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ORIGINAL ARTICLE

Colourful rivers: archaeobotanical remains of dye plants from urban fluvial deposits in the southern Low Countries (Belgium)

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Abstract
Although dye plants were a key element in the medieval cloth industry, their use has rarely been documented through archaeobotanical studies. This paper describes and discusses new archaeobotanical finds related to textile dyeing in the southern Low Countries, which was among the most important areas of cloth production and export in Europe during the late medieval period. Remains of weld, madder and woad, the three main medieval dye plant species, were identified via archaeobotanical analysis and high-performance liquid chromatography with photodiode array detection (HPLC-PDA). The remains were found in river deposits, dating between the 10th/12th and 15th century, from two medieval cloth-producing towns, Brussels and Mechelen. Most likely, the finds must be interpreted as waste discarded by textile dyers, which were often concentrated along the urban riverbanks. This study not only documents the use of dye plants in both cities, but also demonstrates the importance of archaeobotanical analyses of fluvial deposits for the reconstruction of artisanal activities within ancient towns. The assemblages are confronted with historic sources and mapped with other medieval remains of dye plants in the region.

Keywords *Reseda luteola* · *Rubia tinctorum* · *Isatis tinctoria* · Urban waters · Textile dyeing · Medieval period

Introduction

Since prehistoric times, and until the arrival of artificial colouring agents in the 19th century (c.), natural resources, mainly plants, were extensively used to colour textile materials. However, these practices have seldom been documented through archaeobotanical studies. The rarity of archaeobotanical finds indicating dyeing with plants can be explained mainly by the type of plant material used in the dyeing process (Hall 1998; Zech-Matterne et al. 2008; Zohary et al. 2012). These are often not seeds and fruits, but more perishable vegetative plant parts such as leaves, stems, and roots, which will preserve in contexts with excellent waterlogged conditions only. Moreover, these vegetative remains are generally less recognisable and diagnostic than seeds and fruits and can be easily overlooked during standard macrobotanical analyses (Tomlinson 1985; Hall 1996). In addition, archaeobotanical remains of plants used in dyeing tend to be restricted to contexts specifically related to textile production, such as workshops and houses of textile workers and dyers, and, unlike food remains for example, will not be found at any random location within

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a town. Such contexts related to textile production have not very often been uncovered and sampled for archaeobotanical studies (Wiethold 2008).

In the southern Low Countries (comprising most of modern-day Belgium) dye plants became of particular economic importance during the late medieval period (Lindemans 1952; Asaerts 1973). At that time, the region was one of the most densely urbanised areas in Europe (e.g. Pounds 2005; Blockmans et al. 2016) and many towns owned large part of their growth and prosperity to the flourishing textile industry, in which dyestuffs played an essential role. From the 11th–12th c. AD, woollen broadcloth produced in Flemish towns, such as Ghent, Bruges and Ypres, conquered international markets, while in towns from the Duchy of Brabant international export started from the mid-13th c. onwards (Verhulst 1983). Along with the development of this industry, dye plants were intensively cultivated, traded on a large scale, and widely used by specialised craftsmen organised in guilds (Lindemans 1952; Asaert 1973; Thoen 1992). Although medieval dyeing practices are well documented in written records from the region, material evidence, including archaeobotanical finds, is scarce.

In Belgium, first clear archaeobotanical evidence of plants used in textile dyeing was excavated at the end of the 1990's in Ghent, where concentrations of *Rubia tinctorum* (madder) root/rhizome fragments and bundles of whole *Reseda luteola* (weld) plants were found (Bastiaens 1998). Several years later similar concentrations of *Rubia* root/rhizome fragments and *Reseda* seeds were excavated in the medieval dyer's quarter in Bruges (Hillewaert et al. 2004). These finds remain exceptional, as it was not until recently that new assemblages of abundant remains of multiple plant species, directly related to textile dyeing, were brought to light.

This paper describes and discusses these new finds of plants used in textile dyeing, excavated in the city centres of two towns situated in the ancient Duchy of Brabant, Brussels and Mechelen, which were internationally renowned for the production and export of woollen cloth during the late medieval period. The remains from both towns were found in very similar contexts, in the waterlogged deposits of urban watercourses. The new finds are mapped with previous records of dye plants in the region and confronted with information from historic sources.

Previous studies of deposits from ancient watercourses, often revealing excellent waterlogged preservation conditions, illustrated and critically discussed the potential of archaeobotanical analyses of this type of context for the reconstruction of the local and regional vegetation (e.g. Cappers 1993; Knörzer 1996; Kozáková et al. 2014; Steiner et al. 2020). Besides remains of the vegetation, these contexts often contain plant remains from anthropogenic activities discharged in the water, providing information on past crop cultivation, animal and human food consumption and trade (e.g. Knörzer 1996; Bertacchi et al. 2008; van Amen and Brinkkemper 2009; De Cupere et al. 2017). In addition, the results of this study highlight the importance of the analysis of plant remains from river deposits for the reconstruction of artisanal activities in urban towns, which were often concentrated along watercourses.

Medieval dyers in historic sources from Brussels and Mechelen

The earliest mentions of dyers in Brussels date back to the 14th c. They were established close to the river Senne, similar to other artisans who needed water for their activities, such as fullers and cloth finishers (Wouters 1972; Deligne 2003). Undoubtedly dyeing of wool was practiced already earlier in Brussels. Written records mention the import of English wool and dyestuffs from the beginning of the 13th c. The first mention of the town's cloth hall dates back to 1221, while Brussels broadcloth became internationally renowned from the second half of the 13th c. (Henne and Wauters 1845; Billen 2000).

The late medieval dyer's quarter in Brussels was situated on the right riverbank, just within the 13th c. first city wall, a few 100 metres upstream of the excavated site Parking 58 (Fig. 1). A large concentration of dyehouses, as well as the dyer's guild house were located in the current Verversstraat ("Dyer's Street"), a toponym dating back to 1377, still referring to the medieval activities in this quarter (Vannieuwenhuyze 2008). The Verversstraat led to a bridge over the Senne, which from 1456 was called Verversbrug ("Dyer's Bridge"). Within the same quarter, there was a narrow alley called den Hoec, first mentioned in 1302. In 1491 its name changed to Vershoek ("Dyer's Corner"), due to the large number of dyers established there (Vannieuwenhuyze 2008). The street and adjacent buildings were completely demolished in 1869 when the boulevard Anspach was created (D'Osta 1979). Beyond this most important cluster of dyers, there are few indications for late medieval dyers in the Overmolen district and near the Sint-Goriks island (Deligne 2003) (Fig. 1).

In Mechelen the oldest records on dyers date to 1276 and relate to the river Melaan (Kinnaer and Troubleyn 2014). Dye plants appear in administrative and legislative documents from the end of the 13th c. (ESM 1). As is the case for Brussels, it seems assumable that dyeing activities started already earlier in Mechelen. Written sources suggest the processing of local wool in the 12th c. From 1213, Mechelen had a cloth hall (Croenen 2003) and, like Ypres and Douai, from 1202 the town owned a sales hall in Lagny,

Fig. 1 Map of Brussels by Jacob van Deventer (*circa* 1550) with the river Senne, the archaeological site of Parking 58, the location of the medieval dyer's quarter (**A**) and two other areas with some historical indications for dyers: Sint-Goriks island (**B**) and Overmolen district (**C**)

France (Laurent 1935). This period also sees the first mentions of skippers from Mechelen in England in the written records, while the import of English wool becomes more extensive in the mid-13th c. (Joosen 1942). The presence of dyers along the Melaan during the late medieval period is well documented. Many dyers were housed in the Vetterstraat (currently Rik Woutersstraat), the backyards of the houses in this street gave onto the Melaan river, in the area of the excavation (Fig. 2). In the 16th c., the overall number of dyers in Mechelen decreased and during this period they were mainly situated along the Heergracht, north of the Melaan (Kinnaer and Troubleyn 2014).

