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Traditional adhesive production systems in Zambia and their archaeological implications

Sebastian Fajardo [a,f,*], Jelte Zeekaf [b], Tinde van Andel [b,d,e], Christabel Maombe [g], Terry Nyambe [h], George Mudenda [h], Alessandro Aleo [a], Martha Nchimunya Kayuni [i], Geeske H.J. Langejans [a,c]

[a] Delft University of Technology, Department of Materials Science and Engineering, Mekelweg 2, Delft 2628CD, South Holland, the Netherlands
[b] Wageningen University, Biosystematics Group, Droevendaalsesteeg 1, Wageningen 6708 PB, Gelderland, the Netherlands
[c] University of Johannesburg, Palaeo-Research Institute, 42 Bunting Rd, Johannesburg 2092, Gauteng, South Africa
[d] Naturalis Biodiversity Center, PO Box 9517, Leiden 2300 RA, South Holland, the Netherlands
[e] Leiden University, Institute of Biology, Clusius Chair of History of Botany and Gardens, Sylviusweg 72, Leiden 2333 BE, South Holland, the Netherlands
[f] Leiden University, Leiden Institute of Advanced Computer Science (LIACS), Niels Bohrweg 1, Leiden, 2333 CA, South Holland, The Netherlands
[g] National Heritage Conservation Commission, Dedan Kimathi Rd, Lusaka Box 320013, Lusaka Province, Zambia
[h] Livingstone Museum, Mosi-Oa-Tunya Road, Livingstone 20100, Southern Province, Zambia
[i] Max Planck Institute of Geoanthropology, Kahlaische Strasse 10, Jena 07745, Thuringia, Germany

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ABSTRACT

This study explores traditional adhesives using an ethnobiological approach within a multisocioecological context in Zambia. Through semi-structured interviews, videotaped demonstrations, and herbarium collections, we investigated the traditional adhesives people know and use, the flexibility of production processes, resource usage, and knowledge transmission in adhesive production. Our findings reveal flexibility in adhesive production systems. People use a wide range of organic and inorganic materials in their adhesive recipes. Recipes are flexible, demonstrating the ability to adapt to changes and substitute materials as needed to achieve the desired end product. Additionally, our study reveals a variety of redundant pathways for knowledge transmission typically confined within individual population groups. These include same-sex vertical transmission and distinct learning spaces and processes. Also, we identified material procurement zones showing that people are prepared to travel 70 km for ingredients. We use our findings to review the archaeology and we discuss the identification of archaeological adhesives, the functional roles of adhesive materials, adhesive storage, and the sustained human interaction with species from families such as Euphorbiaceae and Apiade. Our findings underscore the diversity and adaptability of traditional adhesive production and suggest that further research on adhesives would reveal similar diversity within the archaeological record.

1. Introduction

Adhesives have been produced for at least 200,000 years in diverse types of environments, activities, processes, and using a variety of combinations of materials (Mazza et al., 2006; Langejans et al., 2022). These ancient technologies are frequently discussed in relation to the development of modern human behavior (Koller et al., 2001; Wadley, 2010; Roebroeks and Soressi, 2016; Niekus et al., 2019; Schmidt et al., 2022). The production of early adhesives seems to require the utilization of multiple cognitive resources and control mechanisms to manage their inherent complexity (Fajardo et al., 2023; Kozowyk et al., 2023; Fajardo et al., 2022). Nonetheless, many aspects of non-industrial adhesive technologies remain under debate (Kozowyk et al., 2020b; Schmidt et al., 2019; Schmidt, 2021), and at least three aspects of have yet to be resolved.

First, the degree of production flexibility for non-industrial adhesives in real-world systems remains unclear. Both experimental and modeling evidence (Schmidt et al., 2022; Fajardo et al., 2022) suggests the involvement of complex behaviors in adhesive production. Additionally, minor adjustments to ingredient ratios show to significantly impact

* Corresponding author.
E-mail address: s.d.fajardobernal@tudelft.nl (S. Fajardo).

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adhesive efficiency (Kozowyk et al., 2016). Nevertheless, ethnographic observations (Wadley et al., 2015) document production variants, indicating the potential extent of adhesive production flexibility beyond controlled environments.

Flexibility is a common characteristic of complex systems (Fraccascia et al., 2018). In archaeology it reflects the expectation of different designs and production strategies for similar technologies depending on their role, demand and material availability (Binford, 1979). Flexibility can be expressed as the capacity of a system to be reorganized to absorb changes in state variables, driving variables, and parameters (Holling, 1973). Traditional adhesive production systems may exhibit flexibility in response to disturbance and changes, when environmental or socioeconomic factors restrict, reduce or change the timing of plans, including access to raw materials. When a traditional production system can absorb such changes, we would observe preservation of traditional knowledge and practices alongside new knowledge or products (Reyes-García et al., 2014); multiple mechanisms for individual or collective learning that ensure vertical transmission of knowledge (Zank et al., 2019) that are not limited by dichotomies such as male–female spheres (Hendon, 2006); and flexibility of production techniques and material sources (Hendon, 2006).

Second, the cultural and demographic aspects of adhesive production systems in regions with different technological and ecological characteristics are not fully understood. Only a limited number of studies conducted with contemporary craft specialists and experimental research provide analogies to infer the variability of technological procedures with which adhesives were made (Weedman, 2006; Zipkin et al., 2014; Wadley et al., 2015; Bradfield et al., 2015; Kozowyk et al., 2017; Sahle, 2019). Little is known about the regularities and variability in production across cultures and different environments. For instance, the characteristics of adhesive technology systems in multicultural contexts remain unknown.

Finally, what generalizations can be made about adhesive production processes is unclear. Ecological models (Albuquerque et al., 2015), and archaeological (Langejans et al., 2022) and ethnographic (Bradshaw, 2013) data indicate the large variability in raw materials. However, the diversity in production processes is less clear. Production processes may vary widely due to ingredients, cultural and ecological factors: some may be highly localized while others are similar across different regions.

In this study, we use an ethnobiological approach to fill the gaps in these three aspects. Our primary research question focuses on assessing what is the level of production flexibility in non-industrial adhesives. To address this question, we provide detailed descriptions of production processes so they may be used as input in formal modeling studies (e.g. Fajardo et al., 2022; Fajardo et al., 2023; Kozowyk et al., 2023). We investigated the knowledge system of traditional adhesives in Zambia, observed people who made non-industrial adhesives and asked about their ingredients, production, use, tasks, products, and cycles. We document differences between materials, processes, and the ways people use adhesives.

While acknowledging the inherent difficulty of making direct analogies between contemporary settings and those of the past, we explore the potential connections with the archaeological record. We aim to see if there are similarities in the variability and dominance of certain adhesive products. We also explore what variability implies for archaeological identifications. We also explore other behaviors that we observed in Zambia and explore the implications for archaeological record, for example the storage of adhesives. Finally we are interested in the interplay between human behavior and the environment; what inspiration could our ethnobotanical findings provide for the interpretation of the archaeological record.

2. Methods

In May and August 2022 fieldwork was carried out as part of a multidisciplinary project. We collected three types of data: semi-structured interviews about the production and use of traditional adhesives with participants from four districts in Zambia (Sinazongwe, Mongu, Kitwe, and Kafue); videotaped demonstrations of the production and use of the traditional adhesives; and herbarium vouchers of plants, along with samples of materials used in adhesive production.

