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The early book herbaria of Leonhard Rauwolf (S. France and N. Italy, 1560–1563): new light on a plant collection from the ‘golden age of botany’

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Abstract

The 16th century was a golden age for botany, a time when numerous naturalists devoted themselves to the study and documentation of plant diversity. A prominent figure among them was the German physician, botanist, and traveler Leonhard Rauwolf (1535?–1596), famous for his luxurious book herbarium containing plants from the Near East. Here we focus on the less studied, early book herbaria of Rauwolf. These form a three-volume plant collection bound in leather and gold, which contains over 600 plants that Rauwolf collected between 1560 and 1563 in S. France and N. Italy when he was a student of medicine. We show the botanical value of Rauwolf's early book herbaria, exemplified by two exotic American specimens, namely one of the oldest surviving specimens of tobacco (*Nicotiana rustica*), collected in Italy, and the oldest known French record of prickly pear (*Opuntia ficus-indica*). We discuss Rauwolf's professional botanical network during his student years and suggest that the famous Swiss botanist Johann Bauhin (1541–1613), friend and companion of Rauwolf during his field excursions and their medical studies in Montpellier, has played a significant role in the compilation of this precious historical plant collection. We also reconstruct the story of the compilation of the book herbaria, as evidenced through observations of paper watermarks and written texts in the book volumes and show that all four book herbaria of Rauwolf were probably bound between 1577 and 1582.

1. Introduction

During the 16th century, numerous scholars across Europe devoted themselves to the documentation, description, collection, and preservation of the natural world (Ogilvie 2006; Cooper 2007). Turning to nature in search for the plants described in antiquity, these 16th-century naturalists discovered new plants, unknown to the ancient authors, and attempted for the first time in history to catalogue all then known species (Ogilvie 2006; Cooper 2007; Egmond 2018). They carried out field expeditions to collect plants, press-dried and glued them on paper sheets, compiling the oldest book herbaria that survive today. It was through these processes that botany diverged from a medicinal practice into a scientific discipline of its own (Stefanaki et al. 2019). In this so-called botanical Renaissance of the 16th century, no other naturalist exhibited the adventurous and pioneering spirit of the German physician, botanist, and traveler Leonhard Rauwolf (1535?–1596).

Rauwolf was born in Augsburg, a bustling merchant city in southern Germany. He became famous as the first post-Medieval European to travel to the Near East in search for new medicinal plants (Walter 2009; Ghorbani et al. 2018). This hazardous journey that lasted three years (1573–1576) is documented in detail in Rauwolf's personal travel account (Rauwolf 1583), a book that became a bestseller at its time, published in multiple editions and translations (Walter 2009; Ghorbani et al. 2018). In the first lines of his travelogue, Rauwolf finely outlines the concept of 16th-century botany, expressing his keen interest, since very early in his life, in the plants described by the ancient Greek and Arabic authors. He expresses his intention to acquire knowledge on these plants and see them in their native habitats (Rauwolf 1583). The

output of this profound, life-long desire was a large collection of almost 900 dried plant specimens bound in four book volumes.

Long before reaching fame, Rauwolf started the compilation of his plant collection while a young student of medicine. After a short attendance at the universities of Tübingen (1554) and Wittenberg (1556), he moved to the university of Montpellier (Ganzinger 1963; Dannenfeldt 1968). There, he studied medicine between 1560 and 1562, under the teachings of the renowned botanist, and pupil of Luca Ghini, Guillaume Rondelet (1507–1566) (Dannenfeldt 1968). During his student years, Rauwolf eagerly botanized in the surroundings of Montpellier, and also around Languedoc, Provence, Auvergne, and Rhône Alpes. The plants he collected formed the first two book herbaria. Rauwolf graduated in 1562 from the University of Valence, Dauphiné (Dannenfeldt 1968). In 1563, heading back to Augsburg, he traveled for the purpose of his *peregrinatio academica* in the Alps and N. Italy, heading forward through Switzerland to Germany, collecting on the way the plants that formed the third book herbarium. During this homeward journey, Rauwolf visited Conrad Gessner (1516–1565) in Zurich, accompanied by his friend and classmate from Montpellier, Johann Bauhin (1541–1613) (Durling 1965). According to Legré (1900), that same year, Rauwolf met in Augsburg with Carolus Clusius (1526–1609), to which he presented the plants he had collected in France and Italy, and presumably accepted Clusius' annotations and corrections of several plant names. Doubting Legré's argument, Ganzinger (1963) attributed the numerous annotations and corrections found in Rauwolf's herbaria to Leonhart Fuchs (1501–1566), suggesting that Rauwolf, on his way back to Augsburg in 1563, also visited Fuchs, his old teacher from his student years in Tübingen. Ganzinger (1963) also observed that Fuchs has marked several plants with the phrase 'Soll gerissen werden', an indication to illustrator Jerg Ziegler to draw these plants for Fuchs' upcoming herbal (Seybold 1990; Kusukawa 2006). The latter was an impressive collection of over 1500 plant illustrations that remained unfinished due to Fuchs' death and only saw the light of publication in 2001 (Baumann et al. 2001).