Materials and methods

Archaeological contexts and samples

Brussels: Parking 58

In 2019, a large excavation (ca. 6,000 m^2) in the city centre of Brussels revealed the remains of the late medieval port. Besides the discovery of a 12th–13th c. wooden bank reinforcement and an impressive 14th–16th c. stone quay wall, several metres excellently preserved fluvial layers from different phases of the medieval river Senne were excavated

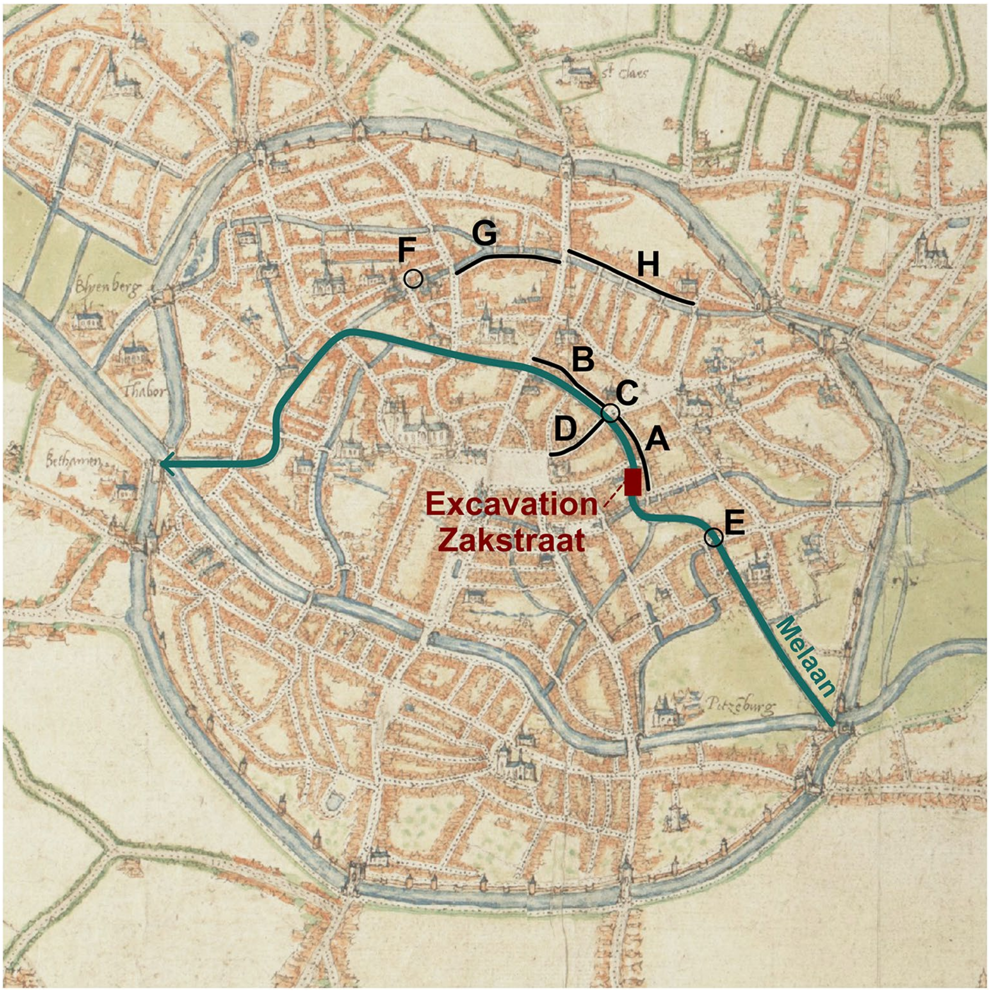

Fig. 2 Map of Mechelen by Jacob van Deventer (*circa* 1550) showing the river Melaan, the location of the excavation at the Zakstraat and the locations where dyers were present during the 13th and 14th c. according to historical sources: Vettersstraat (**A**), Varkensstraat (**B**), Beffersbrug (**C**), Beffersstraat (**D**), Heynemeysbrug (**E**), corner Peperstraat/Straatje van de Hove (**F**), Korte Heergracht (**G**), Lange Heergracht (**H**). For more details see Kinnaer and Troubleyn 2014

Table 1 Overview of the studied samples from Parking 58, Brussels

Phase	Description	Chronology (c. AD)	Samples
II	Fluvial sediments in oldest medieval riverbed	10th–13th*	24
III	Sediments from the 12th–13th c. bank reinforcement consisting of two rows of wooden piles filled with sediments and construction material	Mid-13th	1
V	Sediments recovering the fill of the 12th–13th c. bank reinforcement, deposited during flooding events or voluntarily brought in as backfill	2nd half 13th–1st half 14th	1
VII	Fluvial sediments deposited in the riverbed of the Senne, canalised by a stone quay wall	2nd quarter 14th–2nd half 15th	57

* The archaeological study of phase II, which will allow a more precise dating and subdivision of this phase, is still ongoing

(Ghesquière et al. in press). These layers, dating between the 10th and the 15th c., were extensively sampled over the whole excavated length of the river (ca. 160 m). Macrobotanical remains from 83 samples (354.9 L of sediment), collected from 17 profiles have been analysed (Table 1, ESM 2).

Mechelen: Zakstraat

Simultaneously with the study of Parking 58 in Brussels, samples from a very similar context from a smaller excavation in the city centre of Mechelen (about 30 km north of Brussels) were analysed. In 2018, fluvial deposits from a small watercourse, the Melaan, were sampled during excavations at Mechelen-Zakstraat (Coremans 2020). During the 12th–13th c. this watercourse was reinforced with a wooden structure of posts and planks, later replaced by a stone quay wall. Five samples from one profile dating between the 13th and the 18th–19th c. were analysed (Table 2). Interestingly, according to historical sources, dyers were housed in the area of the excavation during the late medieval period, at the parcels adjacent to the watercourse (Fig. 2).

Method

All studied samples from Brussels (Parking 58) and Mechelen (Zakstraat) were sieved with mesh sizes 2, 1, 0.5 and 0.25 mm using the wash-over method (Hosch and Zibulski 2003). A selection of 21 samples from Parking 58 was studied quantitatively. For these samples, fragmented and whole macrobotanical remains were sorted and counted, whereupon the minimum number of whole remains (MNI) was calculated. The remaining samples were studied semi-quantitatively, implying that residues were scanned and quantities of macrobotanical remains were estimated for each taxon (+: few, ++: tens, +++: hundreds, ++++: thousands). Vegetative fragments such as stems and roots were quantified this way as well, also in the quantitatively studied samples. All five samples from Mechelen were studied semi-quantitatively and a quantitative study was subsequently carried out on the samples which contained remains of dye plants. Macrobotanical remains of both sites were identified using the reference collection of the Royal Belgian Institute of Natural Sciences.