2.1. Research locations

Zambia is a landlocked country in southern Africa. The climate is sub-tropical with 95% of rainfall in the wet season (November-April), during which most plants flower (Bolnick, 1995; Kaczan et al., 2013). Zambia is located in the miombo woodlands ecoregion with 16% of its area covered by primary forest, c. 37% by secondary forest, and the rest corresponding to grassland and agricultural fields (Phiri et al., 2019). The north is wetter (average annual rainfall of 1200 mm) than the south (700 mm) (Smith and Allen, 2004), which results in an evergreen wet miombo vegetation in the north (Timberlake and Chidumayo, 2011) and dry miombo vegetation in the south. The wet miombo is characterized by predominantly closed canopies of typically 15 m high and an herbaceous understory. The dry miombo has a lower floral diversity and a lower canopy than the wet miombo, trees that are deciduous for more than a month, and an understory that consists of sparse C4 grasses. Mopane woodland is a common type of dry miombo vegetation. The dominant species is *Colophospermum mopane*, and the general species richness is low (Timberlake and Chidumayo, 2011). The prehistoric climate was 4–8°C colder 18,000 years ago, which meant significant differences with the current climate and vegetation (Elenga et al., 2000).

The research reported here draws on interviews and observations conducted in four districts of Zambia, representing different socio-ecological regions: Sinazongwe (Southern Province), Mongu (Western Province), Kafue (Lusaka Province), and Kitwe (Copperbelt Province) (Fig. 1). The Sinazongwe and Kafue district are predominantly associated with dry miombo and Zambezi Mopane vegetation: open dry savannas with elevations around 500 m and annual precipitation between 400 and 800 mm, very few grasses and trees usually aggregated as shrubs. The dry miombo has elevations from 500 m in Sinazongwe to around 1200 m in Kafue (Sayre et al., 2013). The Kitwe district is in wet miombo area with an elevation around 1200 m and woody areas with trees larger than 4 m tall. The Mongu district consists of Baikea woodland and savanna, an ecosystem linked to deep Kalahari sands of eolian origin with an annual precipitation of 400–600 mm and an elevation around 1200 m. The canopy can reach up to 20 m in mature forests, but mostly of the current vegetation is secondary shrubland (Sayre et al., 2013).

2.2. Participant communities

Most of the ethnic groups in Zambia have a unique Bantu-speaking ascendancy (Vansina, 1995), although other sub-Saharan genetic ancestry is also present (Breton, 2020; Kayuni, 2017). Markets are ubiquitous in the countryside and rural populations practice subsistence farming, pastoralism, or fishing, and occasionally hunting (Banda, 2016; Battera, 2016; Kanene, 2016; Spring and Hansen, 1985). All groups are actively involved in craftsmanship, including blacksmithing, wood carvings, pottery making, basket weaving, and bead making. Maize is the staple crop in Zambia, but sorghum and millet are also cultivated, although flocks of birds feed on sorghum and millet (Warburton and Perrin, 2006; Ward et al., 1979), decreasing their yield. Harvest usually starts at the end of the rainy season in July (Simpungwe et al., 2017).

Participants identified themselves as part of four distinct groups: Tonga, Lozi, Luvale, and Nsenga. The **Tonga** reside in southern Zambia. Participants in Sinazongwe self-identify with this group. Historically, these communities displayed a hierarchical organization with differences in wealth, observed sometimes in their burial practices (Katanekwa, 2016). Today, this hierarchical system continues to exist,

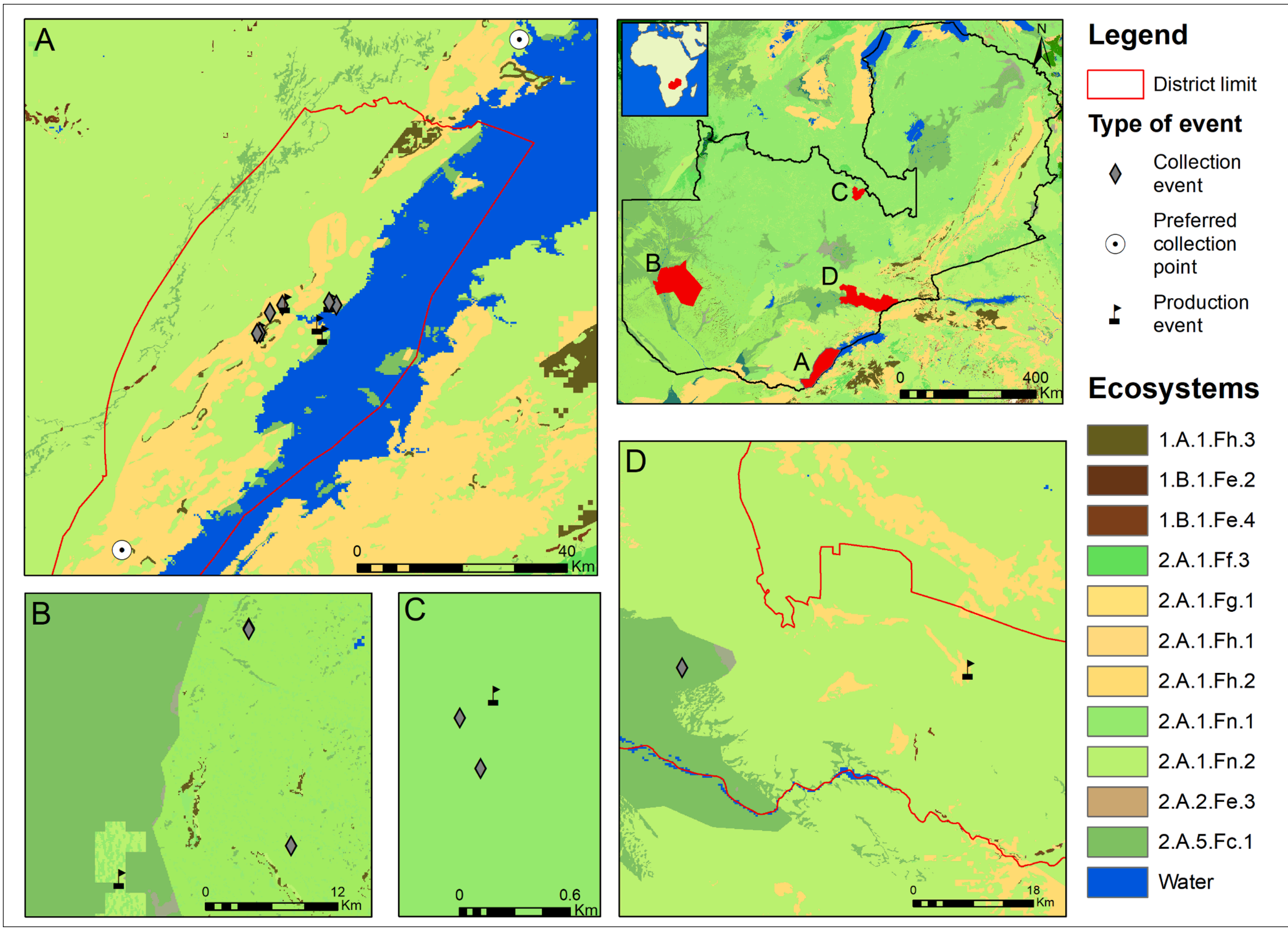

Fig. 1. (2-column fitting image) Study areas and African ecosystems based on Sayre et al. (2013). Ecosystem labels correspond to the following: 1.A.1.Fh.3 - Zambesian Cryptosepalum Dry Forest; 1.B.1.Fe.2 - Northern Afrotemperate Forest; 1.B.1.Fe.4 - Northern Mistbelt Forest; 2.A.1.Ff.3 - Gabono-Congolian Mesic Woodland & Grassland; 2.A.1.Fg.1 - Dry Combretum - Mixed Woodland & Savanna, 2.A.1.Fh.1 - Limpopo Mopane; 2.A.1.Fh.2 - Zambezi Mopane; 2.A.1.Fn.1 - Wet Miombo; 2.A.1.Fn.2 - Dry Miombo; 2.A.2.Fe.3 - Afromontane Grassland; 2.A.5.Fc.1 - African Tropical Freshwater Marsh (Dembos). Districts of the research locations are marked as (A) Sinazongwe, (B) Mongu, (C) Kitwe, and (D) Kafue. Collection events indicate the places where herbarium specimens and plant ingredients were collected in the field. Production events mark the places where demonstrations were conducted by participants. Preferred collection points indicate the approximate locations of the preferred sources of pl.ant ingredients.