In 1571, Rauwolf was appointed city physician of Augsburg, a position that he lost seventeen years later due to his religious beliefs (Herde and Walter 2010). Having financial difficulties, he decided to sell his herbaria, which he achieved for a remarkable price; the four book volumes were bought in 1593 by a commissioner of the Habsburg Emperor Rudolf II (1552–1612) and came to Rudolf's famous art cabinet in Prague (Callmer 1973; Walter et al. in press). They were later stolen by Swedish troops and handed to Queen Christina of Sweden, and, together with the Italian En Tibi herbarium which was also part of Rudolf's curiosities collection, they were brought to Stockholm (Callmer 1973; Stefanaki et al. 2019). From Christina they came to the possession of the Dutch librarian Isaac Vossius (1618–1689). When Vossius died, his heirs sold Vossius' collection of books to Leiden University and the book herbaria finally came to Leiden, in 1690, where they are preserved to this day. The first volume is on display at the Boerhaave museum, and the remaining three volumes are kept in the treasure room of Naturalis Biodiversity Center.

The botanical content of the fourth volume comprising the plants that Rauwolf collected in the Near East was recently studied by Ghorbani et al. (2017, 2018). Our work focuses on the first three volumes of

Rauwolf's plant collection (hereafter Rauwolf's early book herbaria), compiled during his student years. Unlike Rauwolf's travels to the Near East, this early period of Rauwolf's botanical activity is hardly known. According to Dannenfeldt (1968) and Herde and Walter (2010), the best historical source for the travels of Rauwolf in France and Italy is Rauwolf's herbaria themselves, which have remained to date largely unexplored. Several attempts by J.G. Boerlage (1849–1900), former director of the Rijksherbarium in Leiden, to catalogue and identify the specimens of the three volumes, have remained incomplete (Naturalis archives). Part of the botanical contents of the first and second volume were published by Legré (1900), but the plant specimens of the third volume were never studied. Images of specimens contained in the herbaria have been published by Thijsse (2016), Stech et al. (2018) and Stefanaki and van Andel (in press). A full inventory of the plant species included in the herbaria is in preparation by some of the authors of this paper. Here we present some exotic specimens contained in the herbaria, discuss the professional botanical network of Rauwolf in the period when the herbaria were compiled, and elucidate the history of compilation of this precious historical collection.

2. Materials And Methods

To demonstrate the botanical value of Rauwolf's early book herbaria we focused on two specimens collected in Italy (tobacco, *Nicotiana rustica* L.) and France (prickly-pear, *Opuntia ficus-indica* L.). We searched for specimens of these two species in other surviving 16th-century book herbaria from Italy, France and other European countries, namely the herbaria of U. Aldrovandi (Soldano 2000–2005), A. Cesalpino (Caruel 1858), M. Merini (Chiovenda 1927), J. Girault (images of its index provided by the National Museum of Natural History, Paris), C. Bauhin (https://herbarium.unibas.ch), F. Platter (https://platter.burgerbib.ch/herbar), C. Ratzenberger (Kessler 1870), H. Harder (Speta and Grims 1980; http://daten.digitale-sammlungen.de/~db/0001/bsb00011834/images/), the Erbario Ducale Estense (Camus and Penzig 1885), the En Tibi herbarium (Stefanaki et al. 2018) and Erbario A and B (Penzig 1905).

To explore the botanical network of Rauwolf in the period of compilation of his early book herbaria, we identified the naturalists who contributed handwritings in the three book volumes. For this we compared the handwritings of plant names, descriptions and annotations found next to the plant specimens and in the indices with samples of the handwriting of Rauwolf in two autograph letters, to Joachim Camerarius dated 27 March 1579 (http://gateway-bayern.de/BV043447612) and Carolus Clusius dated 06 September 1584 (Special Collections, Leiden University Library; https://clusiuscorrespondence.huygens.knaw.nl/edition/entry/1428), and the handwritings of other 16th-century naturalists that are reported to have been connected to Rauwolf in the 1560s. These are (i) Carolus Clusius, of which we used autograph letters to various recipients held at the Special Collections of Leiden University Library, the Trew collection (www.trew-letters.com), and Clusius' correspondence: a digital edition-in-progress (https://clusiuscorrespondence.huygens.knaw.nl/edition/); (ii) Leonhart Fuchs, of which we used two autograph letters to Joachim Camerarius, dated 24 November 1565 (http://gateway-bayern.de/BV044375082), and 27 May 1543 (Stübler 1928); (iii) Conrad Gessner (two

autograph letters, to Hieronymus Frobenius dated 15 January 1561 and to Georg Cassander dated 09 October 1562, both held at the Special Collections of Leiden University Library), and (iv) Johann Bauhin (six autograph letters to Joachim Camerarius sent between 1578 and 1597, available from the University Library Erlangen-Nürnberg, https://ub.fau.de/).

