venice**	**Dyestuff for silk**	***Gomma de laccha***	**–**	[147]
Liegnitz *Taxa*	–	1662	Germany	Commodity	*Gummi laccae crudae* (sticklac) *Gummi laccae ablutae* (shellac)	–	[148]
Crutchley Archive	**Book 7, various**	**1726–28**	**London/Dutch-Flemish**	**Dyestuff for wool**	***Stock lack*** ***Lack*** ***Best Lack*** ***Slegt Lack*** ***Lack*** ***Lack***	**–** ***Scarlatt*** ***Scarlatt*** ***Wine*** ***Scarlatt*** **–**	[129]
	Book 15, n. 27–37	**Undated**	**London/English**		***Stick lack***	***Scarlatt***	
***L'art de la teinture des laines*, Jean Hellot**	**Chapter 15**	**1750**	**France**	**Dyestuff for wool**	***Gomme-Lacque***	***Ecarlatte de Gomme-Lacque***	[149]
***Arte de teñir las lanas, sedas, hilo, y algodon*, Miguel Jerónimo Suárez y Núñez**	**Chapter 14**	**1779**	**Spain**	**Dyestuff for wool**	***Goma-laca***	***Escarlata de goma laca***	[150]
Dictionnaire raisonné des sciences, des arts et des métiers (Encyclopédie)	**Vol. 16**	**1765**	**France**	**Dyestuff for wool**	***Gomme laque***	***Ecarlates de gomme laque***	[151]
***Philosophy of Permanent Colours*, Edward Bancroft**	**Chapter 5**	**1814**	**London**	**Dyestuff for wool and silk**	***Stick lac***	***Lac lake*** ***Lac-dye (superior quality)***	[132]
***A practical treatise on dyeing of wollen, cotton, and skein silk*, William Partridge**	**p.88–90**	**1823**	**New York, US**	**Dyestuff for wool and silk**	***Stick lac***	***Lac lake***	[152]
***Arte da tinturaria geral da lã, seda, algodão, e linho*, João Baptista Lúcio**	**f.111**	**1830/1831**	**Portugal**	**Dyestuff for wool**	***Laca; goma-laca*** ***Laca em paus; laca em grão; laca em pastas delgadas***	***Escarlate de Goma Laca***	[153]
***Manuel complet du teinturier*, Amand Denis Vergnaud**	**Chapter 5**	**1832–36**	**France**	**Dyestuff for wool**	***Laque en bâtons*** ***Laque en grain*** ***Laque en écaille***	***Lac lake*** ***Lac dye***	[154]
***Art de la teinture des laines en toison*, Michel Denis Gonfreville**	**Chapter 3**	**1848**	**France**	**Dyestuff for wool**	***Gomme laque/ Résine-laque*** ***Laques en bâtons (stich-lac)***	***Lac-lake*** ***Lac-dye***	[155]
***La Teinture au dix-neuvième siècle*, Théophile Grison**	**Part 4**	**1884**	**France**	**Dyestuff for wool**	***Laque en bâtons***	***Lac-lake*** ***Lac-dye***	[156]
***A Manual of dyeing*, Edmund Knecht, Christopher Rawson and Richard Loewenthal**	**Part 6**	**1893**	**England**	**Dyestuff for wool**	***Stick-lac***	***Lac-dye***	[157]

Written trade sources are highlighted in grey. Dyeing treatises with recipes mentioning lac dye are indicated in bold. Written sources with recipes for lac dye lake pigments are indicated with no highlight. The titles of the written sources are indicated in italic.

Strasbourg manuscript [26], where *nobre karmen* (fine scarlet) and *paris rot* (red) were the desired hues when using *laka* and *lagga*, similarly to what is described in texts of Islamic tradition. In the 15th and 16th centuries, *ghoma de lacha* and *gomma de laccha* are present in recipes for dyeing leather [124] and silk [147], whereas *gomlak* appears in a list of painting materials owned by the British grocer William Watkyns dated 1544–45 [146]. A few years later, the Portuguese physician Garcia da Orta printed in Goa the *Coloquios dos simples, e drogas he cousas mediçinais da India* (1563), which included a first-hand report on the Indian lac insects [127]. Da Orta referred to the material produced by the insects as *lacre*, which could be sold on the markets in form of straws (*canudos*) or sticks (*paos*). The editor, Conde de Ficalho, who provided a critical edition of Garcia da Orta's text in 1895, compared this information with another contemporary source, the *Lyvro dos pesos* (the book of weights). He mentioned that the lac in *paos* was also named *shell lac*, which was obtained by boiling the *lacre* and filtering it through a cloth. The lac in *canudos, lacca bruta* or crude lac consisted of the resinous material containing the female insects. We believe that the editor confused *lacca bruta* and *shell lac*, giving an erroneous description of the two. This indicates that, even in more recent times, there is still confusion about the raw material and its products after processing. Between the end of the 16th century and the beginning of the 17th century, shellac became progressively present in Europe, where it was used as sealing wax and later on as a furniture varnish [70,160]. In the price list (*Taxa*) of artist's materials released in Liegnitz in 1662, two terms are mentioned: *gummi laccae crudae* (sticklac) and *gummi laccae ablutae* (shellac) [148].