including family inherited leadership (Chaplin, 1960; Katanekwa, 2016; Goldstein et al., 2021). In rural areas, they are primary farmers and cattle herders but they also engage in fishing and hunting. Although, men and women could own cattle, cattle herding was exclusively considered a male activity (Colson, 1949). The **Lozi** people's homeland is traditionally called Barotseland, which houses around 40 ethnic groups (Katanekwa, 2016). All participants in Mongu self-identify with this group. Lozi society is highly stratified, with a monarch at the top and those of recent royal descent occupying high positions in society (Mainga, 2010). One of their most important ceremonies is the Kuomboka, which allows Lozi people to synchronize their year cycle with the floods and maintain a sense of unity among of the ethnic diversity in the Barotse plains (Neeta, 2016). The **Luvale** of the North-western Province are a matrilineal and uxorilocal group. Participant 8 in Mongu self-identifies with the Luvale and Lozi groups. Luvale economy is mainly based on agriculture and fishing. Meat is acquired through hunting and livestock. Luvale people celebrate two important traditional ceremonies: Likumbi Lya Mize and the Mukanda (Wele, 1993). The latter is a coming to age ceremony that includes circumcision of boys and transmission of skills to children between 8 and 12 years. The ceremony is led by adults attired with cloth and wooded masks to represent Makishi spirits (Simanga, 1982). In Zambia, **Nsenga** have a hierarchical organization under a Senior Chief and are part of the Nsenga Luzi of the Luangwa valley in Chief Nyalugwe, Mboloma and Lwembe and the Chikunda of Luangwa Boma (Feira) (Katanekwa, 2016; Yoshida, 2016). The participant interviewed in Kitwe self-identify as Nsenga. The **Soli** are a matrilineal group, mostly agriculturalists and the original inhabitants of the Lusaka Province (Manachishi, 2019). All participants in Kafue identify as Soli, with participant 10 also identifying as Tonga.

2.3. Participants

Participants were selected opportunistically based on informal talks with local leaders and other community members in each region. We interviewed 13 participants in Sinazongwe ($n = 6$), Mongu ($n = 2$), Kafue ($n = 4$), and Kitwe ($n = 1$) with the help of native speakers of the local languages as interpreters. We obtained permission to conduct the research from the heads of the communities. Efforts were made to interview male and female participants from all ages. We obtained approval for this research from the Humanities and Social Sciences Research Ethics committee of the University of Zambia, the Human Research Ethics Committee of Delft University, and the Natural Heritage Conservation Commission of Zambia. All participants gave their prior verbal and written informed consents for the use of their provided information and images for research purposes. In the text, we utilize a binary category for sex classification (male/female) based on the visible external anatomy of participants at the time of the interviews. We chose to anonymize the names of participants in our study as a precautionary measure to protect their privacy. Clean data is presented in the results section (Tables 1 and 2). Media files and codes of the interviews are available as an open-access dataset (Fajardo et al., 2023). Our research findings are accessible to the broader audience at Fajardo et al. (2024) and Langejans Lab.

2.4. Interviews

Questions during interviews included demographic information (name, age, village of residence), descriptions of the adhesive production-use processes, and information about resources, tasks, products, and production moments during the day, year, and life cycles. All answers, comments, and English interpretations were coded and

Table 1

Scientific names and families of identified material ingredients for traditional adhesive production. Asterisks (*) placed at the end of the scientific name indicate that herbarium specimens of the plant were collected in the field.

	Scientific name	Family	Vernacular name (Language)	material	Location	Uses
IDENTIFIED PLANTS	*Diplorhynchus condylocarpon* (Müll.Arg.) Pichon*	Apocynaceae	Muntowa (Tonga) Mulembalemba (Lozi)	latex; fruit	Sianzongwe; Mongu	Repair objects; woodworking; seal seams canoes; hafting.
	Landolphia parvifolia K. Schum*	Apocynaceae	Mulya (Lozi); Mukenge (Luvale); Mutowa(Tonga); Mabungo (Nynga), muwiriwiri (Soli)	latex; fruit	Sinanzongwe; Mongu; Kitwe	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
	Langenaria sp. Ser.	Cucurbitaceae	Matyla (Soli); Mponda(Nynga); Miungo(Tonga)	seeds	Kafue	Oil for adhesive production and cooking.
	Euphorbia cooperi var. *calidicola* L.C. Leach*	Euphorbiaceae	Chinsu (Tonga); Bulimbo (Tonga)	latex	Sinazongwe	Bird traps; repair objects; woodworking; seal seams canoes.
	Euphorbia fortissima L. C. Leach*	Euphorbiaceae	Bulimbo (Tonga)	latex	Sinazongwe	Bird traps; repair objects; woodworking; seal seams canoes.
	Euphorbia ingens E. Mey. ex Boiss.*	Euphorbiaceae	Muzumangwa (Tonga); Bulimbo (Tonga)	latex	Sinazongwe	Bird traps; repair objects; woodworking; seal seams canoes.
	Euphorbia matabelensis Pax*	Euphorbiaceae	Chizanda (Soli)	latex	Kafue	Bird traps; repair objects.
	Euphorbia tirucalli L.*	Euphorbiaceae	Imbala (Tonga); Chitibi (Tonga)	latex	Sinazongwe	Adhere paper.
	Vachellia sp. L.	Fabaceae	Mukoka (Tonga)	exudate	Sianzongwe	Seal seams canoes.
	Brachystegia floribunda Benth*	Fabaceae	Mutuya (Lozi)	gum	Mongu	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
	Colophospermum mopane (J.Kirk ex Benth.) J. Léonard*	Fabaceae	Mopane (English); Muani, Mupani (Tonga)	bark resin	Sinazongwe	Bird traps; repair objects; woodworking; seal seams canoes.
	Agelanthus cf. *subulatus* (Engl.) Polhill*	Loranthaceae	Silwilya (Lozi)	fruit	Mongu	Bird traps; repair objects.
	Tapinanthus cf. *forbesii* (Sprague) Wiens*	Loranthaceae	Silwilya (Lozi)	fruit	Mongu	Bird traps; repair objects.
	Tapinanthus dependens (Engl.) Danser*	Loranthaceae	Silwilya (Lozi)	fruit	Mongu	Bird traps; repair objects.
	Sterculia africana (Lour.) Fiori	Malvaceae	Mukoso (Lozi)	exudate	Mongu	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
	Ficus cf. *thonningii* Blume	Moraceae	Mutata (Lozi)	exudate	Mongu	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
	Ficus fischeri Warb. ex Mildbr. & Burret*	Moraceae	Male kachele (Nynga)	latex	Kitwe	Bird traps; adhere paper.
	Ficus verruculosa Warb.*	Moraceae	Female kachele (Nynga)	latex	Kitwe	Bird traps; adhere paper.
UNIDENTIFIED PLANTS	–	–	Dwebedwebe (Tonga)	exudate	Sinazongwe	Construction.
	–	–	Incomba (Tonga)	exudate	Sinazongwe	Construction.
	–	–	Mulamatila (Lozi)	exudate	Mongu	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
	–	–	Mutomboli (Bemba)	exudate	Mongu	Bird traps; bird traps; repair objects; woodworking; seal seams canoes; hafting.
	–	–	Mukutingi (Lozi)	exudate	Mongu	Bird traps; repair objects; woodworking; seal seams canoes; hafting.
ANIMAL PRODUCTS	*Apis mellifera* L.	Apidae	honey bee (English)	wax	Mongu	Repair objects; woodworking; seal seams canoes; hafting.
	Meliponini tribe (?)	Apiade	Stingless bees (Tonga)	black wax	Sinazongwe	Seal canoe seams; repair objects.
	Bos taurus sp. L.	Bovidae	Cow (English)	hide	Mongu	Repair objects; woodworking; seal seams canoes; hafting.
	Hippopotamus amphibius	Hippopotamidae	Hippopotamus (English)	hide	Mongu	Repair objects; woodworking; seal seams canoes; hafting.
	–	Iridinidae	Snail shell (Tonga)	powdered shell	Sinazongwe	Repair objects.

