Herbarium specimens: is there a best approach to mount dried plant specimens?

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Abstract

The basic principles for attaching dried pressed plant specimens to a mounting medium have not changed significantly since the 16th century when the first specimens were made. However, a wide range of variations in the practice of plant mounting can be seen today. Based on a survey, the three most common methods are totally adhered, partially adhered and strapped. We evaluated the robustness and efficiency of these approaches, alongside the un-mounted approach, by sending a set of test specimens of vascular plants (seed plants and ferns) on loan to expose them to mechanical risks and recording both failures of the mounting technique and damage to the specimen. In light of the results of this study, we analyzed their stability and suitability for maintaining the material useful for yet unforeseen studies (which can go beyond genetic studies). The present study can help towards determining what might be considered best practices (approach) to mount dried plant specimens, aiming to use a less/or a non-invasive mounting technique.

Keywords: botanical specimens, collections, dried plants, herbarium, plant mounting, preservation.

Introduction

The world's herbaria contain specimens that have been prepared, maintained, and curated for 400 years. According to *Index Herbariorum* there are ca 3095 active herbaria today that collectively are estimated to house more than 396 million specimens (Thiers, 2023). These herbaria provide a vast, distributed resource of specimens that are not only the physical evidence of species occurrences in place and time but that also provide resources of DNA, and associated organisms together with information about cultural heritage and history. Herbarium specimens can help to answer a plethora of questions across disciplines, from conservation to climate change, domestication, and colonial history, though taxonomy remains at the heart of the research using these collections (Carine, *et al.*, 2018; Funk, 2003; Heberling and Isaac, 2017; James, *et al.,* 2018; Lang, *et al.,* 2019; Schindel and Cook, 2018).

The origins of the approach of dried plants being attached to paper can be traced to at least Luca Ghini (1490 – 1556) in the late 15th or early 16th century (Pavord, 2005). However, a range of mounting techniques have evolved and been used over past centuries.

Bridson and Forman (1989) examined two approaches for mounting, namely 'strapping' (the 'straps' being thread, linen tape, archival self-adhesive tape or plastic glue) and 'overall gluing'.

We use the term 'adhered' since most adhesives used in herbaria today are not animal-derived glues but synthetic adhesives.

They focused on the pros and cons of these techniques in terms of stability and the risks of physical damage to the specimens as objects and noted that specimens are susceptible to damage if they are strapped, while adhering reduces damage, and gives them better long-term protection. However, as Yesilyurt (2009) noted that the mounting technique adopted may impact on longevity not only the physical integrity of herbarium specimens but also their value as a scientific resource, given the range of questions they are now used to address (e.g. Gutaker, *et al,* 2019).

In contrast to Bridson and Forman (1989), Grenda-Kurmanow (2021) suggested that the total adhesion of specimens could contribute to their degradation on many levels while Heberling and Isaac (2017) also highlighted the impact of mounting method on the scientific value of the specimens, not least for future, unanticipated uses of herbarium specimens. They concluded that further consideration of the techniques used for mounting specimens is needed to ensure that their scientific value is not compromised.

Aims of this project

Given the importance of mounting technique used for ensuring the long-term preservation of herbarium specimens, both as physical objects and as a scientific resource, this paper has two main aims. First, we aimed to gauge the range of plant mounting techniques in use worldwide.

Second, we tested the hypothesis that a herbarium specimen would suffer greater damage if not well attached ('overall gluing' of Bridson and Forman, 1989) through assessing the damage to specimens included in test loans to institutions to both UK and international locations when specimens that were totally adhered, partially adhered, strapped or un-mounted were dispatched through the post. Finally, we consider the pros and cons of these plant mounting methods, considering both the scientific sustainability of a specimen, protecting its functionality for unanticipated applications and uses, as well as its physical endurance.

Material and Methods

2.1 Herbarium mounting techniques worldwide

To document the mounting techniques used in herbaria worldwide, a questionnaire was sent via e-mail to 175 institutions from 46 different countries in which they were asked about the technique used to mount dried plant specimens. Each institution was additionally asked to provide information on the number of plant mounters and volunteers; the number of working hours; the number of specimens mounted; whether or not the specimens were pressed after adhering, and if so, what it was; the mass of the object/s used to press the specimens and the pressing duration; the adhesives used; mode of application of the adhesive; how long the institution had used the adopted technique; and whether or not institutions sent specimens on loan. Only the data to gauge the range of plant mounting techniques in use worldwide is presented here. The survey was conducted in 2009.