In Northern Europe, *lack* is the Flemish word used in several recipes present in the Crutchley Archive [129]. Some of the oldest recipes, dated between 1726 and 1728, refer to *best* (good) *lack* and *slegt* (bad) *lack* to produce scarlet and wine colours on wool. *Sticklac* is instead the preferred term used in non-dated recipes within one of the Crutchley's dye books. In 1750, Jean Hellot referred to *gomme-lacque* as a raw material to obtain *ecarlatte de gomme-laque* or scarlet cloth [149]. Similarly, in the *Dictionnaire raisonné des sciences, des arts et des métiers* (*Encyclopédie*) (1751–72), raw lac is named *gomme lacque* or *gomme resine*, which is used to obtain *ecarlatte* [151]. By the end of the 18th century, with the East India Company consulting experts in dyestuffs for the manufacture of a ready-to-use lac powder, the words

lac-lake and *lac-dye* became of common use across Europe and beyond [131,132,152]. In the 19th century, a commercial-oriented terminology spread across the technical manuals on dyeing, providing descriptions of the lac insects and the various forms of raw lac sold on the market: *laque em bâton* (sticklac), *laque en grain* (seedlac), *lac laque en écaille* (shellac) and *lac-lake* or *lac-dye* [154,156].

With the advent of shellac and its widespread uses in Europe, raw lac became more commonly known for its resin rather that its red dyestuff, and resin-related terminology spread ever since.

The term *lacquerware,* for instance, started being used from the 17th century to describe "lacquered" objects, i.e. objects with a glossy surface. In Europe, *lacquer* referred to shellac resin as a coating material, and also to various oils and resin used on furnitures to imitate Oriental artefacts [161,162]. The latter became known as Asian lacquer, creating further confusion on the nature of these tradiational objects, typically obtained from the sap of various trees belonging to the family Anacardiaceae [163].

5.2. Lac dye in medieval to early modern times (until end 1700)

Evidence of the use of sticklac as the direct source to extract lac dye can be found in the technical literature from the medieval period onwards.

According to Castro et al. (2016), there are up to fourteen recipes for the production of lac-based paints across seven European sources from the 9th to the 17th centuries [164]. Arabo-Islamic treatises also describe the use of sticklac for making red inks and paints, including the 11th century *Ibn Bādīs* [22,143] and three manuscripts from the 13th century recently translated in Spanish and Italian [144,145]. Spanning eight hundred years, the twenty recipes identified so far demonstrate that lac dye has been a renowned colouring material to produce painted artefacts since at least the Middle Ages.

On the other hand, the presence of lac dye in the Western European textile dyeing literature is far more limited and recent, in fact the earliest existing recipe giving instructions for dyeing with lac dye belongs to the *Plitcho* written by Rosetti in 1548 [37] (Fig. 7).

One possible reason for the absence of lac dye in the medieval technical literature has been attributed to the difficulty of using raw lac in the dyeing process [2]. As it has been corroborated by contemporaneous experiments, the lac resin is easily transferred into solution at various pH and temperature above 60 °C [128,164,165], making a complete separation of the resin from lac dye hard to achieve, even with modern methods [41]. In such conditions, the fibres or fabric added to the warm bath to be dyed would suffer from the presence of the sticky resin. In his recipe, Rosetti seems to overcome this problem by putting the silk into a bag before immersing it into the red-coloured dye bath containing powdered sticklac [37]. Lac dye appears more systematically in technical sources from the 18th century onwards. The comprehensive study of the Crutchley Archive done by Anita Quye, Dominique Cardon and Jenny Balfour-Paul has highlighted the presence of lac dye in several recipes from the 1720s, of which the oldest ones are written in Flemish [129]. According to the authors, this fact proves the knowledge transfer between the world-renowned dyers from the Netherlands and the English ones considered less skilled in comparison. In the Crutchley books, lac dye is extracted directly from sticklac and used on wool broadcloth mostly for scarlet, crimson and wine colours. To obtain this range of hues, the expert dyers mixed lac dye with other dyestuffs (cochineal, madder and turmeric) and employed tin, alum and tartar mordants [166].

In 1750 the French chemist Jean Hellot published a description of lac dye in his technical manual *L'art de la teinture des laines et des étoffes* […] and provided various methods to dye with it in place of, or in combination with, cochineal [149]. Hellot's instructions are quite elaborate and involve leaching of the raw lac, precipitation, filtering and evaporation until a dyeing powder is obtained and then mixed with tin mordant. According to Hellot, lac dye provided a better fastness on wool. However, working with raw lac was troublesome and only skilled dyers would know how to improve the extraction and dyeing process. In fact, Hellot was not trained as a dyer nor had he practical knowledge on lac-dyeing [2]. Nevertheless, his manual became a reference for later technical and scientific works, including *Arte de teñir las lanas, sedas, hilo, y algodon* by Jerónimo Suárez y Nunes (1779, Spain) [150], *Essai sur l'art de la teinture* (1803, France) by Scheffer [167] and *Arte da tinturaria geral da lã, seda, algodão seda, algodão, e linho* by João Baptista Lúcio (1831, Portugal) [153].