Fig. 2. Examples of adhesive products and traps in Zambia. (A) Chembwe trap made in Sinazongwe. (B) Beeswax used as an adhesive in Sinazongwe. (C) Final adhesive product made in Kafue using *Euphorbia matabelensis*. (D) Adhesive product from *E. matabelensis* in two stick holders used to prepare bird traps in Kafue.

analyzed using Atlas.ti Windows (Version 23.0.8).

2.5. Demonstrations

After the interviews, we asked participants to demonstrate the collection of natural ingredients, produce their adhesives, and apply them. We opted for demonstrations to document these procedures comprehensively, as direct observations of adhesive production were often hindered by the infrequency of the practice or resource unavailability. For instance, one participant in Mongu was not able to demonstrate the production process due to the unavailability of raw materials. While we recognize that observations of regular schedules may offer more profound insights, the demonstrations allowed for detailed documentation essential for formal modeling. During these demonstrations, we refrained from interrupting participants with questions in order to capture natural behavior and collect structured visual data on the production process.

2.6. Herbarium specimens and natural ingredients

We collected herbarium specimens and samples of the natural ingredients and traditional adhesives identified in the field. If a species or ingredient was mentioned by a participant but we were unable to find specimens in the field, we attempted to identify it using ethnobotanical literature and the vernacular names provided by the participants. If we were still unable to identify the species or ingredient, we marked it as unidentified. Labelled duplicates of botanical specimens were deposited at the Naturalis Biodiversity Center in the Netherlands, the Zambian National Herbarium in Lusaka, and the Livingstone Museum in Livingstone (Zambia). Additional work was conducted on the molecular composition of these ingredients, and the results of this are published separately (Chasan et al., 2024).

3. Results

3.1. Sinazongwe

3.1.1. Maker and user types

Participants included one female and five males, ages ranging from 44 to 78 (Table 2). Four participants are farmers who engage in seasonal fishing activities in Lake Kariba. Out of the participants, only participant 6 (P6) self-classified himself as a boat maker and fisherman. All of the participants have been producing adhesives since their early years, between the ages of 5 and 15. Male makers in Sinazongwe use adhesives mainly for bird catching while participant 5 (P5), the mother of P6, reported production of adhesives for repairing objects and woodworking. The adhesives produced serve primarily personal purposes, with the exception of P5 who reported producing adhesive for others as well. Final users are both female and male and they are more numerous than makers.

3.1.2. Materials and properties

The number of plants species known to make adhesives varied per individual. Glue-makers reported the use of up to four different species but only one production process for latex-based adhesives. Participants used exudates from four species of *Euphorbia*; *Euphorbia cooperi*, *Euphorbia ingens*, *Euphorbia fortissima*, and *Euphorbia tirucalli* as principal components in the production of adhesive materials. The resin from *Colophospermum mopane* is added also as component. They also mentioned the fruit from *Diplorhynchus condylocarpon* to make adhesives or as chewing gum (Table 1). Water is also used in the production process. *C. mopane* resin, sand, pounded shell (Iridinidae), and black beeswax (Fig. 2B), likely from a genera of stingless bees (Meliponini), are combined in the only animal-based adhesive. P5 reported the use of exudates from two unidentified trees, known as dwebedwebe and incomba in Tonga to make a type of cement. P6 mentioned the use of exudate of the mukoka (Tonga) tree, an *Vachellia* sp., to seal canoe cracks.

Material properties determined the selection of plants with similar exudates. According to reports from Participants 2 (P2), 3 (P3), and 4 (P4), there is a hierarchical order in the strength of latex-based adhesives. They noted that *E. fortissima* latex produce the strongest adhesive, followed by *E. cooperi* latex, which is stronger than *E. ingens* latex. P3 and P4 used the latex from *E. tirucalli* directly to stick paper, but Participant 1 (P1) indicated that this exudate does not produce a strong adhesive for other uses and processes.

Participants gave different explanations for properties of materials and adhesive products. For instance, the mixing of latex and mopane resin involves boiling both components in water. Participants acknowledged this step but P1 stated that water is not actually part of the mixture. Additionally, P1 claimed that *E. cooperi* latex does not cause irritation, but emphasized the need to wash hands after the process. In contrast, P2 avoided using *E. cooperi* latex due to its toxicity. The addition of *C. mopane* resin was recognized by participants as necessary to obtain the final product, but the effect indicated was different. P1 described mopane resin as a softening additive while P2 said this resin as gave strength to the mixture. Participants reported softening of *Euphorbia* latex-based adhesives if exposed to heat, including direct sunshine in normal conditions. P1 also indicated that the latex-based adhesive is ineffective to bond metals. According to P6, latex-based adhesive are less effective than beeswax-based adhesives to seal canoe seams, but latex-based adhesives can be used when beeswax is not available. The effectiveness of beeswax as a waterproof sealant is explained by P6 because bees collect various exudates and compounds from plants for food and to build their nests. As a result, bees combine these natural components, making beeswax a strong adhesive mixture.

3.1.3. Uses

People use adhesives in Sinazongwe to set bird traps, make wood objects, and repair objects including temporary filling of canoe seams. Latex without any processing is used to glue soft materials, such as paper and textile. Adhesive production in Sinazongwe relies on exudates from bark, wood pith, and fruits. Adhesive makers usually have one primary use for latex-based adhesives. P6 uses latex-based adhesives to temporarily repair canoe cracks or seams. A permanent and preferred solution is achieved using wild beeswax. Other makers, like P5, use traditional adhesives to mend earthware, plastic containers, and to make wood chairs. Participants indicated that stored adhesives are heated before use to make them malleable and regain strength.