Information on mounting techniques used by other herbaria was also gathered from specimens loaned to Natural History Museum (NHM here and after) for taxonomic research undertaken by Yesilyurt (2004).

2.2. Testing the robustness of methods used to mount dried plant specimens, when sent in transit ('loan-exercise' experiment)

To test the robustness of herbarium specimens in transit, we prepared specimens, using four different approaches, which were sent to five institutions. The selected approaches were: unmounted specimens (leaving them loose inside species covers, made from paper); partially adhered (mounted by applying adhesive in some key point areas of the specimen); totally adhered (mounted by applying adhesive all over the surface of the specimen) and strapped (securing the specimens by adding straps in some parts of the specimen). Many of the specimens selected for the study were particularly vulnerable to mechanical damage such as ferns that were overdried (specimens that have been exposed to (high) heat for long period during the drying process, resulting into a very dark brown to sometimes black colour, e.g. Fig. 7B and 7E), and brittle and very fragile or plants with leaves with long petioles. A number of open three-dimensional fruit specimens were also chosen to be part of the experiment. For some specimens mounted using the strapping approach, we applied straps to areas such as the tips of leaves to investigate the impact of strapping in this way since this approach has been used in the past at the NHM.

A range of adhesives and straps were used in the present study. However, since previous studies (e.g. Croat, 1978; Clark, 1986; Grenda-

Fig 1: Examples of the specimens prepared for the sets.
A: sample of two sets of collections, illustrating that the specimens were, whenever possible, either the same or with similar structures and/or type of plants (Image: J.C. Yesilyurt, 2022).
B: examples of ferns and climbers (Image: J. Jackson, Natural History Museum, Photo Unit, 2024).

Kurmanow, 2021) have examined the use of different adhesives, the present paper will be focusing on the results for subset of the specimens that were mounted using one of two types of adhesives that have been used at the NHM (Polyvinyl Acetate (PVA hereafter) and Methylcellulose (MC hereafter) and of the two types of straps that also have been used at the NHM ('Gunned linen tape' (S-I hereafter) and 'SUALTC 7150' (S-II hereafter)). However, overall figures of the adhesives used during the study will be provided to contextualise the outcomes discussed here. PVA has been used at NHM for mounting specimens during for at least the past 49 years, while MC has been occasionally for repairs. For strapping, the NHM has used S-I for nearly 45 years and S-II for the past 20 years.

Six sets of specimens were prepared with one was retained at the NHM (herbarium acronym BM; acronyms follow Index Herbariorum: IH, here and after) as a control. Specimens were sent to the following herbaria: E (Edinburgh, UK), P (Paris, France), SPF (São Paulo, Brazil), MICH and US (both from United States of America). Acronyms for the herbaria follow the *Index Herbariorum* (IH, here and thereafter). These herbaria- were selected to represent a range of geographical distances from BM (London, UK). All institutions were consulted prior to taking part on the study and agreed to participate and follow the guidelines. Specimens were despatched using courier companies or mail and with label 'Fragile' attached to them.

Fig 2: Examples of the specimens prepared for the loan exercise, with printed copy of the photographs. A: examples of two unmounted specimens, inside flimsies; the herbarium sheet was removed to take this photograph to show the loose material and labels. B: example of mounted specimen. (Images: J. Jackson, Natural History Museum, Photo Unit, 2024).

Specimen sets were selected so that they would include both fragile and flimsy specimens, those that were brittle and those that have thick twigs and bulky structures (e.g. fruits/seeds). Wherever possible the sets were similar regarding the type of vouchers (Fig. 1), so that, each herbarium/ institution received a duplicate of the same type of dried plant specimen. Where this was not possible, herbaria received a specimen selected to have similar characteristics, and whenever possible, they were prepared with the same mounting method.

Each loan comprised between 41 and 49 specimens within which 6-10 were totally adhered, 8-11 were partially adhered, 21-28 were strapped and 2-3 were unmounted. In total, for the study 37 specimens sent on loan were totally adhered, 48 partially adhered, 127 strapped and 11 unmounted.