The dyestuff in a selection of plant remains was analysed with high performance liquid chromatography with photodiode array detection (HPLC-PDA). The analyses were carried out on an ACQUITY Arc system (Waters Belgium) equipped with a quaternary pump and a PDA model 2998 diode array detector with an analytical flowcell ensuring a low noise performance of $<10^{-4}$ absorbance units. The detector consists of 512 diodes that scan absorbance within the wavelength range of 190–800 nm with an optical resolution of 1.2 nm, and a scanning rate of one scan per second. Using this technique, different chromophores present in a sample can be effectively separated and subsequently identified. This is achieved by comparing their characteristic spectral properties and the time they retain on the column with these of the dye compounds of the reference database of the Royal Institute for Cultural Heritage. An end-capped LiChrosorb RP-18 column (Merck, VWR, Belgium) was used as stationary phase, while the mobile phase consisted of: (A) methanol (HPLC grade, purity > 99.8%, sourced from Acros Organics), (B) a mixture of methanol and Milliq. water (ASTM Type I, resistivity: 18 MΩ.cm and TOC < 5ppb, from Waters) in a volumetric ratio of 1/9, and (C) a 5% phosphoric acid solution (85 wt% pro analisi, from Acros Organics). The analyses were run according to the following gradient: 0–3 min: isocratic elution with 23 A/67B/10 C, 3–29 min: linear gradient to 90 A/0B/10 C, and 30–35 min: isocratic elution with 23 A/67B/10 C (Vanden Berghe et al. 2009).

Sample preparation consisted of the extraction of the plant material in 250 µL water/methanol/37% hydrochloric acid (1/1/2, v/v/v) for 10 min at 105 °C after which the extract was filtered and evaporated under vacuum (Genevac EZ-2, Sysmex, Belgium). The residue was dissolved in a solution of 30/30 µL methanol/water from which 20 µL was injected for analysis.

To obtain more precise chronological information, radiocarbon analyses were carried out at the Royal Institute for Cultural Heritage on remains of dye plants from one of the oldest samples with dye plants from Brussels, which contained very few datable archaeological remains (phase II, sample US 909) and from the late medieval–post-medieval sample from the embanked Melaan (phase 7, sample MB18).

Table 2 Overview of the studied samples from Zakstraat, Mechelen

Phase	Description	Chronology	Samples
3	Fill of the Melaan riverbed with wooden bank reinforcement	13th c. AD	2
4	Fill of the Melaan riverbed with wooden bank reinforcement	14th c. AD	1
7	Fill of the Melaan riverbed, embanked by a stone quay wall	Late medieval–post-medieval period	1
8	Fill of the Melaan riverbed, embanked by a stone quay wall	18th–19th c. AD	1

Results

Remains of dye plants

Three dye plant species were identified, though initially only the yellow dye plant *Reseda luteola* (weld) was recognised. The small seeds of this plant (Fig. 3) appeared abundantly in 15 of the 17 studied profiles from Brussels (Fig. 4). They are present in the 0.5 mm-residues of all 57 samples from the 14th–15th c. canalised Senne riverbed, as well as in the sample from the 13th–14th c. accumulations, in the sample from the bank reinforcement (mid-13th c.), and in 16 samples of the oldest medieval Senne deposits (10th–13th c.). The radiocarbon analysis on *Reseda* seeds from one of the oldest samples containing dye plants yielded a date between the end of the 10th and the third quarter of the 12th c. (Table 3). In most samples from Parking 58 several hundreds of *Reseda* seeds per litre sediment were observed (Tables 5 and 6, ESM 3). Most seeds are preserved by waterlogging, while

Fig. 3 Seeds of *Reseda luteola* (weld) from the fluvial deposits; scale bar = 1 mm

carbonised *Reseda* seeds appear in small numbers in 12% of the samples. Liquid chromatography analysis indicates that the yellow dyestuff, luteolin, is present in the archaeological seeds (Table 4), even though the seeds by themselves were not used for dyeing.

In the river deposits from Mechelen *Reseda* seeds were also abundantly present in the uppermost 13th c. sample, in the 14th c. sample predating the stone quay wall and in the more recent sample from phase 7 (Table 7). The radiocarbon analysis of the *Reseda* seeds in this sample yielded a date between the end of the 13th and the 14th c. (Table 3). In the lowermost (13th c.) and uppermost (18th/19th c.) samples indications for textile working were absent.

In most of the samples containing *Reseda* seeds, crushed reddish woody fragments were observed (Fig. 5). These were not immediately recognised as identifiable remains, but because of their remarkable colour, quantities and frequency, an attempt was made to identify them during the macrobotanical study. The fragments seemed to match well with modern reference material and descriptions in literature of *Rubia tinctorum* (madder) roots and rhizomes (Tomlinson 1985; Hall 1998; Schweingruber et al. 2011). However, the fragments lacked diagnostic features to be determined with certainty via archaeobotanical analyses. Therefore, high performance liquid chromatography with photodiode array detection (HPLC-PDA) was carried out on two samples from Brussels and one sample from Mechelen. The main components detected in both samples: alizarin, purpurin and pseudopurpurin (Table 4), which are the three

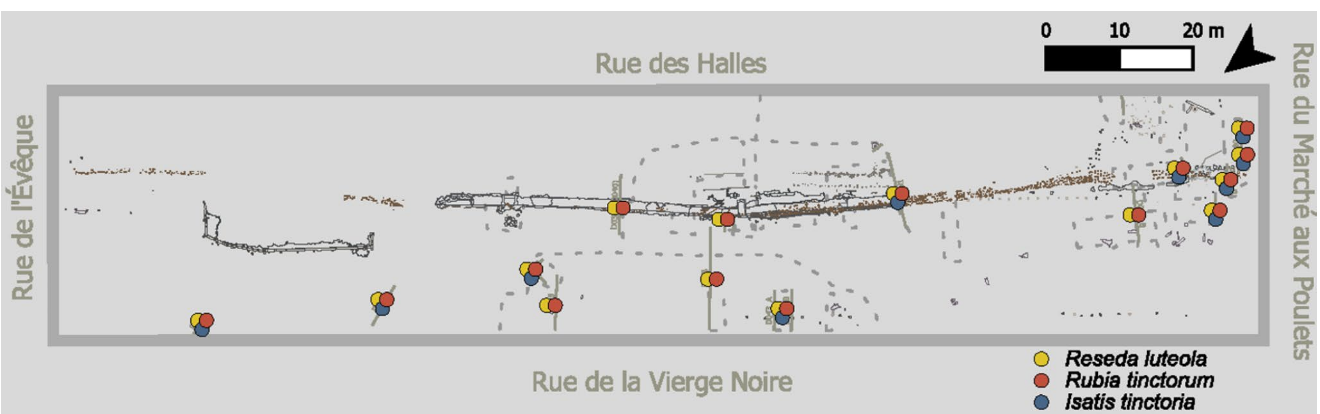

Fig. 4 Site map of Parking 58 (Brussels) indicating the profiles with finds of *Reseda luteola*, *Rubia tinctorum* and *Isatis tinctoria*

Table 3 Results of the radiocarbon analyses

Lab.code	Site, sample, phase	Material	^{14}C age (BP)	Cal AD (1 and 2σ-range)
RICH-34070	Brussels Parking 58 US909 phase II	*Reseda luteola* seeds	986±29	68.2% probability 1020–1050 (28.5%) 1080–1150 (39.7%) 95.4% probability 990–1160 (95.4%)
RICH-32799	Mechelen Zakstraat MB18 phase 7	*R. luteola* seeds	637±27	68.2% probability 1300–1325 (29.6%) 1355–1390 (38.6%) 95.4% probability 1280–1400 (95.4%)

main marker dye molecules referring to cultivated *Rubia* roots/rhizomes, confirmed the identification.