Bird catching is the most common use of adhesives among male farmers in Sinazongwe and a frequent activity for children throughout the country. People catch birds by covering sticks with adhesives, and place them near water sources or crop fields. Birds land on the stick and are caught. Farmers also use these adhesive sticks in sophisticated chembwe traps (Fig. 2A). Caught birds include guinea fowl (Numididae) and flock birds that feed on sorghum and millet such as the black-cheeked lovebird (*Agapornis nigrigenis*) and the red-billed quelea (*Quelea quelea*). For chembwe traps farmers capture birds and put them in a cage before the crop harvest. The cage is situated in a small hut made of branches of around 2 m high placed in the middle of a field. Farmers place a stick with branches covered with adhesive, along with few dead birds attached, through a hole in the center of the roof, so it can be pulled inside of the hut. Birds in the cage receive some grains, which makes them produce sounds that together with the sight of (dead) birds on the roof attract bird flocks. The newly arriving birds land on the branches coated in adhesives and are pulled in by the hunter hidden inside the hut. They put the newly captured birds inside the cage with the other birds. Farmers repeat this process until they catch a large sack of birds.

Farmers catch birds as a way of pest control, but also to use birds as food. Bird catching and producing latex-based adhesives are less frequent in Sinazongwe today than in the past. According to participants this change occurred as a result of new regulations against wildlife poaching and the replacement of millet and sorghum for maize. they said that bird catching does not impact bird population because birds migrate to other places and large flocks are still common in the area. Participants noted that the sound of birds eating inside a chembwe attracts dangerous snakes. Snake encounters are considered a risk during chembwe trapping and adhesive material collection.

3.1.4. Transmission of knowledge

How to make traditional adhesives is transmitted from parents to children or grandchildren within households. Male makers learned from their fathers, and from their grandfather when the father was not part of the household or passed away during childhood. Similarly, P5 learned from her grandmother because her mother died while she was a child. People reported transferring their knowledge to their offspring. P5 did not mention whether his son, P6, knew how to make adhesives. Additionally, P6 conveyed his techniques to produce and use adhesives to other fishermen who procured canoes from him. The learning process occurs in the residential unit and crop fields, where adhesives are produced and used. The learning process combines apprentice-style and experiential learning. Apprentices acquire their knowledge from their parents or parental figures via instructions, observations, questions, and hands-on experience. According to participants, use of spiritual and religious elements are absent from the learning process.

3.1.5. Collection and production

Collection occurs usually in distant forest and shrublands, and sometimes near residences. *Euphorbia* latex comes mostly from the stems. Only *E. tirucalli* latex is extracted from the branches of shrubs that are planted as hedges between residential properties. The other *Euphorbia* trees occur within 10 km of the participant's residential places, but participants prefer to travel—up to 87 km—to obtain the latex because larger quantities of the preferred species grow in these distant locations. This allows gathering from several trees, without needing to search for dispersed plants. Latex collection for bird traps occurs once per year, usually between March and June. A round trip takes two days and latex collection at the location can take one to three days. Collection takes time because the latex drips slowly from damaged trunks (Fig. 3B). Participants stated they often collect latex individually, while several individuals may gather latex simultaneously at preferred locations.

Participants in Sinazongwe make vertical cuts with an axe in the tree trunks of *Euphorbia* species and hold a container under each cut to collect the emerging exudates. During demonstrations, plastic bottles were used as containers, but P2 mentioned that cow horns are preferred for the collection process because of their effectiveness gathering the latex. P1 indicated that latex collected from several trees is then transferred to one container before going back to their residential location. Latex from *E. tirucalli* is simply collected by breaking a green branch and directly applied without any further steps.

Collectors gather the *Colophospermum mopane* bark near their residences immediately before starting the production event. Using an axe, they remove parts of the inner and outer bark, with a preference for trees that show coagulated exudate in the outer bark (Fig. 3A). Within a few minutes, they collect pieces of bark without removing the exudate dripping from the trunk cuts. To ensure the tree's survival, collectors do not ring-bark the tree. In contrast, P5 collects *C. mopane* only exudate in small quantities from a tree in her residence.

Beeswax can be collected at any time of the year, but it is particularly easy to collect during the rainy season. Accordingly to P6, this is because the rain causes bees to leave the nests, making it easier for collectors to find nest locations. Unfortunately, P6 could not provide any further information about the specific methods used for collecting beeswax in Sinazongwe because he hires other people to collect for him. P5 collects Iridinidae shell from a near water sources and *C. mopane* resin, sand, and charcoal, near her residence.

Participants produce adhesives in large quantities for catching birds.

Table 2
Participant data reported or observed during interviews and demonstrations. Presence is indicated by the number 1 for the following variables: uses, harvested parts, species families, components, steps, teaching methods, apprentices types, oral tradition, help from others, and collection months. Counts or participant-provided answers are reported for the remaining variables. "CH" indicates childhood, "ND" indicates that no data was available for the variable, and "IDK" indicates that the interviewer did not have an answer. The following abbreviations are used to indicate the location where the data was collected: SZ for Sinazongwe, KW for Kitwe, MG for Mongu, and KF for Kafue.

PARTICIPANT		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
AREA		SZ	SZ	SZ	SZ	SZ	SZ	KW	MG	MG	KF	KF	KF	KF
SEX		male	male	male	male	female	male	male	male	female	male	female	male	male
LEARNING AGE		9	15	CH	CH	CH	10	12	9 and 35	CH	5	ND	8	7
CURRENT AGE		IDK	44	50	56	78	51	34	47	60	70	75	10	13
ADHESIVE MAKING DIFFICULTY		easy	easy	easy	easy	ND	ND	hard	hard	hard	hard	hard	easy	easy
USES	Traps	1	1					1	1	1	1	1	1	1
	Repair objects	1	1	1	1	1		1	1	1	1			
	woodworking	1	1			1			1	1				
	Construction					1								
	Seal canoe seams	1					1		1					
	Hafting								1					
	Adhere soft materials paper			1	1			1						
HARVESTED PART	Bark plant	1	1			1	1							
	Trunk plant	1	1			1	1	1	1		1		1	1
	Fruit							1		1				
	Branches			1	1									
	Seeds											1		
	Nest insect					1	1		1					
	Hide mammal								1					
SPECIES FAMILIES	Apiade					1	1		1					
	Apocynaceae			1	1			1	1		1			
	Bovidae								1					
	Cucurbitaceae										1	1		
	Euphorbiaceae	1	1	1	1		1		1		1	1	1	1
	Hippopotamidae								1					
	Iridinidae					1								
	Fabaceae	1	1	1	1	1	1		1					
	Loranthaceae									1				
	Malvaceae								1					
	Moraceae							1						
	Undetermined species				1	1			1					
OTHER COMPONENTS USED	water	1	1			1				1	1	1	1	1
	charcoal					1		1						
	sand					1			1					
	vegetable oil										1	1	1	1
PRODUCTION STEPS	heat				1	1	1							
	Dry	1	1									1		
	Boil	1	1					1	1	1	1	1	1	1
	Pound					1			1	1		1		
	Cut	1	1	1	1	1		1	1					
	Sieve									1		1		
	Knead	1	1			1				1	1		1	1
	Stir	1	1					1	1		1		1	1
	mix	1	1			1		1	1		1	1	1	1
	Make fire	1	1			1	1	1	1	1	1	1	1	1
	Cool								1				1	1
	store	1	1				1	1	1		1			
	clean	1	1						1	1		1		
TEACHING METHOD	Instructions	1	1	1	1	1	1	1	1	1	1		1	1
	Observations	1	1	1	1	1	1	1	1	1	1	1	1	1
	Practice	1	1	1	1	1	1	1	1	1	1		1	1
APPRENTICES TYPES	Younger	1	1	ND	ND	1			1	1	1	1		
	Peers			ND	ND		1	1	1				1	1
ADHESIVE MATERIAL ORAL TRADITION	myths								1		1	1		