Specimens were placed inside thin, non-archival quality paper species covers (flimsies here and thereafter; Fig. 2A). Unmounted specimens (Fig. 2A) were placed inside flimsies with a herbarium sheet placed underneath. Photographs of the specimens taken soon after specimens being mounted were also included inside the flimsies, underneath the herbarium sheet (Fig. 2B), and these were used to allow recipients to assess and mark failures (of the materials) and damage (to the specimens) upon receipt.

Specimens were sent on loan as parcels wrapped in two layers of brown paper and similar packaging was requested for the return of the specimens. Cardboard or boxes, that are standard packaging for herbarium specimens, providing support, were not used so to maximise the expose of specimens to possible risk of damage during transit.

Recipients were asked to compare the specimen with the printed image on receipt and to annotate all damage on the printed image, including observation of debris, broken parts and/or lose fragments and any tears of the straps or failure of the adhesive they observed. The specimens were further scrutinised for damages and/or failures upon their return to BM. Changes to the specimen as a result of transit were categorised as *Failure* if the method or the material failed (this would include detachment of the specimen or detachment, tears or breakage of the straps) and *Damage* if the damage was to the specimen itself.

Results

3.1. Herbarium mounting techniques worldwide

83 of the 175 herbaria contacted responded to the survey. Herbaria from all regions defined by Thiers (2023, online) were represented with the exception of the Pacific. Information on a further 15 institutions was based on material loaned to Jovita C. Yesilyurt (JCY hereafter) for taxonomic revisionary work (Yesilyurt, 2004). Table 1, lists the herbaria by geographical region, based on Thiers (2023, online).

In total, 70% indicated that they use a single mounting method, with strapping being predominant (37%) over adhesion (33%). Sewing, stitching or pinning were grouped under strapping and adhesion included key-point adhesion method (Table 2).

Regional variations are evident from Table 2 (see also Fig. 3). Strapping is the most frequently used technique in Europe with a combination of methods also common and few herbaria only using adhesion. In contrast, none of the North American respondents used strapping as their sole (or main) technique and in the Caribbean and Central and South American region and most strikingly in central America (Fig. 3), adhesion was the most popular method among respondents.

Consistent with the survey data, observations on material loaned to Yesilyurt (2004) revealed that strapping was the commonest approach, although this was sometimes supported with stitches, especially in the bulkier parts of the specimens. A wide range of materials were considered strap mounted (e.g. commercial tapes, adhesive; see Fig. 4).

3.2. Testing the robustness of material sent in transit.

Of the 223 specimens sent on loan, 113 (51%) were affected with 64 specimens (29%) presenting a failure (the failure of the material which included detachment of the specimen; detachment, tears or breakage of the straps) and 49 (22%) showing damage to the specimen itself (Table 3).

Damages and failures were not observed on 54% (69 out of 127 specimens) under the strapped approach, 36% (4 out of 11) of unmounted specimens, 29% (14 out of 48) of partially adhered and 11% (4 out of 37) from totally adhered specimens.

Table 1: The distribution of herbaria for which information on mounting method was obtained by geographical region (after Thiers, 2023 [online]). Acronyms follow Index Herbariorum (IH)

Region	Number of herbaria listed in IH	Herbaria providing information (bold = collections loaned to JCY)	Data only from material loaned to JCY	Total number (percentage of regional herbaria surveyed)
Europe	828	34: AIX, BCN, BHUPM, **BR**, BRLU, **C**, CGE, CL, E, FR, GB, H, JE, **K**, KUO, **L**, LE, LEB, MAF, MSM, O, ORT, OXF, **P**, PC, PAL, **PI**, RO, **S**, TFC, TRH, TUR, UPS, WAG	8: B, BOLO, FI, G, M, PR, TCD, U	42 (5%)
Africa	179	4: BOL, EA, J, YA	0	4 (2.2%)
Temperate Asia	785	5: HUJ, IBCA, IBK, KUM, TI	1: PE	6 (0.8%)
Tropical Asia	212	6: **BO**, KEP, LAE, SAN, SING, VNM,	0	6 (2.8%)
Australia and New Zealand	48	6: BRI, CANB, CHR, HO, MEL, WELT	0	6 (12.5%)
Pacific	12	0	0	0 (0%)
North America	844	11: A, AMES, CAN, ECONN, FH, **GH**, **MO**, MT, NEBL, **NY**, QFA,	2: UC, US	13 (1.5%)
Caribbean, Central and South America	416	17: BBS, COL, CONC, CTES, EAP, FCQ, HAC, HULE, IBUG, IEB, INB, LAGU, PMA, SGO, **SPF**, UADY, UB	8: BHBC, FURB, GUA, MBM, OURP, PACA, RB, SP	21 (5.0%)

Failures have been higher under both strapped (36 specimens; 28%) and partially adhered (16 specimens; 33%) approaches compared to totally adhered (12 specimens; 32%).