To elucidate the history of making of Rauwolf's early book herbaria, we transcribed the calligraphic text of the title pages of the three book volumes, and carried out observations of the watermarks and characteristics of the paper by means of transmitted light, using a thin, flexible electroluminescence sheet. We attempted to trace the watermarks found in the three volumes in the catalogue of the Memory of Paper database of the Bernstein project, www.memoryofpaper.eu/BernsteinPortal.

3. Results And Discussion

The three early book herbaria of Rauwolf are large (32 x 21.5 cm), leather-bound volumes, which can be closed with metal, copper-coloured clasps. Although several conservation treatments have been performed in the past, the bindings are still mainly in their original state. The leather on the boards and the spine of the books show gold embossed decorations (Fig. 1). The three books have the same content arrangement, each one consisting of a calligraphic title page (Fig. 2; Online Resource 1), followed by more than 200 plant specimens glued on both sides of the paper sheets, and an ascending index of plant names at the back of each book (Fig. 1). Strips of green-coloured paper, decorated with silver embossed motifs are found attached to all margins of the herbarium sheets. These strips were added to protect the plant specimens from abrading each other. The strips were probably added by the book binder, as their embossed decoration appears to have been made by means of roll, a known stamp tool in the bookbinder's workshop. The first and second volumes contain mainly native species of S. France. The third volume mostly contains plants native to N. Italy and the Alps, and some exotic species. A number of plants contained in the third volume have been collected in Switzerland and Germany.

3.1. Tobacco

Among the New World plants that are present in the book volumes, we find a specimen of tobacco, *Nicotiana rustica* L., which Rauwolf collected in Italy in 1563 (Fig. 3). *N. rustica* is an Andean species that was cultivated by N. American colonists before common tobacco, *N. tabacum,* but was replaced by the latter because *N. tabacum* was preferred by European importers (Lewis 2011). *N. rustica* is distinguished morphologically from common tobacco by its yellow flowers with wider corolla tubes slightly exceeding the calyx (Knapp et al. 2004).

According to Meyer et al. (1999), *N. rustica* was first introduced into Europe in the Low Countries, in the mid-1540s through Spanish merchants. Its earliest scientific illustration appeared in 1553 by the Flemish Rembert Dodoens and carries the name 'Hyoscyamus luteus' (Dodoens 1553; Meyer et al. 1999). In 1558 it was brought from Flanders to Portugal (Meyer et al. 1999) and according to De Toni (1940) through Portugal it reached Italy around 1561. However, this latter introduction step is obscure, as the tobacco plants brought to Italy from Portugal may have been *N. tabacum*, as currently believed (Vincentini et al.

2020 and references therein). Possibly, *N. rustica* was already cultivated in Italy the decade before, as Gessner remembers that in 1554 he had received seeds from either France or Italy (Kusukawa 2012). Since these statements are uncertain, we can at least infer from the fact that Rauwolf acquired his specimen during his visit to Italy in 1563 that *N. rustica* was most likely cultivated by that year in the country. Rauwolf knew tobacco already from France, as he calls it 'Priapeïa', a name apparently used for *N. rustica* by Rondelet (Kusukawa 2012), Rauwolf's teacher in Montpellier. Besides the Rauwolf herbaria, the only Italian 16th-century collection that contains specimens of *N. rustica* is the herbarium of Aldrovandi. One specimen, approximately dated 1554–1560, is named by Aldrovandi as 'Hyosciamus Gallicus' (Soldano 2003), implying a French provenance, and a second specimen did not come from a plant grown in Italian ground, but was sent to Aldrovandi from Jean de Brancion from Mechelen, Flanders, between 1563 and 1568 (Soldano 2004). Three specimens of *N. tabacum* included in the Aldrovandi herbarium are all of Italian provenance and dated c. 1565–1580 (Soldano 2004), and one specimen contained in the Erbario Estense is dated 1570–1598 (Camus and Penzig 1885; Vincentini et al. 2020). A plant specimen named 'Priapeia' in the French Jehan Girault herbarium from 1558 probably belongs to either *N. rustica* or *N. tabacum*. Other early tobacco specimens are found in German herbaria compiled later in the 16th century, namely those of Caspar Ratzenberger from 1592 (*N. rustica, N. tabacum*) (Kessler 1870), and Hieronymus Harder from c. 1576–1594 (*N. tabacum*) (http://daten.digitale-sammlungen.de/~db/0001/bsb00011834/images/), and c. 1599 (*N. rustica, N. tabacum*) (Speta and Grims 1980).