(continued on next page)

Table 2 (*continued*)

PARTICIPANT		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
	songs											1		
HELP FROM OTHERS	Collection	1		ND	ND	1	1	ND	1					
	production	1	1			1		ND				1		
	Use							ND			1			
REPORTED COLLECTION MONTHS	January rainy						1	1	1					
	February rainy						1	1	1					
	March rainy	1	1				1	1	1					
	April rainy	1	1				1		1					
	May cold-dry	1												
	June cold-dry	1												
	July cold-dry													
	August hot-dry													
	September hot-dry									1				
	October hot-dry									1				
	November hot-dry						1		1					
	December rainy					1	1		1					
	Any month			1	1						1	1	1	1
COUNT PLANT SPECIES MENTIONED FOR ADHESIVE PRODUCTION		4	4	4	4	3	3	3	10	2	3	1	1	1
COUNT COMPONENTS USED IN ADHESIVES		3	3	1	1	5	1	2	2	2	3	2	3	3
COUNT ADHESIVE PRODUCTION PROCESSES KNOWN		1	1	1	1	3	2	2	2	1	1	1	1	1
SIZE COLLECTION PARTY		1	1	ND	ND	1	ND	5	3	3	1	1	2	2
SIZE PRODUCTION PARTY		1	1	1	1	1	1	1	1	1	1	1	2	2
MIN. NUMBER OF DAYS COLLECTION		3	1	1	1	1	ND	2	2	1	1	1	1	1
NUMBER OF DAYS PRODUCTION		1	1	1	1	1	1	1	1	1	1	1	1	1
MAX. FREQUENCY PRODUCTION PER YEAR		1	1	anytime	anytime	anytime	4	ND	ND	1	anytime	anytime	anytime	anytime

They reported the same production process for this use and considered the production of adhesive an easy task. After collecting glue-makers let the Euphorbiaceae latex dry between two days to one week to remove water content from the exudate. Participants emphasized the importance of drying the exudate to prevent the production of a watery mixture instead of an adhesive product when heating adhesive components in hot water. Once the latex is dry, they prepare a fire and heat water in a pot. The solidified latex is submerged into hot water, and the pieces of *C. mopane* bark are added. Participants do not add loose *C. mopane* resin, the resin comes to the mixture during boiling from the pieces of bark in the pot. The mixture is brought to a boil and constantly stirred with a stick. Once the mixture becomes soft and elastic, the pot is removed from the fire. Makers wet their hands with water, extract the resulting dough from the pot and start kneading it (Fig. 4A). While kneading, they extract pieces of bark from the dough. Large pieces of bark and water used remain in the pot. Makers occasionally dip the dough into the hot water while kneading. In minutes they obtain an adhesive ball. If the adhesive is not directly used, it can be stored for up to a year inside a polyethylene bag under a heap of ash, to prevent spoiling. Stored adhesives solidify and have to be heated before use. The latex from *Euphorbia* species (Table 1) and mopane bark are harvested in equal amounts. P1 described that 0.35 l of latex can be obtained from five *E. cooperi* trees. P1 and P2 used together roughly 417 g of latex and 434 g of mopane bark with resin to make 366 g of adhesive (Fig. 5). This resulted (during the production demonstrations) of around 85% of *Euphorbia* latex to the total adhesive weight. However, participants do not measure materials to calculate adhesive yield.

Participants produce adhesives in small quantities to mend or fix objects. P5 made an adhesive mixing mopane resin, Iridinidae shell, beeswax, charcoal, and sand. She starts the process by heating the beeswax and pounding the shell and the charcoal. Some 5 g of heated beeswax are kneaded with around 1 g of pounded shell, mopane resin, charcoal ashes, and sand. Once fixed, the adhesive is heated again using a hot metal blade (Fig. 4B). P6 employs two variants of the latter process to seal cracks or canoe seams depending on the material available: he heats a solidified exudate from the mukoka tree (*Vachellia* sp.) to then apply it directly to the crack or simply kneads beeswax and applied directly to the hole in the canoe. P6 indicated that both processes are

Fig. 3. (A) Collection of *Colophospermum mopane* bark in Sinazongwe. (B) Exudate collection of *Euphorbia ingens* in Sinazongwe. (C) Collection of *Diplorhynchus condylocarpon* exudate in Mongu. (D) Collection of exudate and fruits from *Landolphia parvifolia* in Kitwe.

Fig. 4. (A) Kneading adhesive to extract pieces of bark of adhesive ball in Sinazongwe. (B) Heating and applying adhesive to seal a water pipe in Sinazongwe. (C) Heating beeswax to mix with tree exudates in Mongu. (D) Stirring fruits to obtain adhesive from *Landolphia parvilofia* in Kitwe.

effective seals for the cracks and help to prevent any further damage to the canoe. P5 also briefly explained that the exudates of dwebedwebe and incomba trees (Table 1) are mixed with sand to create a cement that is utilized in the construction of foundations for houses.

3.2. Mongu

3.2.1. Maker and user types

People in the Mongu district produce adhesives for their own use. We interviewed participant 8 (P8, 47-year-old male) and participant 9 (P9, 60-year-old female) both produced adhesives since childhood. P8 worked as a fish merchant, but now he is involved in the production and sale of wood crafts. P9 made adhesive together with her parents and siblings to catch birds, but this ceased when her parents passed away. She currently practices farming and produces and sells basketry. Both participants mentioned more adhesives makers and concurred that children catching birds are the most common producers and users.

3.2.2. Materials and properties

P8 reported 10 plants that produce exudates which can be used to obtain adhesives. He most frequently uses exudates from *Landolphia parvifolia*, *Diplorhynchus condylocarpon*, *Brachystegia floribunda*, and *Ficus thonningii* as well as exudates from an unidentified tree called mulamatila in Lozi. Additionally, he also mentioned other unidentified plants that can be utilized for making adhesives (Table 1). He uses any of these plants or a mixture of those available as an adhesive component. The other components are derived from animals: most frequently beeswax from wild honeybees (*Apis mellifera*). When beeswax is

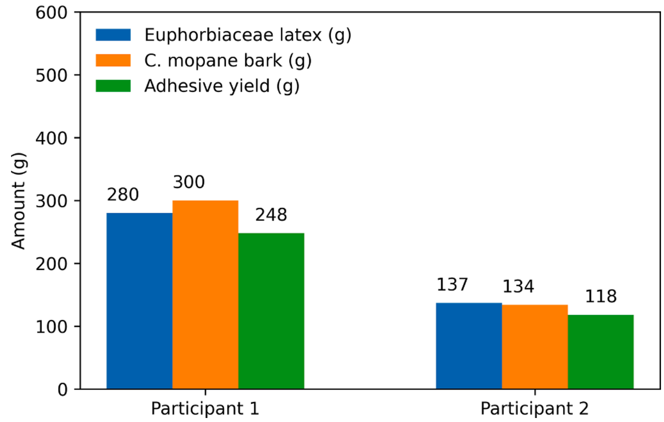

Fig. 5. Amounts of *Euphorbia* latex and *Colophospermum mopane* bark used by P1 and P2, and adhesive yield in grams.

unavailable, bituminous tar discarded from road construction is used as a replacement. P8 also reported producing adhesives with cowhide or hippopotamus skin (Table 1), which he mixes with the plant exudates mentioned above. He sporadically uses river sand as additive when sealing canoe seams.