Although unmounted specimens had the highest number of damages (7 specimens; 63%), among mounted approaches, damages were highest with the totally adhered specimens (16 specimens; 43%), followed by partially (9 specimens;19%) and strapped approaches (17 specimens; 13%). The highest number of specimens with both damages and failures have been recorded to partially adhered (9 specimens;19%), followed by totally adhered (5 specimens; 13%) and strapped (5 specimens; 4%) approaches (Table 3).

Failures were recorded on 15 (7%) specimens following their outward journey and 20 (9%) following their inward journey; none of them were on the same specimen. Damages were recorded on 24 specimens (11%) following their outward journey and 31 (14%) following their inward journey. Damages were reported for the five specimens (2%) following both journeys. One of them was unmounted, two were partially adhered and two strapped mounted. Damages included broken petiole, tips of the leaves and/or fruits.

Damages recorded using the strapped method were largely observed on those areas where the straps have been attached, particularly on/and or near the tips of the leaves (Fig. 5), followed by the petioles (of the leaves, especially if these have also been strapped). We observed that bulky or raised structures (i.e. fruits, thick twigs, bulky inflorescences) were also susceptible to damage (Fig. 6A, B).

Of 14 specimens mounted using PVA, (six totally adhered and eight partially adhered), three failed and one totally adhered specimen presented damages. Of the ten specimens mounted using MC (five each totally and partially adhered), there were two failures under each method but no damages. S-I was used to mount 28 specimens and S-II used to mount 12. Failure was observed using both strap types (S-I had two failures and S-II, one). Three specimens were damaged when mounted using S-I while there was only one damaged specimen mounted using S-II.

Table 2: The number of herbaria using strapped, adhered or a combination of approaches by region (following Thiers (2023 [online]). Results are based on the survey.

Geographical region	Strapped	Adhered (including partially adhered)	Combinations of methods
Europe	16	5	13
Africa	1	1	2
Temperate Asia	2	3	0
Tropical Asia	1	4	1
Australia and New Zealand	4	1	1
Pacific	0	0	0
North America	0	4	7
Caribbean, Central and South America	7	9	1
Total (percentage)	31 (37%)	27 (33%)	25 (30%)

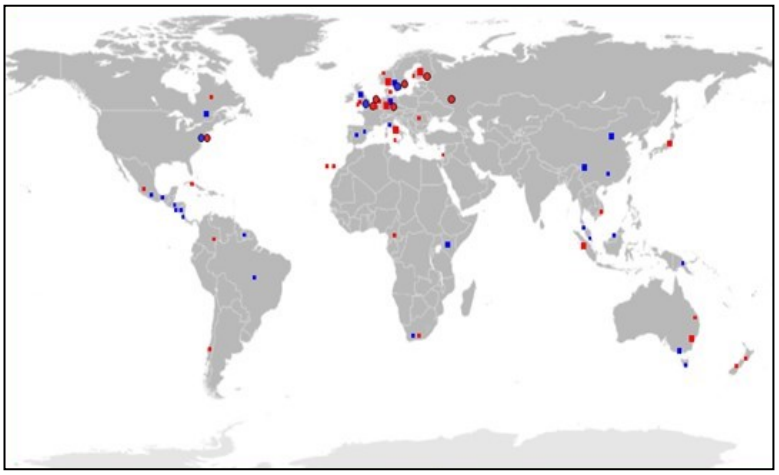

Fig 3: World map showing the distribution of plant mounting approaches displayed into two main techniques: 'strapping' and 'adhesion'. Red circles represent those herbaria that use strapping, sewing/stitching, pinning and/or combinations of one of these methods to mount the specimens. Blue squares represent those herbaria that totally or partially adhere specimens have been adopted. Size of the circles and squares, represents the size of the collection of each institution (based on the survey and data (from Thiers, [online]) gathered on that time: 2009).