3.2. Prickly pear

Another interesting exotic plant included in Rauwolf's early book herbaria is a specimen of prickly pear or Indian fig, *Opuntia ficus-indica* (L.) Mill. This specimen, consisting of a large leaf and a flower, shows the excellent specimen preparation technique of Rauwolf, with the succulent tissue carefully removed and the skin without spines firmly glued on the paper (Fig. 4). There is textual evidence that Rauwolf was also horticulturally familiar with *Opuntia*: on 10 May 1581, Johann Aicholz († 1588), professor of medicine and Clusius' landlord in Vienna, reported to his Nuremberg colleague Camerarius that he had received instructions on how to care for his 'Opuntia' from Rauwolf (http://gateway-bayern.de/BV043425098). This Mesoamerican species, that Rauwolf collected between 1560 and 1562 in S. France, was probably first introduced to Seville, Spain (Casas and Barbera 2002). It was observed growing wild in Rome, Italy, as early as 1549 by Johannes Kentmann, but was still unknown to local physicians (Eggli et al. 2018). On showing the strange plant to Luigi Anguillara, director of the botanical garden in Padua, Anguillara suggested that this was the 'Opuntia' of Pliny; it was through this random incident that this New World plant was accidentally given the name of a plant of antiquity (Kusukawa 2009; Eggli et al. 2018). Kentmann made an illustration of prickly pear and reported the later testimony of a Venetian apothecary that this plant was abundant in the Indies where it produced small sweet figs, and therefore it was then named by Italians as Indian fig (Kentmann 1549). One year later than Kentmann, in 1550, Aldrovandi also reports seeing the plant in Rome (Soldano 2000), and in 1553 he included two specimens from Toscany in the fifth volume of his herbarium (Soldano 2002). Prickly pear appeared in scientific literature again

under the name ‘Opuntia’ in Matthioli’s 1554 edition of his Commentaries on Dioscorides. In the 1558 edition the text is accompanied by the species’ first scientific illustration (Matthioli 1554, 1558; Casas and Barbera 2002; Eggli et al 2018). One specimen identified as *O. ficus-indica* appears also in Erbario A, a 16th-century Italian book herbarium of uncertain origin (Penzig 1905; Stefanaki et al. 2019). Unlike the rich record of prickly pear from 16th-century Italy, no information could be found in literature about France. To our knowledge, the Rauwolf specimen of *O. ficus-indica*, dated 1560–1562, is the oldest surviving French specimen of prickly pear and the earliest evidence of occurrence of this invasive plant in France. Today this species is locally naturalized in continental S. France, in Côte d’Azur and Albères (Tison and de Foucault 2014). Another 16th-century specimen of prickly pear, dated c. 1577–1624, is included in the Swiss herbarium of Caspar Bauhin (online available at herbarium.unibas.ch).

3.3. Handwritings and Rauwolf’s botanical network in the 1560s

The early book herbaria of Rauwolf are not only an important source of early botanical records. They also provide information on 16th-century professional botanical networks, observed through the various handwritings present in the three book volumes. We have identified three different hands that contributed plant names and annotations in the book volumes, of which one was matched to Rauwolf (Fig. 5A) in his autograph letters to Camerarius and Clusius from 1579 and 1584, respectively.

We were surprised to discover that the most frequent handwriting of volumes one and two compiled in France does not belong to Rauwolf himself. The handwriting of Rauwolf appears in less than one fifth of the plant specimens contained in these two volumes. We matched this dominant handwriting of the French volumes to the handwriting of Johann Bauhin (Fig. 5B; Online Resource 2), classmate of Rauwolf in Montpellier and his companion during field excursions in S. France (Longeon 1976). Although we noticed considerable diversity within the handwriting of Bauhin in his autograph letters, and also within the handwriting in volumes one and two identified herein as Bauhin’s, remarkable similarity was observed in the overall hand’s style, in many individual capital and small characters and in the link between characters (Online Resource 2). The only noteworthy dissimilarity we could observe between herbarium volumes and autograph letters was in character ‘h’ (Online Resource 2). Legré (1900) had probably also noticed the presence of another handwriting than Rauwolf’s, but not to its actual extent, since he refers to many of Bauhin’s annotations as if they belong to Rauwolf. Closer observations however leave no doubt that the two handwritings, identified herein as Rauwolf’s and Bauhin’s, belong to two different hands (Fig. 5A, B).