P9 reports to make latex-based adhesives using exudates from *Agelanthus* cf. *subulatus*, *Tapinanthus* cf. *forbesii*, and *Tapinanthus dependens* (Table 1). P8 and P9 both mentioned that people can make adhesives from *B. floribunda*, but P9 did not use this raw material to make adhesives herself. Water is used in processes of both participants, for cooling adhesives after the application (P8), and during the boiling of the exudates (P9).

While participants acknowledge differences in quality depending on the materials used, it is the availability of the materials rather than their specific properties what determines their use in production. P8 indicated that the adhesive of hippopotamus hide has the best quality, but he made it only four times due to limited access to this material. When producing adhesives with beeswax, the quality depends on the types and quantities of other components. Of the exudates, the one from mulamatila tree produces the best adhesives, followed by (*L. parvifolia*), and then (*B. floribunda*) exudates. However, P8 believes that the best adhesives result from a combining large quantities of all known exudates. P9 did not report preferences or differences in quality of adhesives, but rather cited limitations on production because of the seasonal availability of Loranthaceae fruits.

Animal based adhesives can bond between metal, wood, stone, and bone. P8 considers that these bonds are stronger than those made with commercial adhesives. He also stated that beeswax is more effective when it comes mixed with honey. He mentioned that dead bees in the beeswax give a dark color to the mixture and reduce the quality of the adhesive product. P8 also noted that when exposed to water, during collection or production, raw exudates can easily spoil. In contrast, finished adhesives products do not present this property. Water is used to wet the fingers to smooth the surface of the adhesive joint during the application of adhesives containing beeswax and is also poured on the joint to cool the adhesive after application. Hot water is also used to heat adhesives made with Loranthaceae berries to regain strength before use. All materials use by participants in Mongu are non-toxic, with the exception of the exudate from mulamatila tree. P8 indicated that direct contact with this exudate can cause skin or eye irritation.

3.2.3. Uses

P8 uses adhesives for a variety of purposes, including hafting iron blades, binding wood, and filling canoe seams. During demonstrations P8 applied the adhesive hot and then cools it with water. For hafting blades, he fills the socket in the haft with adhesive, inserts the blade, and applies more adhesive around the joint with the help of a stick. For other joints, he applies adhesive to both parts and presses them together. A rope can be used to keep pieces together while the adhesive cures. P9 produced adhesives in her childhood for trapping birds and repairing containers. She made bird traps by covering sticks with adhesive and placing them in sites visited by birds. She also repaired containers by filling cracks or applying adhesive to broken parts and putting pressure to finish the join.

3.2.4. Transmission of knowledge

Knowledge transmission varied between both participants. P8 initially stated that he had learned adhesive production techniques at the age of 35 years from a mentor who taught him how to make crafts. Later during interviews, he revealed he acquired his first knowledge about adhesives during the Mukanda ceremony in the initiation camp at the age of 9. More recently, he became skilled in making adhesives from hippopotamus hide in Chanyaya, a village in the Southern Province. He learned to make adhesive by a combination of instructions, observations and practice. He uses this same combination of methods to teach apprentices. P8 has taught his knowledge to other craft-makers and four woodworking apprentices, who worked at the workshop to pay in kind for these new skills. Apprentices were non-relative males from distant villages. P8 shared his knowledge to teach apprentices how they can live on the natural resources available in the region. However, he mentioned that apprentices are reluctant to produce traditional adhesives because the process involves a considerable investment in time and effort, especially while collecting materials in the bush.

P9 and her siblings acquired knowledge about adhesive making from her parents through a combination of instructions, observations, and practice. In daily family gatherings, parents provided instructions and information on the plant ingredients and the process. The family also made adhesives together. The participant later taught her own children. She did not have other apprentices because people do not see adhesive making as a profitable skill. Therefore, it is difficult to find people interested in learning outside of her household.

3.2.5. Collection and production

Material collection for adhesive production occurs in natural vegetation. Loranthaceae species can be found as parasites on big trees near dispersed farmsteads, while other species are often located far from settlements. Except from Loranthaceae fruits, all exudates are collected from tree trunks. For the demonstration, P8 collected exudates from trunks located 17 km from his workshop. However, he typically hires people in more distant villages to collect exudates and beeswax because he prefers to dedicate his time to his workshop. Collection usually occurs once per year. Tree exudates are collected during the rainy season, between November and April. Then exudate collection can typically last between two and three days, as they produce more exudate, while in the dry season, the same activity can take two weeks.

P8 explained that a collection party is composed of two to three individuals. Exudate collectors avoid killing trees during the collection process. Preparations for material collection are essential and include scouting for places with several trees and gathering several containers to tap more than one tree at the same time. The main challenge during collection is that people cut trees with exudates to produce charcoal. As a result, nowadays trees are found farther from settlements than in the past, making collection more difficult. Seasonality of the exudate yield is another limiting factor.

Collectors make horizontal cuts on the trunks of trees and peel bark sections to obtain the exudates (Fig. 3C). They use a container to collect the exudate and may scrape the exposed wood with a small stick to accelerate the collection process. Small pieces of bark may come with the exudate, but they are not extracted from the container nor later in the process. The exudates are stored together in a container, regardless of their source, and transported back to the home or workshop where the processing takes place. P8 prefers to collect and use the exudate from *Brachystegia floribunda* in liquid form because when it solidifies an additional step of pounding the solid exudate is required during the production process. For an unidentified tree (mukoso), the exudate is obtained by beating the bark then squeezing the softened bark. P8 can collect approximately 2–2.5 l of mixed exudates per day.

P9 indicated that collection of Loranthaceae fruits is challenging because the plants are located on high trees. The fruits are collected between September and October (hot season) when the fruits are still green. This process usually takes half a day. Collectors use long sticks with hooks to loosen the fruits or they climb in trees to obtain them or cut down trees hosting the Loranthaceae parasites. Other tools required during collection are containers and axes or small knives. P9 usually conducted this activity together with 2–3 other household members. The fruits are all put together in a container, which is carried back to home to continue the process.

Wild beeswax is usually available, in part fostered by traditional beekeeping practices in several forest areas near small villages. Beeswax is collected at night or very early in the morning. Collectors cut down trees or branches with nests, and smoke out the bees remaining in the nest. Demonstrations performed by P8 showed that large quantities of beeswax can be obtained during the dry season.

The collection of hippopotamus hide is more opportunistic and relies on the availability of hippopotamus carcasses. According to P8 it is sometimes possible to obtain this hide during the Kuomboka ceremony whenever the Barotse King authorizes the hunt and sacrifice of a hippopotamus as part of the festivities. Alternatively hides can be obtained when the Zambian wildlife authorities are forced to kill aggressive animals.