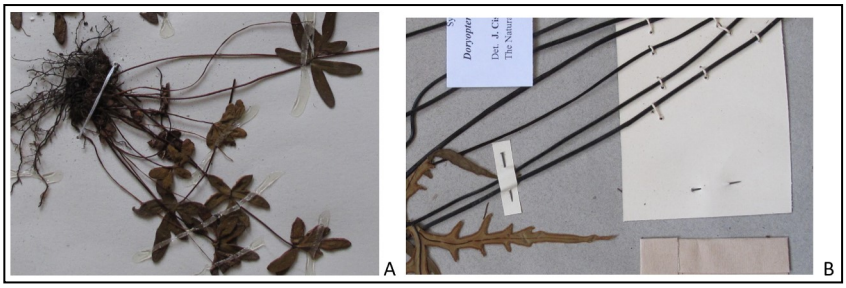

Fig 4: Examples of the strapped method. A: 'straps' have been made of adhesive; rhizome has been sewn. B: straps made of paper attached by pins; petioles being stitched on the paper that has been pinned on the sheet. Both images (from specimens sent on loan to Yesilyurt,2004), are of the fern genus Doryopteris. (Images: J.C. Yesilyurt, 2004).

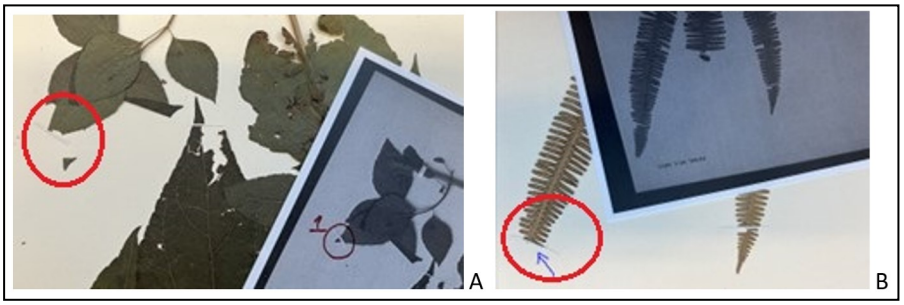

Fig 5: Examples of strap-mounted specimens, demonstrating the damages that occurred as a result of the common practice for strapping specimens at the tip of leaves. A: seed plant specimen; B: fern specimen. (Images: J.C. Yesilyurt, 2022).

Discussion

This paper had two main aims. First, to examine the plant mounting techniques used in herbaria worldwide and second to test the robustness of specimens prepared using different mounting methods through an experiment involving the loan of specimens to a number of different institutions and assessing damage to specimens and material failure of the mounting technique arising from that.

3.1. Herbarium mounting techniques worldwide

The survey suggested that, at a global scale, the proportion of herbaria using strapping (37%), adhesion (33%) and mixed approaches (30%) were broadly similar although at a regional level, there was variation, with the strapped method most common among respondents from Europe whilst in the Americas, the adhered method was predominant. It is interesting to note that while strapping was the most common method among European herbaria, the oldest herbaria, located in Europe, such as those of C. Bauhin (1560 – 1624, Herbarium Basel); U. Aldrovandi (1522 -1625, Bologna University); L. Rauwolf (1535? – 1563, Naturalis Biodiversity Centre); and H. Sloane (1660 – 1753, Natural History Museum) are often totally adhered and there has therefore been a shift in the approach adopted through time. Regional patterns, including the use of adhesion among all but one of the herbaria from Central America for which information was obtained, may reflect the impact of training courses and skills sharing between institutions across a region although it should be borne in mind that within

Table 3: The number of herbaria using strapped, adhered or a combination of approaches by region (following Thiers (2023 [online]). Results are based on the survey.

Method	Total number of specimens	Number of specimens with no observed damage or failure (percentage)	Number of specimens damaged (percentage)	Number specimens with failures (percentage)	Number of specimens with failure and damage (percentage)
Strapped	127	69 (54%)	17 (13%)	36 (28%)	5 (4%)
Partially adhered	48	14 (29%)	9 (19%)	16 (33%)	9 (19%)
Totally adhered	37	4 (11%)	16 (43%)	12 (32%)	5 (14%)
Unmounted	11	4 (36%)	7 (64%)	N/A	N/A
Total	**223**	**91 (41%)**	**49 (22%)**	**64 (29%)**	**19 (9%)**

'adhered' approach, a spectrum exists and the survey results did not seek to differentiate between partially and fully adhered.