This interesting new finding about the relationship between Rauwolf and Bauhin shows an active involvement of the young Swiss fellow student in the making of the early book herbaria of Rauwolf. Bauhin wrote most of the Latin plant name(s) appearing next to the specimens of volumes one and two, and for some plants he also noted down French and German names in Gothic characters. Here and there he even added remarks on a plant’s morphology, biology, habitat or abundance. Bauhin’s thorough annotations show his emerging scholarly interest in the study of plants, which would later be revealed through his *Historia Plantarum Universalis,* Bauhin’s posthumously published *opus magnum* which

described thousands of plants. It is remarkable that Rauwolf hardly ever mentioned Bauhin in his later life, at least not in his surviving mail correspondence. But, interestingly, Bauhin referred to Rauwolf in several plant descriptions in *Historia Plantarum Universalis* (Bauhin 1650–1), showing his esteem to his old field companion.

The making of a plant collection was a personal practice that all students of medicine would learn by Rondelet in Montpellier, it is therefore remarkable that the collection of Rauwolf has such an evident contribution of another student. It can be assumed with good reasons that in France, Rauwolf being still a beginner in botany asked the help of his classmate Bauhin, while later in Italy he had advanced enough to prepare the third volume by himself. In the third volume, the dominant handwriting belongs to Rauwolf himself and the handwriting of Bauhin is absent. It is also likely that Bauhin did not accompany Rauwolf in his plant collections around N. Italy, although he also lived in Italy in 1563 (Cristofolini et al. 1993) and did join Rauwolf in the journey of return from Italy, as we know that the two signed together the *Liber amicorum* of Gessner in Zurich in May 1563 (Durling 1965). By the time that Rauwolf headed to the Near East, he had become a master in methodically identifying and describing plants, even exotic ones; the plant names appearing in his travelogue and fourth book herbarium are botanically and lexicologically flawless (Walter et al. in press). Bauhin also had his own herbarium, which he had presented to Conrad Gessner (see Gessner to Benedictus Aretius, 24 November 1565, www.aerztebriefe.de/id/00016205). These plants may be now part of the herbarium of his younger brother Caspar kept in Basel (Cristofolini et al. 1993).

A third handwriting (Fig. 5C) of small spidery letters that frequently appears in all three volumes has been noticed also by previous authors, who attributed it to either Carolus Clusius (Legré 1900) or Leonhart Fuchs (Ganzinger 1963). Based on our comparison with autograph letters of both botanists, this handwriting was undoubtedly matched with Fuchs' characteristic handwriting. It appears in a total of 162 plant specimens, which is a bit more than the 148 cases that Ganzinger (1963) had observed. Among Fuchs' annotations the indication 'Soll gerissen werden' to illustrator Jerg Ziegler appears in 56 of the herbarium folia. Most of the plants that Fuchs indicated to be illustrated are contained in the first and second volume (20 and 27, respectively) compiled in France. Only nine plants were indicated to be illustrated in the Italian third volume. This shows that it was primarily the French plants that were of interest to Fuchs, rather than those collected in Italy, the latter having been frequently botanized by N. European 16th-century naturalists.

Observing the numerous annotations of Fuchs in the herbarium volumes, it becomes evident that the famous German botanist showed a rather disrespectful attitude to the young and yet unknown Rauwolf. Fuchs 'corrected' Rauwolf's herbaria as if they were a student essay, even crossing out some of Rauwolf's and Bauhin's plant names, replacing them with his own suggestions and adding numerous annotations not addressed to Rauwolf but to Fuchs' illustrator. Moreover, Fuchs never officially named Rauwolf's herbaria as a material source for his illustrated manuscript (although he did mention in 1563 to Camerarius that he included Rauwolf's material in his manuscript; Meyer et al. 1999). Even worse, many suggestions of plant names that Fuchs provided were actually less accurate than the names originally

given by Rauwolf and Bauhin. This is shown for example in two specimens of marigold (*Tagetes erecta* L.), another American species that Rauwolf collected in Italy (Vol. 3, folia 19–20). Rauwolf's reasonable name 'Tagetis' was crossed out and corrected to 'Betonica' by Fuchs. More examples of such inaccurate corrections are provided by Legré (1900; erroneously referring to Clusius). Nevertheless, Rauwolf humbly accepted this and most of the suggestions of his former teacher, discarding his own plant names when he later wrote the book indices.

Legré (1900) incorrectly attributed the handwriting of Fuchs in the Rauwolf herbaria to Clusius, claiming as evidence Clusius' handwriting in his personal archival annotations on his correspondence letters held at the Leiden University Library. Based on our observations, the handwriting of Clusius is not present in any of the three book volumes. Legré's hypothesis that Clusius annotated the herbaria is also historically flawed. When Clusius visited Augsburg in 1563, he was not yet a famous botanist, so it was unlikely that Rauwolf would seek a meeting with him to show him his plant collection. Actually, many years later, in 1582, Clusius wrote to Joachim Camerarius that he did not know Rauwolf personally yet (Walter et al. in press). Moreover, Clusius, like Rauwolf, had studied botany in Montpellier with Rondelet, it is therefore unlikely that such a good botanist with knowledge of the local flora would make erroneous plant identifications. On the other hand, Fuchs, although also a good botanist, was unfamiliar to the Mediterranean flora as he had never traveled to the south and this was the reason why he desired that plants from Rauwolf's herbaria were drawn after for his herbal in preparation.