5.3. Lac dye in modern and contemporary sources

From the end of the 18th century, handbooks and printed manuals on the practice of dyeing became highly informative, providing the readers with clear recipes, scientific information on the raw materials, evaluations on the quality of the dyestuffs in terms of light and wash-fastness and also descriptions of the chemical nature of the dyes used [131].

An example of such expertise and detailed knowledge is the manual written by Michel Denis Gonfreville *Art de la teinture des*

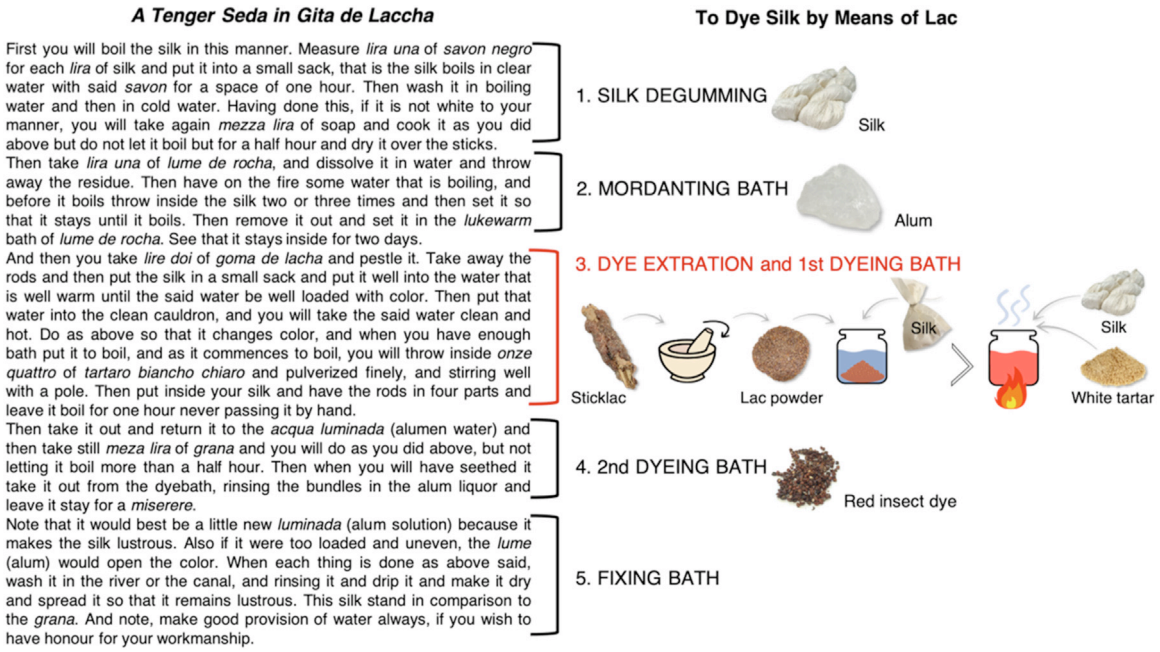

Fig. 7. Scheme of the mordanting and dyeing baths to dye silk with lac dye as described by Gioanventura Rosetti in *Plitcho*. The English translation of the recipe, published by Sidney Eldestein and Hector Borghetty, is reported here. The original terms for dyestuffs, mordants and weight are indicated in italic.

laines en toison, en fil et en tissus, traité complet du manufacturier, published in two editions in 1848 and 1871 [155]. Gonfreville owned a family dyeing business in Déville, France, and in 1827 joined a government mission to India to document the dyeing traditions from the Southeast Indian Tamil Nadu. The sections dedicated to lac dye are highly descriptive and informative of the lac insect morphology; types of by-products obtained from the raw material and sold on the market (*stich-lac, seed-lac, shell-lac*); quality of the colouring substance depending on the age of the lac insects and host plants; and trades of "very good" sticklac from Mysore (Karnataka, India) and modern Myanmar. Along with two recipes for making crimson and scarlet colours with sticklac, alum, tartar and tin mordant, Gonfreville described also the use of a powdered lac dye made by extracting the dyestuff from sticklac with warm water or a weak soda solution and then by precipitating it with alum. The powder was then moulded into cakes like indigo and sent to Europe for silk and wool dyeing.