3.2. Testing the robustness of material sent in transit ("loan exercise" experiment)

3.2.a. Past studies and the materials used (adhesives and straps)

A number of studies have examined mounting methods with most focused on the performance of the adhesives (e.g. Croat, 1978; Clark, 1986; Grenda-Kurmanow, 2021) and physical risks to the specimens. Croat (1978) raised concerns over the use of adhesives to mount plant specimens. Based on a study of mounting methods across 70 herbaria in the USA, Croat (1978) concluded that strapping the specimens would be better and faster than the total adhesion approach. Egenberg and Moe (1991) reviewed the mounting techniques adopted in four Scandinavian herbaria and similarly concluded that strapping was less time-consuming than applying 'dots of adhesive' to the specimen. The authors also argued that direct gluing should in general be avoided, since straps give the specimen a chance to move without exposing them to stress, although at the National Herbarium of Canada (CAN) have been adhering specimens in order to ensure that they could withstand manual handling for a longer period, Shchepanek (2001) noted that the 'linen strips', used at CAN during the first part of this century, continue to provide excellent durability and protection for specimens. In contrast, Bridson and Forman (1989) stated that specimens would be susceptible to damage if they are strapped, while under the total adhering approach, the damage would be reduced, giving much long-term protection to the specimens.

Grenda-Kurmanow (2021) recently identified three adhesives as particularly suitable for mounting dried plant specimens that are also used in paper conservation (e.g. Borges *et al.,* 2018) and that are therefore considered conservation-approved, namely MC, wheat starch paste, and isinglass. The use of wheat starch paste or isinglass may be problematic due to the possibility of material contamination (e.g. by DNA) since they are of plant origin; they also pose a potential increase in the threat from pests.

We were interested in comparing the performance of PVA and MC, given that both have been used at the NHM. Damages and/or failures mounted using MC were observed mostly for

raised or bulkier specimens. This may be because it can be difficult to create a bond between the surfaces with the adhesive (Clark, 1986; Tillet, 1989). However, MC is known for being readily reversible (and more so than PVA), and for this reason it is widely used in conservation and preservation, particularly for botanical collections. If MC is used, it may be advisable to incorporate extra support (e.g. sewing or adding straps) on key areas of the specimen, particularly if they are raised or bulkier.

In the present study, five specimens were mounted (partially and totally adhered approaches) using MC. While failure was recorded for two specimens under each mounting approach, damages were not observed. The failures were on those specimens with raised and/or bulkier areas.

While other studies have investigated adhesives used for mounting botanical specimens, ours also investigated straps. This is, despite the fact that the strapping method is considered in several studies to be one of the best options. The only statement about the performance of straps was by Shchepanek (2021). If strapping is used, good quality straps, such linen-based straps should be used. Consideration should also be paid to where straps should be added on the specimen. For example, the tips of leaves should be avoided (see below for further discussion).

3.2.b. The robustness of the mounting methods through the loan exercise

As anticipated, in our experimental loan, unmounted specimens presented the highest level of damage; nearly two thirds of specimens were damaged in contrast to levels of damage between 13-43% for other methods.

In contrast with the suggestion of Bridson and Forman (1989), our experimental loan results suggested that the 'totally adhered' method does not prevent damages to specimens. Indeed, only 11% of totally adhered specimens in the study showed no damage or failures during the exercise, in contrast to the 54% of specimens prepared using strapping that were returned in good condition. Full adhesion exposes specimens to much higher stresses, which may result in damages. From the perspective of minimizing risk of physical damage to specimens, our results are consistent with the support for the strapping method suggested by Croat (1978), Egenberg and Moe (1991) and Shchepanek (2001).

It should be noted that in this study, all damages were considered equally. We did not attempt to score damages by severity, size or impact on the specimen: a split on a single petiole, damage to several leaves, the fracture of the fruit (Fig. 6) even though some may be more impactful.