Rauwolf must have shown his freshly compiled plant collection to Gessner too during his stay in Zurich in 1563 (Walter et al. in press). But, although the name of Gessner as author of plant names does appear a few times in the book volumes, written either by the hand of Bauhin or Rauwolf, Gessner himself did not make any annotations in Rauwolf's herbaria, as his handwriting could not be found in any of the three volumes.

3.4. Watermarks and the story of making of Rauwolf's early book herbaria

Various types of paper can be distinguished in the three book volumes (Table 1). Volumes one and two compiled in France appear to have paper with the same three watermarks: types 'fish & crown', 'hand/glove & flower', and 'helmet-like'(Table 1; Online Resource 3). Good matches for these watermarks could not be found in the Bernstein 'Memory of Paper' watermark catalogue. Volume three compiled in Italy shows a very different paper composition, including watermark types 'serpent & coat of arms', 'triple mountain & cross', and 'letter B & trefoil' (Table 1; Online Resource 3). Only for the 'triple mountain & cross' type (Online Resource 3), corresponding watermarks were found in the Bernstein catalogue. The most similar ones, registered in paper used in the city of Padua in 1553–1554 (see e.g. https://www.wasserzeichen-online.de/wzis/detailansicht.php?id=34847), appear to confirm an Italian origin. Padua is one of the places that Rauwolf visited in 1563 (Fig. 2), and it seems likely that he acquired this paper there. Paper with again other types of watermarks is present in the volumes' indices and title pages. These differences in the paper and watermark types show that Rauwolf was gradually buying stacks of paper while progressively enlarging his collection. He apparently went to Italy with some

paper leftover from France (the one with the 'helmet-like' watermark type, present in all three book volumes, and the one with the 'heraldic eagle & crown' watermark, present in volumes 2 and 3; Table 1), and continued to gradually acquire more stacks of paper in Italy while progressing the plant collections. The books' title pages, indices, and endpapers have also paper of different quality and watermarks (Table 1), a fact that shows that the title pages, indices, and binding were probably made at a later stage.

Table 1. Watermark types present in the book volumes. Watermarks of the numbered folia are indicated with 'x'. Examples of the watermarks are provided in Online Resource 3.

Watermark	Vol. 1	Vol. 2	Vol. 3
'Fish & crown'	x	x	
'Hand/glove & flower'[a]	x	x	
'Helmet-like'	x	x	x
'Heraldic eagle & crown'[b]		x	x
'Serpent & coat of arms'			x
'Triple mountain & cross'			x
'Letter B & trefoil'			x
'Letters AR & lily'	index, sheet after title page	index, title page	
'Heraldic eagle, small'[b]	title page		
'Heraldic eagle & nimbus'[b]			index

[a]Several variants.

[b]Shape not clear.

For several years Rauwolf must have kept the plants he had collected in France and Italy on loose paper sheets. The indices found at the back of the three volumes, all written by the hand of Rauwolf, were probably made around 1564, as Rauwolf has written in the index of the second volume. In that year Rauwolf was still fresh back in Augsburg, unmarried and without employment. He probably had hardly to deal with patients, as newly graduated doctors were generally avoided. Rauwolf may therefore have had not enough money to let his book herbaria bind, but probably plenty of time to put the plants in order and prepare the indices. Although Rauwolf's early book herbaria are smaller in size and less luxurious that the masterpiece fourth herbarium, all four books share the same calligraphic style in the title pages, numbered in series as Erste, Ander, Dritte, and Vierte Kreütterbuch, similarities that indicate that the four volumes were probably bound in the same period. The title pages of the four books were produced by

distinguished specialists. Augsburg, where Rauwolf lived, was one of the richest cities in Germany, with excellent craftsmen and artists available. The four books were probably not bound before 1571, as in the title pages Rauwolf is named as the city doctor of Augsburg, a position that he only acquired in 1571. Interestingly, on 30 August 1577, Rauwolf declared that he was still rearranging the plants that he had collected in the Orient and glued them in the 'right order' on paper (www.aerztebriefe.de/id/00000167). Rauwolf worked on his travelogue until 1582. His decision in 1584 to sell his herbaria due to financial difficulties makes it unlikely that he would have had the books rebound in a time-consuming and expensive process. We therefore suggest that all four volumes were probably bound between late 1577 and 1582.