While the dyeing process based on the Indian tradition is rather simple, the one developed by Gonfreville is more complex and dangerous. By mixing arsenic, chromium and mercury, the recipe well reflects the 19th-century practice of using newly developed products along with natural dyes to produce deep hues and durable colours. Another example is found in Théophile Grison's book *La Teinture au dix-neuvième siècle*, written in 1884 [156]. In two cases, the author gave instructions for making *ponceau* (poppy red) using a lac dye paste (previously made with a process similar to the one described by Gonfreville) with red tartar, a tin mordant and orange IV (acid orange 5, C.I. 13,080), an azo dye synthetised in 1878 [168]. In fact, the invention of synthetic dyes in the second half of the 19th century marks a pivotal moment in the world of dyes. In a few decades, hundreds of new formulations were synthesised, patented and commercialised with the main aim to be used as alternatives to natural dyes and replicate their hues. Nevertheless, natural dyes, and lac dye in particular, were kept being used as proved by late-19th century dyeing manuals [157] as well as analytical results obtained on 19th- and 20th-century textiles [5,17,169]. Certain synthetic dyes were specifically developed to replace specific natural dyes. For scarlet reds, also referred to as xylidine scarlets, are azo dyes that started being synthesised in 1878 by M.L.B. (Meister, Lucius & Brüning) with the specific intention to imitate the brightness of cochineal red [170]. Although lac dye is not specifically mentioned, cochineal and lac dye were often associated in these years, as mentioned in several recipes advising to mix the two colourants to obtain scarlet, orange and crimson shades [157]. While a general assumption exists that synthetic dyes quickly took over natural dyes at a global scale, ongoing research has shown that the process was gradual and different depending on the geographical areas [17,171–173]. This is particularly true for lac dye, which had centuries of traditional use and still has a symbolic resonance in various parts of Asia. In the Kutch region of north-west India, dark purple wool skirts (*pernus*) and veils (*lodkis*) dyed with lac dye are worn by Rabari women (nomadic Hindu herdsmen) for religious reasons [69]. Similarly, sticklac (*Khang*) is used across Lao-Tai groups to obtain deep crimson or purple silk shawls, traditionally worn by shamans during healing ceremonies [19]. Intense reds are instead the hues favoured in Bhutan according to Jenny Balfour-Paul (2005). There, lac-dyed wool and silk garments had social significance and were worn by village headmen as a symbol of heroism and by Buddhist monks [18]. As recently described by Borah et al. (2019) in Assam, *Karbi* communities still prepare traditional dresses (*Choy-Aan, Rekong-ke-Er, Dokherso pi-sharpi, Poho* and *Wankok*) and bags (*Jambili*) with lac dye [136]. In northern Vietnam, the Nung An artisans from Cao Bang province have preserved the tradition of using lac insects to dye hand-woven cotton. Fig. 8 illustrates some of the steps involved in the lac dyeing process.

6. Analytical characterisation of lac dye in historical textiles

The case studies in which lac dye has been detected are summarised in Table 2.

Lac dye is among the dyestuffs identified by Rudolph Pfister in the 1930s–1940s in his pioneering studies on textiles fragments from Palmyra (1st–2nd c. AD) [174]. This early finding, mainly based on observations of extraction behaviour and chemical reactions, was confirmed later by Böhmer and Karadag (2000)

Fig. 8. Lac dyeing tradition in Cao Bang province, northern Vietnam. Several steps are involved in the lac dyeing process: first, raw lac is soaked in water for several hours (left); second, the resulting paste is filtered through a cloth (centre); finally, Mrs. Kim, a Nung An artisan, dyes hand-woven cotton in her home (right). © Photos by KILOMET109.

through thin-layer chromatography (TLC) combined with UV–vis spectroscopy [175]. This combined method was widely used in the 1990s and early 2000s and enabled the detection of lac dye in archaeological and historical textiles [176–181]. For instance, Gayo García and Artega (2005) identified lac dye in Hispano-Islamic textiles from Al-Andalus dated to the 11th and 12th century [179]. Similarly, Parra and Serrano (1990) detected lac dye on red and orange silk threads from parchment documents with wax seals produced in Spain between the 13th and 15th century [176]. Interestingly, one of these documents with its seal and attached threads is dated 1229 and belonged to Alfonso IX, King of León. Although there is no evidence of the production place of these textiles, it seems that lac dye, a notoriously expensive and prestigious dyestuff, circulated in the royal court almost forty years before King Alfonso X restricted the use of lac dye exclusively to the royal dyeworks [123]. These findings are particularly significant considering that the examples of European textiles from the Middle Ages dyed with lac dye are scarce.

HPLC coupled with (photo)-diode array detectors (DAD/PDA) has been the most commonly used technique for the identification of lac dye components in historical textiles since the end of the 80s. Jan Wouters and Andre Verhecken (1989) optimised the capabilities of this technique for the detection of red dyestuffs of insect origin, identifying for the first time laccaic acids A, B and flavokermesic acid on a variety of textile fragments [182–184]. Notably, lac dye mixed with madder was found on a Merovingian textile from the 7th-8th century, which is, to the best of the authors knowledge, the earliest example of historical textile from Western Europe in which lac dye has been found so far [182].