We would also note, however, that damages recorded under the strapped method may have been inflated since the majority of damages recorded were to the tips of leaves (Fig. 5) and to petioles. At the NHM (and also in other herbaria), specimens have sometimes been strapped at the tips of the leaves. These are among the most fragile points of the specimen, and we included specimens prepared in this way in our study to test the assumption that they are fragile points of the specimen. These damages could be considered

Fig 6: Example of specimens with bulky fruit, mounted under strapping approach. A: specimen with fruit half lost with the petiole; B: fruit broken in half, leaf tips damaged; C: specimen with no damages despite failure of the straps (detached or too loose). (Image: J. Jackson, Natural History Museum, Photo Unit, 2024).

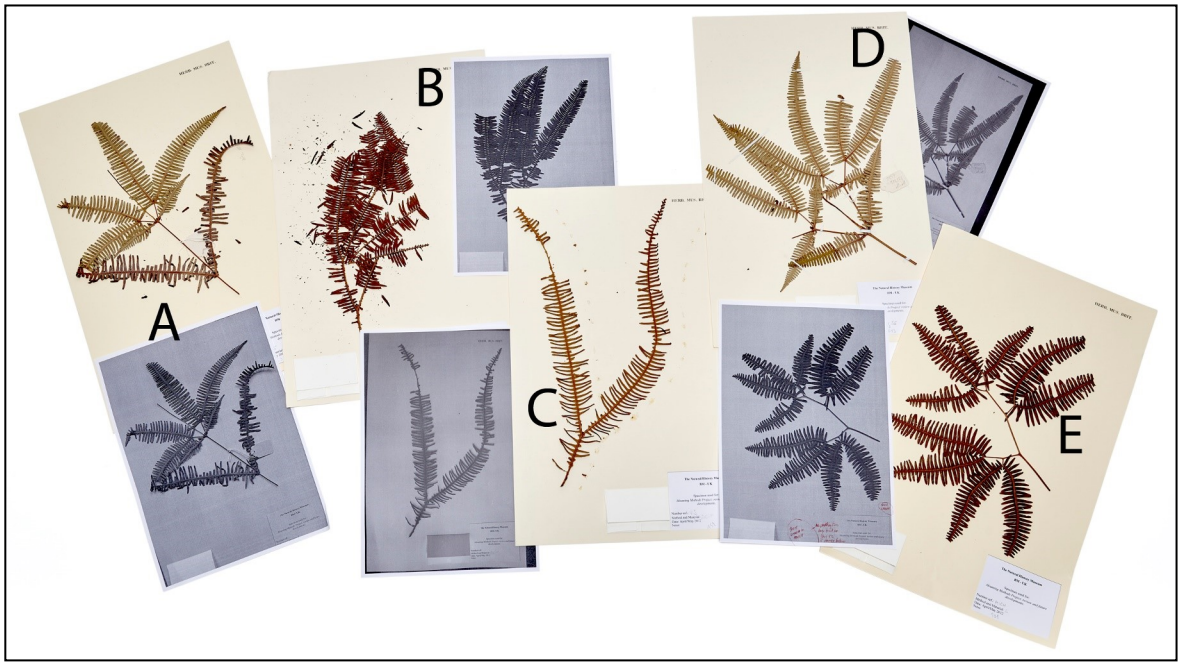

Fig 7: Fern specimens prepared for the loan exercise. A: unmounted, damages recorded to some areas of the leaves; B: overdried specimen, unmounted, specimen severely damaged; C: partially adhered, method failed (specimen detached, as it can be seen the dots of adhesive), no damages recorded to the specimen; D: strapped, method failed (some straps detached), no damages recorded to the specimen; E: overdried, unmounted, no damages recorded to the specimen. (Image: J. Jackson, Natural History Museum, Photo Unit, 2024).

to have resulted from the misuse of the mounting approach rather than the approach itself. The number of damages to strapped specimens would likely have been reduced if the straps have been applied in more appropriate locations on the specimens such as on more robust areas rather or in the middle of long petiole or close to their intersection. This may be particularly true for bulky specimens. Three specimens with bulky fruits were included in the set of strapped specimens in our loan experiment and two were damaged (Fig. 6A, B), a much higher level of damage than overall for this method (13%).