The *Rubia* fragments were present in 15 of the studied profiles from Brussels (Fig. 4). They were observed in all 57 studied samples from the 14th and 15th c. canalised Senne (mostly tens to thousands of fragments per sample), in the samples from phases III and V, and in more than half (14) of the samples from phase II. In the oldest phase, the remains are generally less numerous (Tables 5 and 6). In the samples from Mechelen, tens to hundreds of *Rubia* fragments were recorded, exclusively in three layers which also contained *Reseda* seeds (Table 7).

The size of the *Rubia* root/rhizome fragments varies excessively. The remains were observed in all studied sieving fractions (> 2–0.25 mm), with a maximum length of 14 mm and a maximum diameter of 7 mm. Sometimes fragments of the loose-celled cortex were still attached. The ends of the larger fragments (in the > 2 mm fractions) often show very regular and flat surfaces on both sides, suggesting that they have been chopped (Fig. 5) rather than broken.

The remains of the blue dye plant *Isatis tinctoria* (woad) were much sparser. Few pod fragments were found in 21 samples (25% of the samples) and in nine profiles from Brussels (Fig. 4). In Mechelen *Isatis* was observed in the oldest 14th c. sample (Table 7). Only the central boat-shaped halves of the fruits, which enclose the seeds, are preserved. The fragments were identified by comparing them with modern reference material, soaked in a 10% KOH solution. The texture of the eroded exterior is spongy with a coarse reticulated pattern of veins while the hollow interior shows fine longitudinal stripes with transverse waves (cf. Knörzer 2007) (Fig. 6).

The remains of the dye plants represent 2–39% of the total MNI of the identified and counted remains in the quantitatively analysed samples from Brussels (Fig. 7) and 11–34% in the samples from Mechelen (Fig. 8). *Rubia* remains were not included in these calculations, because these vegetative fragments of varying sizes were semi-quantitatively quantified.

Other plant remains in the fluvial deposits

The dye plant remains in the fluvial deposits are mixed with other macrobotanical remains (> 100 taxa in Mechelen, see taxalist ESM 4, and > 300 taxa in Brussels, see Ghesquière et al. in press) of various origins, including the vegetation along the riverbanks, domestic, artisanal, and excremental waste. In 15% of the samples from Brussels and in the three samples that contained dye plants from Mechelen peat fragments were recognised. A portion of them were carbonised, indicating that they were used as fuel.

Other botanical finds which might relate to textile production are *Cannabis sativa* (hemp) fruits, seeds and capsules of *Linum usitatissimum* (flax), and fruits and flowerhead

Table 4 Results of the liquid chromatography analyses (HPLC-PDA)

Lab. code	Site, sample	Material	Analysis no., extract	Dye composition (%)	λ (nm)	Biological source(s)
14434b/02	Brussels Parking 58 US896	*R. luteola* seeds	02/210908/08 SHCL	77 Σ ferulic acid 12 protocatechuic acid 11 luteolin	255	*R. luteola*
				56 luteolin 44 flav(rt 16.9–17.3)	350	
14434/01	Brussels Parking 58 US1035	Red woody fragments	02/210222/16 HCL	52 alizarin 47 purpurin 1 nordamnacanthal + anthragallol	255	*R. tinctorum*
			02/210222/14 OA	55 alizarin 36 purpurin 8 pseudopurpurin 1 nordamnacanthal + anthrapurpurin, anthragallol, flavopurpurin	255	
14434/02	Brussels Parking 58 US909	Red woody fragments	02/230320/11 OA	1 munjistin 41 alizarin 54 purpurin 3 nordamnacanthal 1 lucidin	255	*R. tinctorum*
14434b/01	Mechelen Zakstraat MB19	Red woody fragments	02/210908/06 HCL	63 purpurin 19 ferulic acid 16 alizarin 1 nordamnacanthall 1 anthragallol	255	*R. tinctorum*

fragments of *Dipsacus sativus* (fuller's teasel). *Cannabis* fruits appeared in most Senne samples in small quantities (80% of the samples). In Mechelen few remains were observed in the most recent sample only. *Linum* remains appear in 89% of the Senne deposits and in four samples from Mechelen. *Dipsacus sativus* is a plant which was cultivated for its use in the finishing process of woollen cloth. The dried flower heads of this plant were used to raise the nap of the cloth, after which it could be sheared (Hall 1992). Remains of this species were exclusively recorded in the Senne deposits which also contained dye plants. They were present in 80% of these samples. Likewise in Mechelen, the species was present in the three dye plant containing samples only.

Discussion

Cultivation, trade and use of *Reseda luteola*, *Rubia tinctorum* and *Isatis tinctoria* in the region

Late medieval historic documents indicate that *Reseda*, *Rubia* and *Isatis* were the main dye plants in the region (e.g. Lindemans 1952; Asaert 1973). These three plants produce colourfast dyestuffs, allowing to obtain the primary colours. Secondary colours were applied by subsequently dyeing in different dye vats: to obtain green for example, textiles were firstly dyed with *Isatis* and subsequently with *Reseda* (Hofenk de Graaff 1992).

Reseda luteola (weld)

The yellow dye plant, weld, is a biannual plant in the Resedaceae family, in its first year it develops a basal rosette of leaves, while in the second year a long stem with many pale-yellow flowers develops (Wiethold 2008). The species is native to the eastern Mediterranean and south-west Asia but became naturalized far beyond these regions (Zohary et al. 2012). The oldest archaeobotanical remains of *R. luteola* in Belgium date to the Roman period (e.g. Vanderhoeven et al. 1999). The species was most likely introduced in the area during this period. Archaeobotanical finds of *R. luteola* become much more common during medieval times (cf. § Archaeobotanical finds of medieval dye plants in the region).

According to Lindemans (1952), *R. luteola* was the most cultivated and most widespread dye crop in the southern Netherlands. The 16th c. physician and botanist Dodoens (1554) wrote that it was a common crop, particularly in the region of Brussels and Leuven, while in the close vicinity of Mechelen 15th c. toponyms also indicate local cultivation (ESM 1). The dye crop was still cultivated in Belgium during

Table 5 Remains of dye plants in the fully quantitatively studied samples from the medieval Senne (Brussels); +: few, ++: tens, +++: hundreds, ++++: thousands, c: carbonised, w: waterlogged. In the column date, the upper case letter B indicates the 2nd half of the century, lower case letters (b, c, d) indicate the 2nd, 3rd and 4th quarter of the centuries. Dates are mainly based on ceramics and stratigraphy, for US 909, a radiocarbon date was obtained Table 3