When available, HPLC-DAD coupled with MS has proven to be the most reliable method to unequivocally detect the molecular profile of lac dye, and to disclose complex mixtures [8,13–15,41,43,173,185–192]. Over the past decade, advances in tandem and high-resolution mass spectrometry have further enabled the identification of xantholaccaic acids in various textiles, and provided insights into the structure of laccaic acids by studying their fragmentation pathways [47,97,169,171,193–197].

Along with lac dye components, erythrolaccin, one of the colour-giving molecules associated to shellac resin has been first detected on several Asian [5,169,198] and Southeast European textiles [186,196,199]. As demonstrated by Berbers et al. (2019), shellac easily dissolves under various conditions during the dyestuff extraction from raw lac [165], and erythrolaccin is therefore transferred into the dyed textile. In one case [10], shellac markers were used to pinpoint the presence of lac dye in Chinese silks from Dunhuang when laccaic acids had degraded.

Besides the most used DAD/PDA and MS detectors, Surface-enhanced Raman spectroscopy (SERS) has been occasionally used for the identification of lac dye in historical textiles [6,7,200,201]. Brosseau et al. (2009) applied for the first time TLC-SERS to the dye analysis of a 16th-century Turkish carpet, revealing the presence of lac dye and cochineal in red and pink fibers [200]. Fourier-transform surface-enhanced Raman spectroscopy (FT-SERS) has been used by Zaffino and co-workers [6] to detect the presence of lac dye in a chair cover from China (18th century). This finding was later confirmed by HPLC-SERS [7]. Gulmini et al. (2017) used chromatographic (HPLC-DAD-MS) and spectroscopic techniques (fibre optics reflectance spectroscopy and fluorimetry) to identify lac dye in Coptic textiles from the late Roman and Byzantine periods (5th-7th century) [119]. According to the authors, this finding demonstrates that lac dye and lac dyed textiles circulated in the Mediterranean basin before the Islamic conquests in Egypt in the 7th century, as it had been suggested in previous studies [117,118]. More recently, Abataleb and co-workers (2022) identified lac dye by HPLC-DAD and Fourier-Transform infrared spectroscopy (FTIR) in a 6th-century Coptic textile from the Nubia Museum of Aswan (Egypt), which seems to support the Gulmini's hypothesis [202].

The earliest textiles to have been proposed as dyed with lac dye are from the burial site of Mebrak in Western Nepal dated from ca. 400 BC to 50 AD [48]. Since this early example, lac dye appears to have been mixed with other dyestuffs, mainly anthraquinones (madder and cochineal) and indigoids. In Asia, the use of lac dye mixed with madder spans centuries with findings in archaeological and historical textiles from Mongolia (1st c.) [4], China (2nd-4th c.) [14], Nepal (5th-7th c.) [198], Central Asia (7th-9th c. and 17th-20th c.) [5,172,203,204] and India (15th-18th c.) [11,182]. Among the plants of the family Rubiaceae from Asia, chay root (*Oldenlandia umbellata* L.) [2] was detected once by Verhecken (2006) on polychrome silks from the 7th-9th-century [203]. Another rubiaceous plant species, *Rubia cordifolia* L., also known as munjeet or Indian madder [2] was first found in Indian silks [11] and later in archaeological textiles from Nepal [198]. Turmeric, a yellow plant colourant deriving from *Curcuma longa* L. (Zingiberaceae) [2], has been detected along with lac dye in Nepalese [198] and Eastern European textiles [194]. Interestingly, the ancient practice of adjoining red and yellow dyestuffs is still present today in Assam and Orissa, where skilled dyers combine lac dye and munjeet on cotton and lac dye and turmeric on silk, respectively [16].

In the Mediterranean area, early examples of mixtures of lac dye, madder and indigo can be found in several textiles from the 5th century onwards [119,197,202,205,206–208]. Lac dye alone or combined with madder have been commonly identified in liturgical embroideries from Romanian provinces (15th-18th c.) [185,196,209,210] and in post-Byzantine garments from the Holy Mount Athos, Greece [211,212]. After the 16th century, madder use seems to decline, while cochineal becomes more frequent, as evidenced in Persian carpets (16th-19th c.) [12,213], Turkmen weav-

ings (17th-20th c.) [5], Chinese silks (18th-19th c.) [13,190,214] and European textiles (18th-19th c.) [49,50]. However, early evidence of mixing insect red dyes dates back to an early date. Korpova et al. (2016) detected lac dye and cochineal on red-purple leggings from the 1st century from Mongolia [4]. The same mixture was detected by Liu at al. (2021) on silk textiles from Xinjang, China (2nd-3rd c.) [50] and Central Asia (7th-10th) [204]. According to the authors, the presence of cochineal, a colouring material non-typical of Asia, exemplifies the long-distance connection between indigenous cultures from China and Northern India, Central Asia and the West. In the Mediterranean area, mixtures of lac dye with Armenian cochineal [115] or with both Arme-

Table 2
Lac dye identification in case studies where the analytical techniques used are described. Other publications report the presence of lac dye but do not specify the methods employed for its identification. The case studies are listed in chronological order, from the earliest to the most recent. The table includes information on the object, date, provenance, technique(s) applied for identification, the colour-giving molecules detected alongside lac dye and literature references.