It should also be noted that many of the specimens selected for the study were particularly vulnerable to mechanical damage notably ferns that were overdried, brittle and very fragile and that this may also have increased the levels of damage observed (Fig.7).

3.2.c. Further observations

The opportunity of observing ca 5000 fern specimens from 30 herbaria for *Doryopteris* during the course of revisionary work by JCY also gave insights on how specimens behaved under different mounting methods, including specimens loaned unmounted. *Doryopteris* specimens have naturally a brittle nature, particularly in the petioles that are long and which can break easily even when freshly collected. Moreover, specimens that have been dried for too long or too quickly may be very fragile. Remarkably, among the *Doryopteris* collections that were loaned to BM, those that were unmounted (observed from three herbaria) showed very little damage, and where it did occur, it was typically only to the petiole. While this is at odds with our experimental loan results, physical damage to the specimen is not the only risk that unmounted specimens present since they are also susceptible to other risks such as the dissociation of specimens from labels. An interesting point to make is the comparison of material used (same fern species), where some specimens have been overdried. The experimental loan has shown that those specimens that were overdried, were the ones that suffered most impactful damages (see Fig. 7B) as others, despite also been unmounted, did not present damages (Fig. 7A), including when the method failed, and they have returned loose (Fig. 7C, D). Overdrying seems to be a plausible explanation of their susceptibility to extensive damage/breakage. The damages observed from other loose specimens (unmounted specimens) sent on loan exercise, were much smaller or less impactful (e.g. one leaf was detached, fragile tips of a plant were broken, or a few flowers from the inflorescence detached).

From the loans to JCY, specimens with bulky parts, which were totally or partially adhered or strapped, often had extra re-enforcement by straps, stitches, or even both and while these do not always spare the specimens from damages, the use of additional support needs careful consideration on a case-by-case basis to minimise specimen damage. It should also be noted that sometimes damage resulted from the detachment of straps, leaving the specimen loose in certain areas, which made them prone to move and friction. If strapping is used, the straps must be used correctly, tight to the specimen so they are holding and securing the specimen to prevent movement.

It should also be noted that many of the specimens selected for the study were particularly vulnerable to mechanical damage notably ferns that were overdried, brittle and very fragile and that this may also have increased the levels of damage observed (Fig. 7B). They may be stabilised if totally adhered however, one will need to bear in mind the consequences of this approach, for these kind of material/specimens as they will not be reversible and if so, it will be in several small pieces. Nevertheless, these caveats do not detract from our key finding that strapped specimens experienced fewer damages and failures than those that were adhered.

3.3. Herbarium specimens: is there a best approach to mount dried plant specimens?

A consideration of mounting methods at this time may appear unnecessary, since digitisation efforts, are increasingly making herbaria virtual and digitally available, across the world (e.g. Soltis 2017; Soltis, Nelson and James, 2018), and this already appears to be impacting on the number of requests for loans (e.g. Holstein, 2019). Physical damage through loans may therefore be less likely to occur in the future.

Nevertheless, specimens will still be used and they do still need to be conserved to a high standard. In addition to the support from strapping from our loan experiment, the approach also has other advantages over other mounting techniques. First of all, it is less resource-intensive since it is both faster and easier to strap mount specimens (albeit with skill and expertise still needed as noted above). Strapping also provides the stability needed but is less invasive than other methods and is easier to reverse. Herbaria are increasingly attracting new users undertaking innovative research addressing a wide range of questions and societal issues using the specimens they contain (Carine *et al.*, 2018; Davis, 2023) and both current and potential uses in the future need to be considered.

As the results of our survey revealed, the way in which herbarium specimens are mounted is varied. In the herbarium of the future, the needs of the diverse range of users of botanical specimens are likely to best served by mounting techniques such as strapping that, as our loan experiment suggests, are successful in preventing physical damage while also maximising flexibility in their uses in the future. Similarly, sewing can also be a good option though it would be time consuming and, probably more expensive, as a result.

The findings from the present study hopefully can help towards re-evaluation of the best practices for botanical collections, more precisely, on 'mounting' the vascular plants (i.e. seed plants and ferns) and aim for a non-invasive mounting technique/s, or to at least a less- invasive approach. One could argue that no method would be totally satisfactory, and, in some cases, it might be that more than one approach could work better for certain specimens, to have a stable and sustainable herbarium specimen.

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