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ECO-FRIENDLY REPLACEMENT FOR PAPER CONSERVATION: ADHESIVES COMPRISING POTATO STARCH AND SOY FLOUR

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Abstract:

Adhesives for the preservation of paper-based heritage materials should be stable, reversible, safe for the artefact as well as effective. This study aimed to evaluate and compare the performance of natural glues derived from soy, potato, and corn flour in terms of their applicability to heritage conservation. Using A4 paper sheets of two different weights (70gsm and 100gsm), the adhesives were assessed for physicochemical and curing properties such as colour, texture, and pH; alongside curing time, bonding strength, and their long-term effects on the physical and visual integrity of the paper. Among the formulations, the potato flour-based adhesive (pH 7.40) exhibited optimal performance, showing excellent appearance, zero residue, strong and uniform adhesion, and high visual stability. In contrast, the cornflour (pH 6.32) and soy flour (pH 8.03) adhesives presented shortcomings, including non-uniform adhesion, powdery residues, and potential for discoloration. In line with the current conservation practices that prioritize sustainability and low intervention, the findings suggest that potato starch is most promising natural glue for supporting the stability of the material and ensuring long-term heritage sustainability.

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Preservation Of Paper, Natural Glues, Soy Flour, Potato Flours, Stability of the Material, And Heritage Sustainability

Introduction

To preserve societal history and culture, it is essential to carry out conservation and preservation of cultural heritage materials of all types; particularly paper-based artefacts (Fenech et al., 2022). Long-term preservation is critical, as organic materials like paper are vulnerable to degradation from ageing, handling, and environmental exposure (Strlić, 2023). A critical factor in restoration is the adhesive used, as broken or detached components of heritage objects are often repaired using adhesives (Manser, 2021). Accordingly, conservators prioritize an adhesive's performance, durability, and its long-term interaction with the substrate (Pouli & Ksinopoulou, 2021).

Despite their widespread use, synthetic adhesives raise concerns about toxicity, cost, and irreversibility; issues that conflict with contemporary conservation ethics (Dupont & Chevalier, 2022). Adhering to the principle of reversibility is crucial to prevent permanent damage to original artefacts (Čabalová et al., 2021). Failure to do so may lead to discolouration, paper weakening, and eventual adhesive failure (Manser, 2021). In response to these challenges, conservation science is increasingly exploring natural glues made from biodegradable and renewable resources as more sustainable alternatives (Russo et al., 2023; Lazzara & Di Franco, 2022).

Although soy flour and starches; such as those extracted from potatoes and corn; have long been used in conservation, there remains a lack of systematic studies comparing their effectiveness and long-term stability (Pouli & Ksinopoulou, 2021). Starches are valued for their reversibility and strong adhesion to cellulose fibers (Basiul et al., 2021), while soy flour is recognised for its affordability, protein content, and eco-friendliness, especially in the wood industry (Li et al., 2022). However, in the context of paper conservation, their comparative performance; particularly in terms of the stability of the material and impact on visual appearance; remains unclear.

This study aims to fill this gap by experimentally evaluating the effectiveness of soy flour and starch-based adhesives (potato and corn), identifying locally available materials suitable for sustainable, non-destructive conservation practices. The findings contribute to heritage sustainability by promoting the use of environmentally responsible adhesives.

Methodology

The performance of three in-house adhesives was evaluated using an experimental research design supported by a quantitative approach (Creswell & Creswell, 2021). This design was selected as it enables systematic testing of the effect of an independent variable; the adhesive type; on dependent variables such as adhesion strength and visual stability, under controlled laboratory conditions (Adamson & Heritage, 2020). Quantitative data were gathered through precise measurements and structured observations, ensuring objective comparison and minimising potential researcher bias.

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Apparatus and Materials

The adhesive formulations were based on cornflour, potato starch and soy flour. To ensure purity and prevent any chemical reactions from minerals in the tap water, which would affect the stability of the formulations, battery water, which represents either the distilled or deionised water, was used as solvent (Robb, 2020). In order to examine the effect of the adhesion on papers of different bulk, two types of substrates for the adhesion tests were employed: general A4 paper (70 or 100 gsm). The equipment used for the present experiment is summarized in Table 1. This equipment has been selected as it is available in many labs and ideal for the experiment described ensuring that the experiment can be repeated inexpensively.

Table 1: List Of Apparatus and Function

Apparatus Name	Function
Digital Electronic Balance	To precisely measure the mass of starch and soy flour powders for accurate formulation.
Magnetic Stirrer Hot Plate	To heat and stir the solution simultaneously to ensure even consistency in adhesive paste formation.
Beaker (100ml & 250ml)	Serve as containers for mixing and heating the adhesive components.
Stainless Steel Spatula	A tool for transferring and manually mixing the materials during preparation.
pH Meter	To measure the final acidity or alkalinity of each adhesive formulation.
Paintbrush	To apply the adhesive evenly onto the paper samples.
Small Plastic Containers	To store the prepared adhesive samples prior to application and observation.

Preparation of Adhesive Samples

Three adhesive formulations were prepared using a standard procedure to ensure a fair comparison.