Layer (US)	(Sub) phase	Date (c. AD)	Profile	Vol. (L)	*Reseda luteola*, seeds (w/c)	*Rubia tinctorum*, root/rhizome fragments (w)	*Isatis tinctoria*, pod fragments (w)
909	II	10d–12c	D042-B	2	863/–	++	2
907	II	10–13	D042-B	5	560/–	+	4
593	II	10–13	D042-B	3	1,107/–	+	5
972	VII(b)	14b?	D043	4.8	741/–	+++	1
1563	VII(d)	14B	D090	3.9	4,592/–	+++	6
552	VII(b–d?)	14B?	D024	3	2,274/–	+++	5
502	VII(b–e)	14–15	D020	2	3,317/8	+++	4
971	VII(d–g?)	14–15	D043	5.2	2,900/–	++++	–
978	VII(d–g?)	14–15	D043	2	2,013/–	++++	26
1035	VII(h)	14–15	D043	3	1,244/–	++++	–
108	VII(l)	mid-15	D004	3	533/–	++++	1
960	VII(l)	mid-15	D043	3.9	3,361/12	+++	–
959	VII(l)	mid-15	D043	3.8	4,997/–	+++	8
979	VII(m)	15B	D043	3	849/–	+++	–
902	VII(m)	15B	D042-B	4.3	1,050/9	+++	1
898	VII(m)	15B	D042-B	1	257/–	+++	–
895	VII(m)	15B	D042-B	3	314/–	+++	1
492	VII(n)	15d	D020	5	483/–	++++	–
1033	VII(n)	15d	D043	3	1,179/–	+++	–
1031	VII(n)	15d	D043	3	1,023/5	++++	–
1030	VII(n)	15d	D043	3	1,993/–	+++	–

Table 6 Summarising table of the remains of dye plants in all (fully and semi-quantitatively studied) samples of Parking 58 (Brussels) showing the numbers of the samples in which a certain quantity of the dye plant remains remains occurs; 0: absent, +: few, ++: tens, +++: hundreds, ++++: thousands, c: carbonised, w: waterlogged; see ESM 3 for the detailed dataset

(Sub-)Phase	Date	Samples *n*/L	*R. luteola,* seeds (w/c)					*R. tinctorum,* root/rhizomes (w)					*I. tinctoria,* pods (w)	
			0	+	++	+++	++++	0	+	++	+++	++++	0	+
II	10–13 c.	24/1–24.5	6/24	2/–	2/–	10/–	4/–	10	8	3	2	1	19	5
III	13 c.	1/5	–/1	–/–	–/–	–/–	1/–	–	–	–	1	–	–	1
V	13–14 c.	1/3.5	–/–	–/1	–/–	–/–	1/–	–	–	–	1	–	–	1
VII(b-j)	14–15 c.	22/1–5.2	–/17	1/5	2/–	9/–	10/–	–	1	6	8	4	14	8
VII(l-n)	15 c.	35/1–40	–/32	1/3	10/–	12/–	12/–	–	1	12	15	7	29	6

the first half of the 19th c. but disappeared soon after the development of chemical aniline dyes (Lindemans 1952). Compared to *I. tinctoria* and *Rubia tinctorum*, mentions of *R. luteola* are sparser in medieval administrative records, probably because – unlike *Rubia* and *Isatis* – *Reseda* was locally cultivated.

The crop stayed about 14 months in the field before being harvested, this is the moment when the seeds start to develop. The harvested weld plants (including the seeds) were dried and fragmented (Lindemans 1952). The leaves, inflorescence and seeds contain the most dyestuff, luteolin (Cardon 2014). Before being added to the dye vat the textile or yarn had to be pretreated with a metal salt, allowing to fix the dye to the fibres. In the late medieval period, alum is most often used as a mordant (Hofenk de Graaff 1992).

Rubia tinctorum (madder)

Rubia tinctorum is a perennial herb in the Rubiaceae family with long creeping or climbing stems and small inconspicuous flowers, forming shiny black berries in autumn (Körber-Grohne 1995; Cardon 2014). *R. tinctorum* was the main source of red tinted dyes in the region until the development of the synthetic alizarin, in the second half of the 19th c. (Lindemans 1952; Körber-Grohne 1995). The wild forms of the crop are native to south-west and central Asia. In the Netherlands the crop seems to be introduced in the early medieval period by the Frisians, possibly already during the 6th c. (van Haaster 1997). In the 7th c., Frisian and English merchants bought madder at the fair in Saint-Denis, Paris, and the species is mentioned in the 9th c. *Capitulare de Villis*, which lists the crops to be grown on Charlemagne's royal estates (Cardon 2014).

Unlike *Reseda*, *Rubia* was not cultivated (at least not on a significant scale) in the immediate vicinity of Brussels and Mechelen. The most important areas of cultivation in the region were the heavy clay soils along the North Sea coast of modern-day Belgium and north of Antwerp (the Polders) and the region of Zeeland (part of modern-day Netherlands) (Lindemans 1952). The oldest historical indication for madder cultivation in the Flemish coastal region dates back to the early 12th c. Here, *R. tinctorum* cultivation culminates during the 13th and 14th c. to decline again in the 15th and 16th c., corresponding to the decline of the urban cloth production in the region (Thoen 1992). During the latter period *R. tinctorum* cultivation increases in Zeeland, which becomes the most important area of *R. tinctorum* cultivation in Europe from the 15th c. onwards (Asaert 1973). In the historical archives of the city of Mechelen, *R. tinctorum* is mentioned from the end of the 13th c. The toll accounts of Antwerp indicate that during the 14th c. inhabitants of Mechelen repeatedly bought *R. tinctorum* at the annual fair in Bergen op Zoom as well as from vendors in Biervliet in Zeeland (Doehaerd 1947).

R. tinctorum cultivation was very labour-intensive, the crop was not sown but planted, it required deep and fertile soil and remained in the field for at least two years. The crop is not hardy, so it had to be covered in winter. The red dyestuff (consisting mainly of alizarin and purpurin) is extracted from the rhizomes and roots of the plant. After harvesting, the rhizomes and roots were cleaned, dried in madder stoves, and subsequently pounded in madder mills (Lindemans 1952). Different qualities of *R. tinctorum*, which were carefully monitored, were available at the urban markets. For example, a 14th c. regulation (1361) from Mechelen distinguishes between 'crapmeeden' and 'ghemeine meede'. The former was allowed to contain 1% of soil while the latter could contain 5% of impurities (Installé 1981). Like weld, madder is a mordant dyestuff, implying that the textile was treaded in an alum solution before being added to the dye vat.

Isatis tinctoria (woad)

Isatis tinctoria is a biannual plant in the Brassicaceae family, native to south-west Asia and south-east Europe (Zohary et al. 2012). It was the most important source of blue dye in Northwestern Europe until the 17th c., when the exotic true indigo (*Indigofera tinctoria*) became more and more available (Lindemans 1952). Archaeobotanical finds of *Isatis* seeds and fruits from Germany, France, England, and Denmark indicate that the plant was already introduced before

Table 7 Remains of dye plants in the samples from Mechelen, Zakstraat, Profile PRZ2; +: few, ++: tens, +++: hundreds, ++++: thousands, c: carbonised, w: waterlogged; dates are based on ceramics and stratigraphy and for MB18, a direct radiocarbon date is available (Table 3)

Layer/sample	Phase	Date (c. AD)	Vol. (L)	*Reseda luteola*, seeds (w/c)	*Rubia tinctorum*, root/rhizome fragm. (w)	*Isatis tinctoria*, pod fragments (w)
S127w/MB76	3	13	> 2	–/–	-	-
S127u/MB90	3	13	0.18	91/4	++	-
S1af/MB19	4	14	0.5	38/–	+++	1
S1ae/MB18	7	14	0.16	130/1	+++	-
S1x/MB15	8	18–19	> 2	–/–	-	-