4. Conclusion

The early book herbaria of Leonhard Rauwolf are a valuable source of information on Early Modern students of medicine botanizing in the field in France and Italy. They contain some of the earliest records of useful plants, such as tobacco and prickly pear discussed herein, adding to our knowledge of introduction of these exotic species to Europe. This collection is also an important source of information on professional networking of 16th-century naturalists. Studying the different handwritings present in the three books we follow the relationships of Rauwolf with other famous 16th-century botanists. The study of watermarks and handwritten texts in Rauwolf's early book herbaria allowed us to elucidate the making process of this collection, demonstrating the benefits of interdisciplinary research when studying historic plant collections. The remarkable number of watermarks present in the books, to which no similar ones could yet be found in the existing watermark databases, shows the value of Rauwolf's early book herbaria also for the study of the history of paper. The next step of our research is the botanical inventory of Rauwolf's early book herbaria, expected to reveal more of the botanical importance of this precious historical plant collection.

Declarations

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Conflict of interest

The authors declare that no conflict of interest exists.

Availability of data and material

All data produced in this research are included in the manuscript and its supplementary files.

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Figures



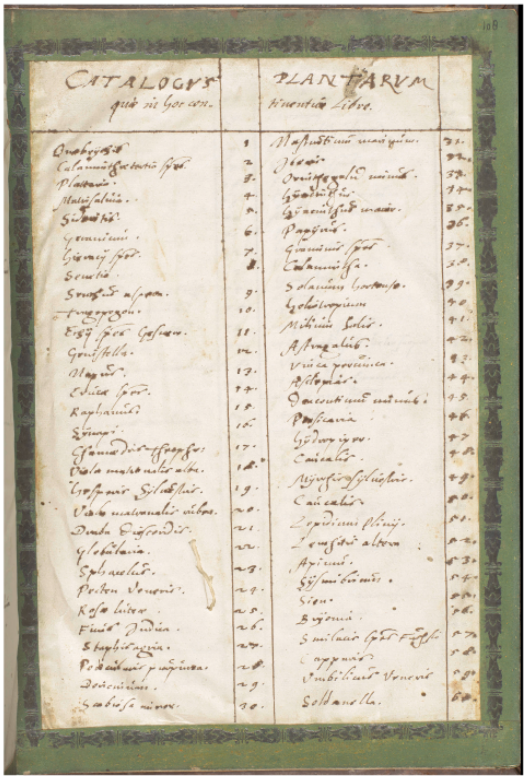
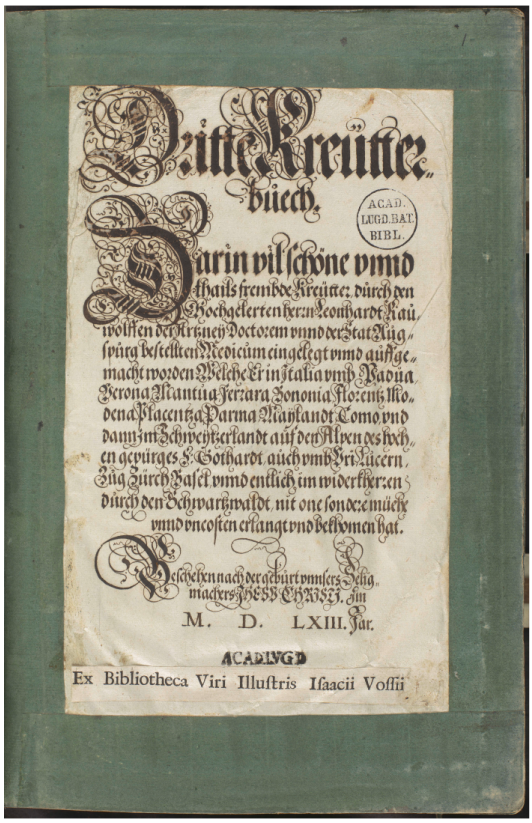


Figure 1

The second volume (left) and index of first volume (right) of the early book herbaria of Leonhard Rauwolf



Dritte Kreütterbuech. Darin vil schöne vnnd thails frembde Kreütter, durch den Hochgelehrten hern Leonhardt Rauwolffen der Artzneÿ Doctorem vnnd der Stat Augspurg bestellten Medicum eingelegt vnnd auffgemacht worden. Welche Er in Italia vmb Padua, Verona, Mantua, Ferarra, Bononia, Florentz, Modena, Placentza, Parma, Maÿlandt, Como, vnd dann jm Schweÿtzerlandt auf den Alpen des hochen gepürges S: Gothardt, auch vmb Vri, Lucern, Zug, Zürch, Basel, vnnd entlich im widerkherren durch den Schwartzwaldt, nit ohe sondere müehe vnnd vncosten erlangt vnd bekhomen hat.

Beschehen nach der geburt unnsers Seligmachers JESU CHRISTI. Im M. D. LXIII. Jar.

[Underneath printed Ex Libris:] Ex Bibliotheca Viri Illustris Isaaci Vossii.