Starch-Based Adhesives (Corn and Potato): A total of 5.0 grams of corn starch or potato starch powder was weighed using a digital balance. The powder was dissolved in 50 milliliters of battery water. The mixture was heated and stirred using a magnetic stirrer hot plate under gentle heat until it thickened, became translucent, and achieved a glue-like consistency.

Soy Flour Adhesive: Similarly, 5.0 grams of soy flour was mixed with 50 milliliters of battery water. The mixture was heated and continuously stirred until a homogenous adhesive paste was formed.

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Application on Paper Samples
For each adhesive formulation, testing was conducted on paper substrates with two different grammages: 70 gsm and 100 gsm. A uniform and thin coating of the adhesive was applied using a brush to one sheet of paper. A second sheet of the same type was then pressed onto the adhesive-coated surface to simulate adhesion.

The following methods were employed to assess and compare the adhesives' performance:

i. pH Determination: The pH value of each adhesive sample was measured to evaluate its chemical stability, as pH plays a critical role in the long-term preservation of cellulosic materials (Botti et al., 2021).
ii. Visual Observation: Observations were made regarding the colour, texture, and homogeneity of the adhesives to assess their aesthetic compatibility and application quality.
iii. Drying Time: The time taken for each adhesive to dry completely was recorded to evaluate usability under practical conservation conditions.
iv. Adhesion and Residue Characterisation: A qualitative assessment was performed to evaluate bonding strength and the presence of residual material on the paper surface after separation.
v. Long-Term Testing: All adhered paper samples were stored under room conditions for 14 days to monitor changes in physical appearance and structural integrity. Given the vulnerability of organic adhesives to biodeterioration, their resistance to visible fungal or microbial growth was also observed (Russo et al., 2023).

Qualitative comparisons of all collected data were used to determine which adhesive formulation demonstrated the most favourable characteristics for conservation purposes (Adamson & Heritage, 2020).

Results
The findings of the experiment clearly demonstrate the comparative performance of the three adhesive formulations.

Adhesives' Physicochemical Characteristics
Table 2 presents the observed physicochemical properties of each adhesive. Among the formulations, the potato starch-based adhesive exhibited the most desirable characteristics, including a smooth, glue-like consistency, high transparency, and a nearly neutral pH of 7.40; aligning with stability benchmarks for conservation applications (Botti et al., 2021). In contrast, the soy flour adhesive was found to be alkaline, with a pH of 8.03, while the corn starch adhesive was mildly acidic, registering a pH of 6.32. These pH values may influence long-term interactions with cellulosic materials, especially in terms of degradation and colour change potential.

Table 2: Physicochemical Properties of Adhesive Formulations

Adhesive Property	Cornstarch	Potato Starch	Soy Flour
pH Value	6.32	7.4	8.03
Colour	Cloudy white	Clear and colourless	Brown with black spots
Texture	Watery with sediment	Semi-solid (glue-like)	Semi-watery and granular

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Curing Time and Adhesion Performance

After 24 hours, notable differences in adhesion quality observed across the three adhesive formulations (Tables 3 and 4). The potato starch adhesive demonstrated superior performance, exhibiting strong, consistent bonding on both 70 gsm and 100 gsm paper without leaving any visible residue. This indicates its effectiveness and suitability for delicate paper conservation. In contrast, the corn starch adhesive failed to bond with either paper type. Instead, it left behind white powdery residues, suggesting poor curing characteristics and limited adhesion capability. The soy flour adhesive also underperformed: it adhered only partially to the 100 gsm paper, leaving a caked residue upon separation, and completely failed to adhere to the 70 gsm paper. These outcomes indicate that both soy flour and corn starch formulations possess limitations in adhesion reliability, especially on lighter paper substrates.

Table 3: Adhesive Performance on 70gsm A4 Paper

Property	Cornstarch	Potato Starch	Soy Flour
Adhesion	No	Yes	No
Residue	White powder	None	Brown granules

Table 4: Adhesive Performance on 100gsm A4 Paper

Property	Cornstarch	Potato Starch	Soya-bean Flour
Adhesion	No	Yes	Yes (Partial)
Residue	White powder	None	Brown granules

Visual and Physical Integrity after Long-Term Effects

The potato starch adhesive maintained excellent structural and visual stability over a 14-day observation period. No signs of degradation, discoloration, or detachment were detected, indicating its strong potential for long-term application in conservation practices. However, all adhesive samples; including those based on soy flour and corn starch; began to exhibit fungal growth after extended exposure at room temperature. This outcome supports findings by Nowotna et al. (2022), which suggest that organic adhesives are prone to biodeterioration unless freshly prepared or stored under refrigeration. Therefore, proper storage and preparation methods are essential to preserve the integrity and effectiveness of bio-based conservation materials.

Discussion

This study provides valuable experimental evidence supporting potato starch as the most suitable natural adhesive for the preservation of paper-based heritage materials.

Potato Starch Excels Due To Its Performance and Compatibility Attributes

Its favorable physicochemical characteristics, particularly its near-neutral pH (7.40), play a crucial role in maintaining the long-term integrity of cellulosic substrates. Given the sensitivity of paper to acidic or alkaline conditions, a neutral pH reduces the risk of degradation and extends shelf-life stability by minimizing chemical decomposition (Zervos, 2021; Botti et al., 2021).