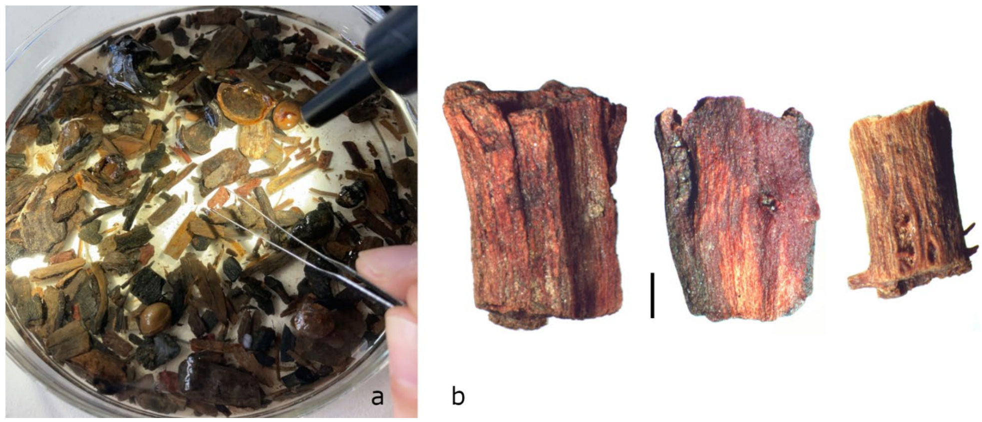

Fig. 5 Remains of *Rubia tinctorum* (madder) root/rhizome fragments, **a**, fragments in > 2 mm sieving residue, **b**, fragments > 2 mm showing traces of chopping; scale bar = 1 mm

Fig. 6 Fruit fragment of *Isatis tinctoria* (woad), exterior, interior, and side view; scale bar = 1 mm

the Roman period (see Zech-Matterne and Leconte 2010 and references therein). Like madder, woad is mentioned in the *Capitulare de Villis* (ca. 9th c.). Historical sources indicate that it was traded at the markets of Arras (France) from the first half of the 11th c., and it was cultivated from the second half of the 12th c. in the region of Cambrai (Herbillon and Joris 1964).

Commercial cultivation of the dye crop seems to lack in the immediate vicinity of Brussels and Mechelen but between the 13th and the 15th c. it was intensively cultivated on the loamy plateaus of the Hesbaye region, situated about 40–50 km south-east of both towns (Lindemans 1952; Herbillon and Joris 1964), and in the region of Lille in France (Thoen 1992). However, historical documents indicate that *Isatis* was also imported in large quantities from further distances. The main *Isatis* producing areas in late medieval Europe were Picardy, Normandy and Languedoc in France, the Rhineland in Germany and Tuscany and Lombardy in Italy (Herbillon and Joris 1964; Asaert 1973). According to the 15th c. toll accounts of Antwerp (Asaert 1973), *Isatis* was mainly imported from the Rhineland. These documents illustrate, for example, that inhabitants of Mechelen purchased *Isatis* from vendors from Grevenbroich, while a 14th c. written document describes the debts of Brussels dyers to woad merchants from Jülich (Des Marez 1904).

The blue dyestuff, indigotin, is extracted from the leaves of the *Isatis* plant, which were harvested five to eight times a year (Lindemans 1952). The leaves were ground to a pulp in woad mills (Herbillon and Joris 1964). This pulp was fermented and subsequently rolled into woad balls, which were kneaded and dried. In this form, *Isatis* could be transported and traded. Before being added to the dye vat, the *Isatis* balls were crushed and moistened, after which the second fermentation took place. The dye bath had a yellowish colour and by removing the textile from the water, it turned blue due to oxidation (de Nie 1937; Hofenk de Graaff 1992; Cardon 2014). Dyeing with *Isatis* did not require any preparation with a mordant but the dyeing process was more complicated and time-consuming, requiring specialised

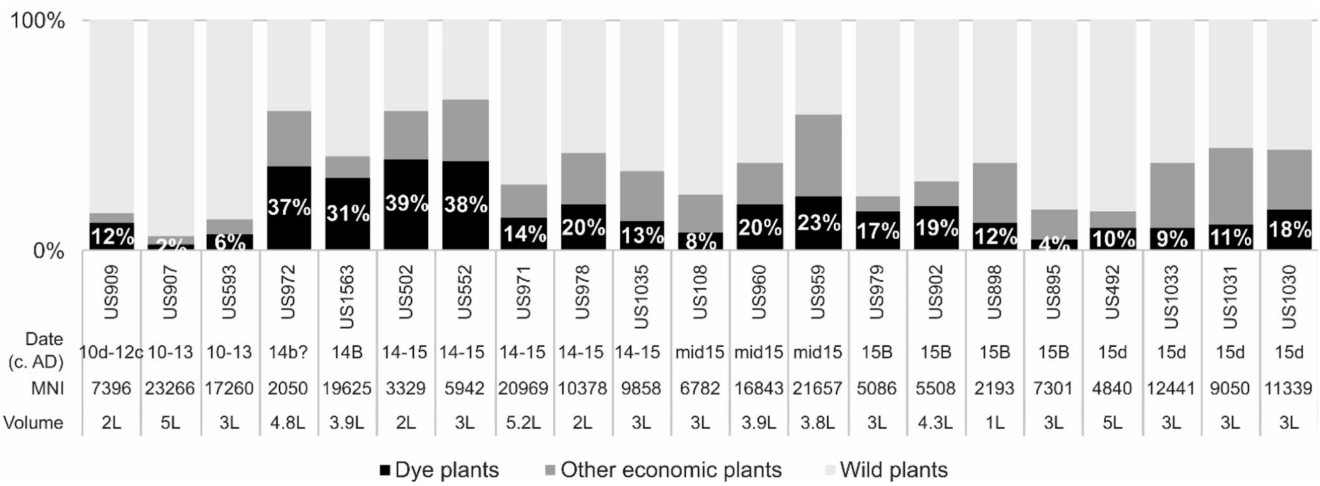

Fig. 7 Proportions of remains of dye plant and other identified plant remains in the quantitatively studied samples of Brussels, Parking 58 (% of the total minimum number of remains (MNI), *Rubia* root/rhizome fragments and other vegetative fragments are not included). The upper case letter B indicates the 2nd half of the century, lower case letters (b, c, d) indicate the 2nd, 3rd and 4th quarter of the centuries

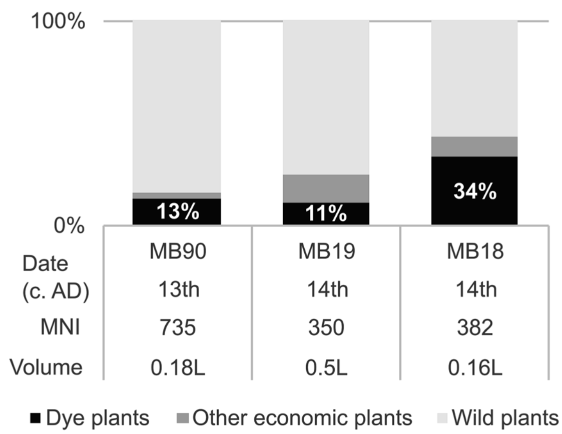

Fig. 8 Proportions of remains of dye plants and other identified plant remains in samples with dye plants from Mechelen, Zakstraat (% of the total MNI, madder root/rhizome fragments and other vegetative fragments not included)

knowledge and skills. Late medieval documents indicate that it was carried out by a separate group of dyers, the blue dyers (e.g. Des Marez 1904; Favresse 1949, 1961).