Object	Date	Provenance	Technique	Detected colour-giving molecules										REF
				laA	laB	laC	laE	laF	fka	Ery	+	n.i.	Other dyes	
Textiles fragments from burial site	400 BC – 50 AD	Nepal	HPLC, UV-VIS spectroscopy									X		2003 [48]
Leggings and tapestries (wool)	1st c. AD	Mongolia	HPLC-DAD									X		2016 [4]
Palmyra Textiles	1st-2nd c. AD	Palmyra	Chemical tests									X		1930s-1940s [174]
Palmyra Textiles	1st-2nd c. AD	Palmyra	TLC, UV-VIS spectroscopy									X		2000 [175]
Niya textiles (silk)	2nd-3rd c. AD	Xinjiang, China	HPLC-DAD-MS	X	X	X	X							2021 [14]
Coptic textiles	Early 5th-7th c. AD	Egypt	HPLC-DAD-MS, FORS, fluorimetry (FL)	X	X				X					2017 [119]
Samdzong textiles	5th-7th c. AD	Nepal	HPLC-DAD	X			X			X				2016 [196]
Coptic textile fragment (wool)	6th c. AD	Egypt	HPLC-DAD, FTIR spectroscopy									X		2022 [200]
Fabrics	7th c. AD	Egypt	HPLC-DAD	X							X			2019 [104]
Merovingian textiles	7th-8th c. AD	Unknown	HPLC-DAD	X							X			1989a [182]
Neckbands fragments (wool)	7th-8th c. AD	Egypt	HPLC-PDA	X	X	X	X		X					2002 [203]
Coptic textile fragments	7th-8th c. AD	Egypt	HPLC-DAD-MS	X	X	X	X	X	X	X	X			2025 [97]
Polychrome *samites* (silks)	7th-9th c. AD	Central Asia	HPLC-PDA	X					X					2006 [201]
Sogdian polychrome silk	7th-10th c. AD	Central Asia	HPLC-PDA-MS	X	X									2015 [202]
Textiles (silk)	7th-10th c. AD	Dunhuang, China	HPLC-DAD-MS	X	X	X	X		X		X			2019 [10]
Carpet fragments	8th-11th c. AD	Fustat area, Egypt	HPLC-PDA	X							X			2011 [210]
Tapestry ornament	9th-10th AD	Egypt	HPLC-DAD									X		1995 [183]
Liturgical textiles	11th-12th c. AD	Al-Andalus	TLC, colour @irr=350 nm									X		2005 [179]
Tellem textiles	11th-12th c. AD	Dogon area, Mali	HPLC-DAD	X	X				X					2003 [211]
Belt from pre-Columbian mummy	11th-13th c. AD	Ancòn, Peru	HPLC-DAD	X							X			2009 [212]
Archaeological textiles (silk)	13th. c. AD	Nubia, Sudan	HPLC-MS	X	X				X					2021 [189]
Seal thread	End 13th c. AD	Spain	TLC									X		1990 [176]
Mamluk textiles (wool)	13th-14th c. AD	Egypt	HPLC-DAD	X					X					2009 [204]
Archaeological textiles (wool)	14th c. AD	Nubia, Sudan	HPLC-MS	X	X				X					2021 [189]
Silk fabrics	14th-16th c. AD	Iran (suggested)	HPLC-DAD-MS	X										2017 [207]
Florentine borders	14th-16th c. AD	Italy	HPLC-DAD	X	X									1995 [184]
Grave garment	15th c. AC	Italy	HPLC-DAD	X	X									2004 [209]
Seal thread	15th c. AD	Spain	TLC									X		1990 [176]
Lampas fabrics	15th c. AD	Ottoman territories	HPLC-MS	X	X				X					2025 [43]
Seal cords from royal documents (silk)	15th. AD	Poland and Lithuania	HPLC-DAD-MS	X	X	X			X	X	X			2025 [194]
Liturgical brocade velvet	Mid 15th c. AD	Romania	HPLC-DAD-MS	X	X				X	X				2020 [197]
Ecclesiastical garment	15th-16th c. (?) AD	Mount Athos, Greece	HPLC-DAD	X							X			2008 [206]
Threads from documents	15th - 16th c. AD	Romania	LC-DAD-MS	X					X					2017 [185]
Liturgical embroideries (silk)	15th - 16th c. AD	Romania	HPLC-DAD	X			X		X	X				2012, 2017 [15,186,187]
Chasuble	15th - 16th c. AD	Italy	HPLC-DAD-MS	X	X	X			X		X			2014 [191]
Indian silks (*Samits* and *lampas*)	15th - 17th c. AD	India	HPLC-DAD									X		1998 [11]
Liturgical vestments	15th - 17th c. AD	Europe	HPLC-DAD-MS	X	X	X	X		X	X	X			2020 [195]
Historical carpet	16th c. AD	Cairo	HPLC-DAD-MS	X	X	X	X				X			2018 [47]