Aesthetically, potato starch is also advantageous: it forms a clear, colorless adhesive layer that preserves the visual appearance of the treated artefacts (Manser, 2021). In contrast, the inferior adhesion performance of corn starch can be attributed to its molecular composition. Potato starch contains higher levels of phosphorus, which promotes better granule swelling and

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contributes to a more viscous, stable paste (Pawlak & Olejnik, 2021; Singh et al., 2023). This structural advantage enhances its bonding strength compared to cornstarch.

Furthermore, the experiment confirms the limitation of soy flour adhesives, particularly their inconsistency in adhesion and potential for visible residue. These observations reinforce the superior conservation compatibility of potato starch.

The findings affirm potato starch as a promising, eco-friendly adhesive for paper conservation, aligning with global trends favoring non-toxic, renewable, and biodegradable materials (Russo et al., 2023; Lazzara & Di Franco, 2022). Its ease of preparation, cost-effectiveness, and availability make it especially practical for heritage institutions and laboratory-based applications (Pouli & Ksinopoulou, 2021). However, given its susceptibility to microbial growth at room temperature, the adhesive should be prepared fresh daily to ensure optimal quality and prevent biodeterioration (Nowotna et al., 2022). Overall, potato starch represents a sustainable and effective alternative to synthetic adhesives for the long-term preservation of paper-based artefacts.

Recommendations for Future Research and Professional Practice

This study affirms that potato starch is a promising and environmentally sustainable adhesive for paper conservation. However, its full adoption into professional conservation practices requires further empirical validation and technical refinement. Future research should consider formulation improvements aimed at overcoming the limited shelf life of organic adhesives. One possible approach involves the use of biological additives with antimicrobial properties, such as clove oil, which may enhance the stability and longevity of the adhesive formulation, particularly under ambient storage conditions (Nowotna et al., 2022). In parallel, incorporating recent advances in materials science; such as nanotechnology; could significantly improve the adhesive's mechanical properties. For instance, the integration of nanocellulose into starch-based adhesives has shown potential to increase both bonding strength and structural resilience (Kargarzadeh et al., 2021). Such interdisciplinary enhancements may enable the development of next-generation starch adhesives that are more durable and resistant to biodeterioration.

In addition to formulation research, there is a need for more precise and quantitative testing methods to substantiate the performance of natural adhesives. While this study employed observational and qualitative assessments, future work should adopt mechanical testing techniques such as peel strength and tensile testing to generate objective and reproducible data (Hasiuk et al., 2022). Quantitative evaluation would provide a stronger foundation for comparing adhesive formulations and establishing performance benchmarks. Moreover, accelerated aging tests should be included in future studies to simulate long-term environmental effects on adhesive-paper interactions. These tests are essential for predicting the durability and chemical stability of adhesives over extended timeframes, thereby informing conservation strategies with long-term relevance (Strlič, 2023).

Equally important is the translation of research findings into professional conservation practice. The dissemination of knowledge through practical workshops and training programmes can equip heritage professionals with the skills and confidence to implement starch-based adhesives in real-world conservation settings (Adamson & Heritage, 2020). Such initiatives are instrumental in promoting sustainable conservation practices within the broader heritage sector. Furthermore, it is critical to investigate the compatibility of starch adhesives with a wide variety of historical media, including inks, pigments, and different types of paper. These studies will deepen understanding of the interaction mechanisms between adhesives and artefact surfaces, thereby reducing the risk of adverse reactions during conservation treatment (Fenech et al., 2022).

In conclusion, a multidisciplinary research agenda; incorporating formulation science, performance quantification, and practitioner training; is essential for advancing the ethical and effective use of natural adhesives in paper conservation. These efforts will help establish a scientifically informed framework for the widespread adoption of starch-based adhesives as a viable and responsible alternative to synthetic options.

Conclusion

In summary, this experimental work has provided clear evidence regarding the performance of three natural adhesives in the conservation of paper-based materials. Among the tested formulations, the potato starch-based adhesive emerged as the most suitable option, demonstrating superior outcomes across all assessed parameters, including physicochemical properties, adhesion strength, and long-term stability. It outperformed cornstarch, which failed to establish a stable bond, and soy flour, which showed uneven adhesion and left behind undesirable particulate residue.

The advantageous properties of potato starch; namely its near-neutral chemical reactivity, strong and clean adhesive lines, transparent finish, and high visual stability; align with the demanding standards of modern conservation practice. These features not only ensure effective intervention but also uphold ethical conservation principles such as reversibility and minimal invasiveness. By offering a combination of scientific reliability and practical applicability, the use of potato starch contributes meaningfully to the growing body of sustainable alternatives in heritage preservation.

Ultimately, this study provides conservators with a robust scientific foundation for selecting adhesive materials that are compatible, safe, and environmentally responsible. It advances the case for natural adhesives in conservation science and supports a broader shift towards more sustainable and ethically grounded heritage management practices for future generations (Čabalová et al., 2021).

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