Other dye plants

The only other vegetal dyestuff repeatedly mentioned in medieval written documents on dyers in Mechelen (ESM 1), and which also seems to be used by the Brussels dyers (Willems 1839; Billen 2000) is "brazilwood". This term was used for multiple exotic species of soluble redwood. Brazilwood imported from eastern Asia (i.e. sappanwood, *Caesalpinia sappan*) was already used in Europe several centuries before the discovery of South America (de Nie 1937). The name of the country Brazil refers to the large number of redwood trees (e.g. *Paubrasilia echinata*, syn. *Caesalpinia echinata*) that grew there. The American brazilwood was exported to Europe on a large scale from the beginning of the 16th c. onwards (Cardon 2014). Like madder, brazilwood was used as a red mordant dyestuff.

Certain plants frequently recorded in the river deposits, such as *Sambucus nigra*, *S. ebulus* (elder), *Vaccinium myrtillus* (blueberry), *Juniperus communis* (juniper), *Myrica gale* (sweet gale) and *Tanacetum vulgare* (tansy), can be used in dyeing but are less colourfast than *Rubia*, *Reseda* and *Isatis*, and also do not appear in the historical documents on the medieval dyers. Most likely, their remains are not associated with textile dyeing but entered the water as remnants of natural vegetation, peat or consumption remains.

Archaeobotanical finds of medieval dye plants in the region

Unlike remains of *R. tinctorum* and *I. tinctoria*, which have not often been found, seeds of *R. luteola* occur regularly at medieval sites in Belgium (Fig. 9), as in the rest of Northwestern Europe (e.g. Hall and Huntley 2007; Knörzer 2007; Wiethold 2008). Most finds date from the late medieval period and were found in waterlogged contexts from urban sites. In the southern part of Belgium finds of *R. luteola* are lacking, mainly because the rarity of waterlogged medieval sites within this area.

R. luteola was found at several archaeological sites in Ypres, Ghent, and Bruges, which were among the most important cloth producing towns in the county of Flanders. Also in Aalst, where the region's most important *R. luteola* market was situated (Lindemans 1952), medieval *R. luteola* seeds were recorded from several locations in the city centre. However, as *R. luteola* thrives as a wild plant in the region, especially in urbanised areas (Van Landuyt et al. 2006),

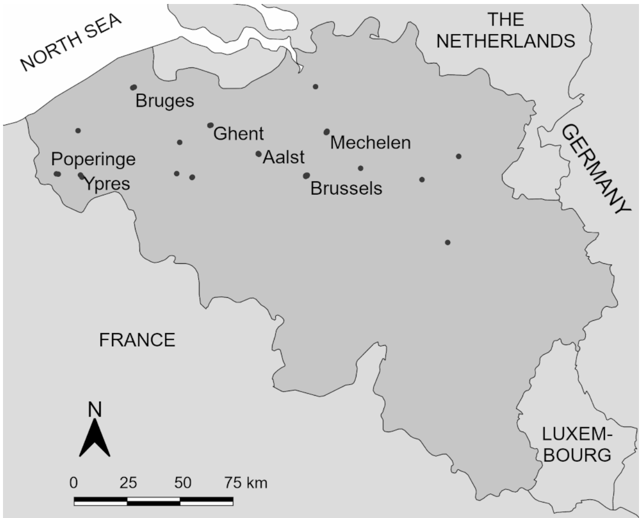

Fig. 9 Medieval archaeobotanical finds of *Reseda luteola* in Belgium (dot marks). Towns with finds mentioned in the text are indicated on the map, for a more detailed map with reference list see ESM 5

archaeobotanical finds of *R. luteola* seeds do not necessarily point to dyer's activities. Nevertheless, large numbers of *R. luteola* seeds, found in co-occurrence with other remains of dye plants or with other indications for textile processing, are most likely the remains of plants used in textile dyeing. For example, in Ypres, *R. luteola* seeds were found in combination with wool processing artefacts, diverse sheep parasites, and the remains of *Dipsacus sativus* (Dewilde et al. 1998; Cooremans and De Groote 2023) and in Poperinge, abundant *R. luteola* seeds were reported together with remains of *D. sativus* and few seeds of *Genista* cf. *tinctoria* (dyer's greenweed) (van der Meer and van Dijk 2018). The clearest previous archaeobotanical evidence for the use and trade of dye plants in the southern Netherlands comes from Ghent and Bruges. At the Korenmarkt in Ghent in the late 1990's, waterlogged organic layers with distinctive yellow and red colours, dating from the 12th/13th c., were brought to light. These turned out to be bundles of *R. luteola* plants and concentrations of *Rubia* root fragments. The maximum length of the *Rubia* root fragments (3 cm) was somewhat longer than those from Brussels and Mechelen, while the maximum diameter (0.5 cm) was similar. The *R. luteola* remains were composed of entire plants with many seeds. As *R. luteola* plants were used in the dyeing process in fragmented form, the remains from Ghent were interpreted as unused merchandise (Bastiaens 1998). During excavations of houses and workshops in the dyer's quarter of Bruges, similar concentrations of red root fragments were observed, in association with *R. luteola* seeds (Hillewaert et al. 2004; Vandevelde et al. 2006). They were found in waste layers and in wooden structures, dating back to the 14th c. at the latest, and can be interpreted as primary deposits of dyer's waste. Layers with concentrations of red-brown *Rubia* roots were reported again during a recent excavation in the same quarter (Van Remoorter 2022).

The *Isatis* finds from Brussels (Parking 58) and Mechelen (Zakstraat) are the first archaeobotanical finds of this species in Belgium. In the wider region medieval archaeobotanical finds of *Isatis* and *Rubia* are scarce too. The most famous and most extensively studied assemblages come from 9th–11th c. occupation layers from York, Coppergate 16–22 (Hall 1996, 1998). At this site *Isatis* pod fragments were found together with concentrations of *Rubia* root fragments, remains of *G. tinctoria* and the clubmoss *Diphasiastrum complanatum*, which was probably used as a mordant. In addition to the pod fragments, concentrations of decayed plants tissue were observed, thought to be the remains of degraded *Isatis* leaves, used in the dyeing process (Tomlinson 1985). Very similar remains of *Isatis* pod fragments and plant tissue were found together with *Rubia* root fragments and abundant *Reseda* seeds in 12th–14th c. occupation layers and a drain fill from Beverly as well as in late medieval Bristol (Jones 1991; Hall 1996, 1998). Interestingly, in Bristol the remains were recorded in a context similar to those from Brussels and Mechelen, e.g. in organic layers at the waterfront and in a dock infill, along the river Avon. Some smaller assemblages containing *Isatis* and *Rubia* have been found in Northern England afterwards (Hall and Huntley 2007). There are not much other published finds of *Isatis* in medieval Northwestern Europe. Few seeds and/or pod fragments were recorded in a 9th–10th c. silo from the Somme valley in Northern France (Bakels 1999), from a 13th c. latrine from Aachen (Knörzer 1984) and from a 14th–15th c. dung pit in Rotterdam (Brinkkemper 2007). In Aachen, remains of *R. luteola* and *D. sativus* were found at the same site, probably indicating textile working in the direct vicinity of the site.