Third herbal book. In which [there are] many beautiful and partly foreign herbs, which were put in and compiled by the highly learned Leonhard Rauwolf, doctor of medicine and town physician of Augsburg, which he acquired and received in Italy around Padua, Verona, Mantua, Ferrara, Bologna, Florence, Modena, Piacenza, Parma, Milan, Como, and then in the Swiss land, in the Alps at the St. Gotthard massif, also around Uri, Lucerne, Zug, Zurich and Basel, and finally on his way home through the black forest, not without special effort and cost.

He did that after the birth of our Savior Jesus Christ in 1563.

Figure 2

Title page of the third volume compiled in N. Italy, with transcription (top right) and English translation (below right)



Figure 3

Specimen of tobacco (Nicotiana rustica L.) from the third volume (N. Italy, 1563)



Figure 4

Specimen of prickly pear (Opuntia ficus-indica L.) from the first volume (S. France, 1560–1562)

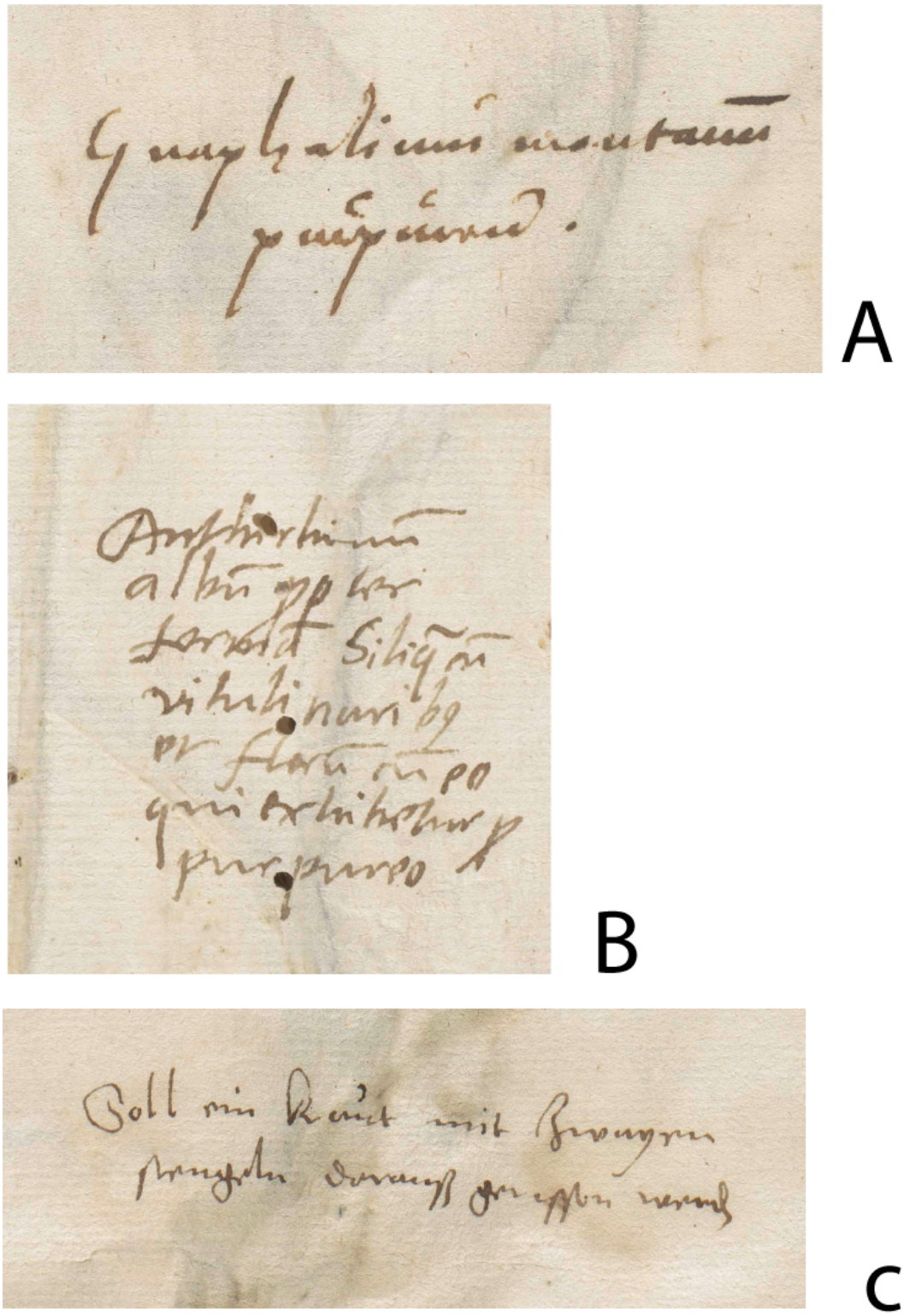


Figure 5

Examples of handwritings from the three book volumes: Leonhard Rauwolf (A); Johann Bauhin (B); Leonhart Fuchs (C)

Supplementary Files

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