(*continued on next page*)

Table 2 (*continued*)

Ottoman brocades (silk)	16th c. AD	Ottoman territories	TLC, UV-VIS spectroscopy							X		1995, 1997 [180,181]
Chair cover (wool)	c. 1700 AD	China	FT-SERS							X		2014 [6]
Chair cover (wool)	c. 1700 AD	China	HPLC-SERS, , visible reflectance spectroscopy	X	X				X		🔵	2017 [7]
"Salting" carpets	16th-17th c. AD	Persia (suggested)	HPLC-DAD-MS	X	X	X	X					2015 [41]
Textiles from the Moscow Kremlin Collection	16th-17th c. AD	Persia and Turkey	TLC, spectrophotometry, spectrofluorimetry							X		1990 [177]
Historical carpets	Late 16th-17th c. AD	Turkey (Istanbul or Bursa)	TLC-SERS							X		2009 [198]
Ottoman carpet	Late 16th-17th c. AD	Ottoman territories	SERS							X		2010 [199]
Historical carpets	16th-17th c. AD	India and Iran	TLC, UV-VIS spectroscopy							X		1997 [178]
Indo-Persian carpets (wool)	16th-17th c. AD	Iran	HPLC-DAD-MS	X	X	X						2007 [8]
Mughal velvets	16th-18th c. AD	India	HPLC-PDA	X								2015 [12]
Safavid velvets	16th-18th c. AD	Persia	HPLC-PDA	X							🔴	2015 [12]
Ottoman textiles	16th-18th c. AD	Ottoman territories	HPLC-DAD							X		2015 [214]
Post-Byzantine textiles	16th-early 20th c. AD	Mount Athos, Greek	HPLC-DAD							X		2015 [214]
Vestments	17th. c. AD	Near East, Turkey	HPLC-DAD-MS	X	X	X		X		X		2020 [195]
Indian floral rugs	17th c. AD	India	HPLC-DAD	X	X			X			🔴	1989a [182]
Lining four-poster bed	End 17th c. AD	England	HPLC-DAD	X	X							2004 [209]
Textile fragment	17th-18th c. AD	Neamt Monastery, Northen Romania	HPLC-DAD, ATR-FTIR spectroscopy	X	X							2020 [215]
Funeral ropes	17th-18th c. AD	Crakow, Poland	HPLC-DAD-MS							X	🟡	2021 [192]
Turkmen carpets (wool)	17th- early 20th c. AD	Central Asia	HPLC-PDA	X			X	X	X		🔴🟣🟤⬜	2016 [5]
Brocade (silk)	Mid 18th c. AD	China (suggested)	HPLC-PDA	X						X	🟣	2017 [208]
Birthday hanging (silk)	18th c. AD	China	HPLC-DAD-MS	X	X						🟣	2014 [13]
Textile fragment, (wool)	18th c. AD	Old Dongola, Sudan	HPLC-MS	X	X			X			🟡	2023 [188]
Carpet fragments	Up to 18th c. AD	Fustat area (Egypt)	HPLC-PDA	X						X	🔵	2011 [210]
Scottish tartans	18th-19th c. AD	Scotland	HPLC-PDA							X	🟣🟡	2000 [49]
Brocade	Mid 18th c. AD	France	HPLC-MS							X	🟣	2022 [50]
Persian carpet	Mid 19th c. AD	Persia	HPLC-MS	X	X							2022 [50]
Folding fan	19th c. AD	China	HPLC-DAD-MS	X	X						🟣🔵⚪	2025 [190]
Karen textiles (silk, wool and cotton)	19th c. AD	Myanmar	HPLC-DAD-MS	X	X	X	X	X		X	🟣🟡⬜	2023 [17] [216]
Textiles (silk)	19th-20th c. AD	Indonesia	HPLC-DAD-MS	X	X	X	X	X		X	🟤	2024 [173]
Hip cloth	19th c. AD	Aceh, Indonesia	HPLC-DAD-MS	X	X	X		X	X		🟤⬜	2025 [169]
Ikats textiles	Second half 19th c. AD	Central Asia	HPLC-DAD-MS	X	X	X	X				🟣🔴🟡⬜	2020 [172]
Textiles (wool and cotton)	19th- early 20th c. AD	Jordan	HPLC-PAD							X	🔴🔵🟣	2011 [217]
Chin and Karen textiles	Early 20th c. AD	Myanmar	HPLC-DAD-MS	X	X	X	X				⬜	2014 [171]
Casula from Maaseik, Zandaniji tissue (Belgium)	Unknown	Unknown	HPLC-DAD	X	X			X				1989a [182]
Coptic textiles (silk)	Unknown	Egypt (suggested)	HPLC-DAD	X	X						🔴🟣🟤	2003 [114]
Coptic textiles (silk)	Unknown	Northern Egypt	HPLC-DAD	X	X						🟣	2004 [115]