Archaeobotanical remains of brazilwood are lacking in Belgium, probably because these kinds of plant materials, often used in powder form, are difficult to recognize. *Caesalpinia sappan* was, however, identified through chemical analyses of a sample from a 17th c. dyer's workshop in Gouda, in the Netherlands (van Haaster 2001). Further, wood fragments of the American *Paubrasilia echinata* (syn. *Caesalpinia echinate*) were recently found in the cargo of an 18th c. shipwreck in the Finnish Baltic Sea together with archaeobotanical remains of *Rubia tinctorum* and *Indigofera tinctoria* (Lempiäinen-Avci et al. 2022).

Interpretation of the remains from Brussels and Mechelen

Historical data on dyers along the Senne and the Melaan versus archaeobotanical remains

The presence of dye plants in urban fluvial contexts seems not surprising, as due to the need for constant water supply, dyer's workshops were often concentrated in the proximity of watercourses. The dye plants from Brussels were found in the area of the medieval harbour. At this location dye plants may have occasionally spilled in the water, for example when loading and unloading merchandise from the boats. However, the large concentrations of remains, which are nearly continuously present over a long period of time and over the whole length of the site, indicate that these plant remains did not end up in the urban waters unintentionally and that they are more likely to be the remains of discarded dyer's waste. After being discarded in the river, the remains got mixed with other diverse plant materials and were transported and deposited by the water. It is plausible that the remains were discharged in the river at the ancient dyer's quarter, which was located upstream of the archaeological site (Fig. 1). The archaeobotanical remains of dye plants and *D. sativus* from Brussels document on dyeing with *R. luteola*, *R. tinctorum* and *I. tinctoria* and on wool-working along the Senne for at least three centuries (end 10th/third quarter 12th c. to end 15th c.). The oldest finds predate the earliest historical information on dyers and cloth production in Brussels (cf. § Medieval dyers in historic sources from Brussels and Mechelen).

The disposal of dyer's waste in the Senne is historically documented. A complaint from the Brussels millers from 1448 describes all kinds of unfortunate practices that were preventing the Senne from fulfilling its role as a source of energy. These included, among other things, the dumping of waste by dyers. The document describes how dyers disposed their waste either directly into the Senne or into ditches which were washed into the Senne by rainwater, or the content of their dye vats was drained into the river via gutters (Deligne 2003). Further, an early 16th c. ordinance prohibited the dyers from dumping their waste into the river Senne any longer (Vannieuwenhuyze 2015).

The dye plants from the 13th and 14th c. fluvial layers in Mechelen correspond well with the historical data. It seems evident that these plant finds also are the remains of waste, discarded into the river by the dyers which were located in the area of the excavated site (cf. Fig. 2). However, it cannot be excluded that the remains entered the water further upstream. Although in Mechelen dyeing activities were located closer to the archaeological site, the remains of dye plants from the Melaan are found in similar concentrations than those from Brussels, and they are likewise mixed with all kinds of other plant remains of various origins.

Plant material used in the dyeing process versus plant remains found

The fragmented and crushed *Rubia* roots/rhizomes correspond exactly with the parts of the plant used in the dyeing process. They also match well with previous archaeobotanical *Rubia* finds in the region (cf. § Archaeobotanical finds of medieval dye plants in the region).

When it comes to dyeing with weld, however, not only the seeds but the whole plants (without the roots) were added to the dye bath, after being dried and chopped. The vegetative parts of the plant, which were also used in the dye bath, are not preserved, or at least not in a recognisable way. Apart from the finds in Ghent, where large quantities of whole plants were excavated (Bastiaens 1998), vegetative remains of *R. luteola* have not been found in the region. *Reseda* leaves are thin and large and are unlikely to be preserved in archaeological contexts (Tomlinson 1985). Hollow stem fragments with distinctive yellow colour, likely to be the remains of *Reseda* stems, were not found during archaeobotanical analyses.

The interpretation of the presence of *Isatis* fruit fragments is less straightforward, because the blue dyestuff is not extracted from the seeds and fruits but from the leaves, which are usually harvested before the plants develop seeds and fruits. As the extraction of the blue dye involves crushing the leaves and bacterial fermentation, it is unlikely to find identifiable archaeobotanical material. However, the co-occurrence of the three dye plant species at both sites, and the rarity of archaeobotanical *Isatis* finds in the region suggest that the pod fragments must somehow also be related to dyer's waste. Possibly, plants which had already formed seeds grew in or near the *Isatis* fields while harvesting and were unintentionally collected and processed with the young leaves. The previous English finds of similarly eroded *Isatis* pod fragments, which were found in combination with degraded plant tissues, likely to be the remains of *Isatis* leaves, and with many other indications for textile dyeing (cf. § Archaeobotanical finds of medieval dye plants in the region), may support this assumption (Tomlinson 1985; Hall 1998). Since only unintentionally processed material from the blue dye plant was recognisable, this explains the sparsity of its remains, compared to the numerous weld and madder finds.

Conclusions

The archaeobotanical studies of medieval river deposits from Brussels and Mechelen revealed, for the first time in Belgium, archaeobotanical assemblages containing the three principal medieval dye plant species, *Reseda luteola*, *Isatis tinctoria* and *Rubia tinctorum*. Most likely, those remains can be interpreted as waste from dyeing activities. The finds provide a valuable addition to previous archaeobotanical finds of textile dyeing, which is scarce in the region, in contrast to historical data. Besides remains of dye plants, both contexts also contained other indications for wool processing, e.g. flower bracts of *Dipsacus sativus*, illustrating the potential of archaeobotanical analyses of fluvial context for the reconstruction of artisanal activities in medieval towns, often concentrated along the riverbanks.

The archaeobotanical finds of the 13th and 14th c. dye plants from Mechelen correspond well with information from historical sources, documenting the presence of dyers along the Melaan and in the vicinity of the excavation during this period. The botanical remains from the Melaan could not, however, confirm the historical indications for earlier local wool processing in the town. On the contrary, the archaeobotanical records from Brussels predate the oldest historical sources on dyers. The archaeobotanical remains of *D. sativus*, *R. luteola*, *R. tinctorum* and *I. tinctoria* indicate wool working and dyeing of textiles along the Senne from the third quarter of the 12th c. at the latest. The finds not only document the use of the plants in both towns, but they also suggest the discarding of waste from textile dyeing in the urban waters for several centuries, practices also recorded in 15th and 16th c. historical sources.

For large urban excavations of fluvial contexts, such as Parking 58, we encourage the application of an extensive sampling strategy, permitting to record both the chronological and spatial distribution of the plant remains, allowing a more profound interpretation of the assemblages. We recommend studying sufficient samples from each chronological phase and from multiple profiles. Less abundant remains, such as the *Isatis* pod fragments, appearing in low quantities in one fourth of the studied samples, may be missed, if only few samples are analysed. Moreover, *Rubia* roots/rhizomes were recognised only after the analyses of about 10 samples with similar assemblages. The lack of archaeobotanical data on textile dyeing is mainly due to the perishability of the plant material used in the dyeing process, which can be found in well-preserved waterlogged contexts only, but also due to recognition and identification issues. Remains of *Rubia* roots/rhizomes were identified combining archaeobotanical and chemical analyses. Such vegetative plant remains are easily overlooked, especially when mixed with other plant remains. For future studies of waterlogged fluvial deposits from textile-producing towns, we therefore recommend paying special attention to this type of plant remains.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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