The following abbreviations were used: laA – laccaic acid A; laB – laccaic acid B; laC – laccaic acid C; laE – laccaic acid E; laF – laccaic acid F; fka – flavokermesic acid; Ery – erythrolaccin; + – other lac dye/shellac molecules; n.i. – no information; 🔵 – an indigoid dye was added; 🔴 – a plant-based anthraquinone dye was added; 🟣 – an animal-based anthraquinone dye was added; 🟡 – a flavonoid dye was added; 🟤 – a tannin was added; 🟣 – gromwell was added; ⚪ – orchil was added; 🟡 – curcumin was added; ⬜ – a synthetic dye was added.

nian cochineal and madder [114] have been detected in Coptic textiles from Egypt and Italian garments from the 14th-15th centuries [193,215].

Other dyestuffs used alongside lac dye include flavonoids (young fustic, weld and larkspur) [5,17,172,176,188,189], tannins [5,114,169,173,203], gromwell [10], orchil [169,190], and synthetic dyes [5,17,169,171,172,216]. Whether these mixtures aimed to achieve a specific colour, reduce the costs of dyeing or improve lightfastness and other properties is difficult to ascertain. Nevertheless, the use of lac dye in combination with colourants of Eastern and Western origins point towards a thriving exchange of raw materials and practical knowledge over an extensive territory resulting in the production of diversified textile heritage.

7. Conclusions

This review summarises the available literature on lac dye, encompassing the existing variety of *Kerria* lac insects, the importance of lac dye in history, its use as a colouring material, and methods for its identification in textiles.

Obtained from the *Kerria* adult female insect, this dyestuff has travelled across continents, being used by numerous civilisations as a medicine, cosmetic and colouring material for textiles and paintings. Praised since an early date for its deep red shades and fastness on wool and silk, lac dye has been a prestigious dyestuff in Asia and the Middle East. However, its history of use in the West still needs of further investigation. Although several documents

confirm the circulation of sticklac and lac dye in the Mediterranean area at least since the beginning of the Christian era, the number of technical manuals describing the use of lac dye as a pigment or dyestuff on textiles is limited. The first known recipe to dye silk with lac dye is from the 15th century, while instructions for making lac lake pigments are more common and date to earlier periods.

The intricate relationship between the lac insects and their host plants reflect the complexity of the raw material and give a sense of the technical expertise that was required to process it. Also, the number of products that could be obtained from it—sticklac, shellac, lake pigment, and lac dye—demonstrate the versatility of lac and its multiple applications. However, this also generated a confusing vocabulary. Different cultures used specific words to describe the colour and the raw material arriving from the East. In the context of pigment production, the Latin *lacca* (and later lake in English) from the Sanskrit *lākṣhā*, came to mean not only a red lac dye-based pigment but also any pigment obtained from a dyestuff by precipitation. In the 16th century, the term "lacquer", also originated from *lākṣhā*, started referring to the resinous part of the raw material, i.e. shellac. In the 17th and 18th century, the application of shellac as a glossy varnish for furniture became wideapread, especially in the context of imitating the lustruous surfaces of Asian lacquerware produced in Japan and China. Therefore, lac, lake and lacquer became terms that overlap with various materials and objects, if not put in the correct context.

This review also reports on the recent advancements in heritage science, particularly in high-performance liquid chromatography (HPLC) and mass spectrometry (MS), that have revolutionised our understanding of lac dye's chemical composition and its use in textile production. The results from these techniques not only allow for the identification of lac dye in heritage samples but also contribute to historical research, by helping reconstruct technological and cultural exchanges. Preliminary comparisons between analytical findings and documentary sources confirm that lac dye was relatively commonly used along the northern coast of Africa as early as the 5th century. The few later examples of textiles from the Iberian Peninsula suggest a continuation of this practice, likely transmitted through the Arab cultural influence. From the 15th century onward, lac dye appears consistently in Eastern European textiles, whereas evidence from Western Europe during the same or earlier periods remains scarce. By contrast, archaeological evidence from Asia shows regular use of lac dye from ancient times onward, particularly after the 2nd century CE with the spread of Buddhism from India, and continuing into the 20th century. More scientific data are needed to better identify patterns of use and trade throughout history.

It also emerges that additional fundamental research is needed on the lac insects, from the revision of the entire genus *Kerria* to the possible identification of species using molecular markers. In the context of textile studies, this work has the potential to refine the provenance of historical textiles dyed with lac dye while contributing to a better understanding of the circulation of the raw material worldwide.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2025.07.026.

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