Both participants reported complete dedication while producing adhesives and expressed that adhesive making requires considerable time and energy, mostly during collection. The production of adhesives with beeswax and exudates by P8 starts by making a fire using charcoal or firewood. Dead bees are cleaned from the beeswax and the beeswax is heated in a pot on the fire and stirred constantly (Fig. 4C). As it reaches the boiling point, the pot is removed from the fire and allowed to cool, while being constantly stirred. Once cool but still molten, the beeswax is mixed with the exudate(s) and again constantly stirred for some seconds. Then, the adhesive is ready for use. P8 mentioned leaving out steps like cleaning bees or adding some of the exudates if the adhesive has to be made quickly or if the materials are unavailable. P8 reported doing the process alone, but he received assistance with setting the fire from a family member during production demonstrations. For P8, proportions are not important as long as beeswax is mixed with plant exudates. He also mentioned that the exudates should be mixed with the boiled beeswax only after the latter has cooled, to avoid destroying the tree exudates. He used approximately the same proportion of exudate and beeswax. Two liters of exudates mixed with beeswax serve to haft around 100–120 hoe blades. The curing time for this adhesive was reported to be 10 to 12 min. If stored, it can last for around one year.

To make adhesive from hippopotamus hide, P8 first removes the hair from the skin. The skin is cut into small pieces and placed in a bowl of water on a fire to boil. Once the water is boiling, the maker adds the exudate and stirs the mixture until it begins to harden. When the mixture hardens, the maker gradually adds water to the pot and stir the mixture until the final product is obtained. P8 reported boiling hippopotamus hide between six and eight hours.

P9 described how she made adhesives from Loranthaceae fruits by first making a fire and boiling the fruits in water until they turn yellow. Then, she removed them from the pot and discarded the water. Boiled fruits were pounded in a mortar until they started to stick to the pestle. She put the pounded fruits in a dish and washed them with water to remove the green parts, remaining with the white material. The white material was kneaded into a pliable ball. Pliability indicated that the adhesive was ready for use. P9 emphasized the importance of following all the steps and indicated that Loranthaceae fruits must not be overboiled during cooking, nor mixed with other materials. For her, the most challenging steps in the production were pounding and washing the cooked fruits. P9 reported that she and her family collected a large bowl of Loranthaceae fruits in around six hours. Boiling time for the fruits was reported to last one hour and the curing time was six hours. The adhesive could be stored for around one year.

3.3. Kitwe

3.3.1. Maker and user types

Participant 7 (P7), the only participant interviewed in Kitwe, is a 34-year-old farmer who learnt to make adhesives when he was 12. He said that adults may practice bird catching, but the activity is mostly linked to childhood activities. Makers produce adhesive for their personal use and it is rarely made of other people. As a child, P7 and five other children frequently made adhesives to trap birds in their spare time. Nevertheless, he mentioned that he recently observed an adult making adhesives for the same purpose. He also noted that his father produced adhesives to glue soft materials in his work as a school teacher. The participant no longer produces adhesive due to his busy schedule with farming tasks.

3.3.2. Materials and properties

According to P7, three types of plants can be used to make adhesives: *Ficus fischeri*, *Ficus verruculosa*, and *Landolphia parvifolia*. P7 preferred the fruits of *L. parvifolia* because they do not require heat to process and can be collected more quickly than the exudates from *F. fischeri* and *F. verruculosa*. However, his father and another adult glue-maker, as reported by P7, used the tree exudates to make their own adhesives. P7 also mentioned dyeing the adhesive with charcoal to camouflage it and prevent birds from avoiding adhesive traps. When inquired about the properties, he indicated that the three plants are not toxic, but they are handled with care during production. This precaution is mostly to avoid eye contact. He also noted that adhesive strength of adhesives produced with the exudates from *F. fischeri* and *F. verruculosa* are reduced during the rainy season, because of the excess of water that is available for the trees, making the exudates more liquid and less viscous. He also indicated that when stored at high temperatures the adhesive loses its strength.

3.3.3. Uses

The primary use of adhesives in Kitwe is for bird traps. In addition, it is used to adhere paper and other soft materials. Children set up adhesive bird traps near water sources in the morning, before the hottest part of the day. Accordingly to P7, the types of hunted birds depend on the season, but generally frugivore birds are targeted because they are easy to catch. Birds are caught for food, to keep as pets, and to flaunt the skills involved in fowling. As fowling tokens, caught birds confer social prestige to the catchers among other children.

3.3.4. Transmission of knowledge

P7 acquired knowledge about plant ingredients and the production process required to make adhesives from his father and elder friends during childhood, learning primarily through observation and practice. P7 also developed a method when he was a child together with other children to use the fruit of *Landolphia parvifolia* to make adhesives without using fire. He preferred his method to the one learnt from his father where exudates from *Ficus fischeri* and *Ficus verruculosa* are boiled using fire. He did not mention transferring his knowledge to others, but at the time of the interview his children were younger than four years old and too young to make adhesives. Neither a specific learning location nor oral tradition were reported to play a significant role in the learning process.

3.3.5. Collection and production

The plants used to produce adhesives are abundant in Kitwe and occur in forest patches. During the demonstrations, exudates were collected less than 300 m from the residence of P7. While adults can collect the materials alone, children collect in groups of five or more to reduce risks of being away from their homes. Collection takes two days. During the first day, collectors assemble tools required for the extraction, such as containers and axes, and scout forest patches for places with many adhesive producing plants. In the second day, the collection process starts after households chores are finished. The collection of *Ficus fischeri* and *Ficus verruculosa* exudates is done by making diagonal or vertical cuts on the tree trunks and placing containers below the cut to gather the dripping exudates. Exudates from both species are collected in the same container and can be mixed. This process is repeated until the desired quantity of latex is collected. P7 noted that under ideal conditions several *F. fischeri* and *F. verruculosa* trees can produce together around 0.5 l in one day. The collected quantities differed between makers depending on, for example, the number of traps to set.

Landolphia parvifolia fruits are harvested when still green. First, the exudate dripping from the pedicel is gathered. Then the fruit is opened in half and the pulp is mashed inside the fruit with an stick or knife and then squeezed in a container with the exudate from the pedicel (Fig. 3D and 4D). This process is repeated until enough material is collected. The hard pericarp of dried *L. parvifolia* fruits can be used as container to collect the pulp and the exudate. The exudates from the pedicel and pulp are stirred in the container until they become a malleable and adherent adhesive mixture (Fig. 4D). P7 reported collecting approximately 0.2 l of exudate, which was sufficient to produce 3–4 bird traps. To obtain the same 0.2 l of adhesive from *L. parvilofia* fruits, a maker requires between 100 and 200 fruits.

The production of adhesive from *F. fischeri* and *F. verruculosa* involves heating their exudates in a container without the addition of water. The exudates are constantly stirred during the heating until they reach the desired thickness. Once the desired consistency is achieved, the adhesive is removed from the heat source and allowed to cool before use. If the adhesives are intended for bird traps, charcoal is mixed with the adhesives. This requires pounding the charcoal and adding it to the adhesive prior to use. The adhesives can be stored in a dry and cool place for about a year.

3.4. Kafue

3.4.1. Maker and user types

We interviewed four individuals from the same household, participant 11 (P11, 75-year-old female), participant 10 (P10, 70-year-old male) son-in-law of P11, and two male children of P10, participant 12 (P12, aged 13), and participant 13 (P13, 10 years old). P11 is a farmer and never produced adhesives, but she makes oil from *Lagenaria* sp. seeds used in the past in adhesive production. P10 works as farmer and merchant, and at a younger age, he made adhesives for traps. P12 and P13, currently attending school, produce adhesives on a regular basis, and they mentioned at least other five children who also produce adhesives with similar characteristics and frequency. P10, P12 and P13 learnt adhesive production between 5 and 8 years old. Participants produce adhesive materials for personal use and they do not engaging in activities such as selling, buying or collecting from or for other people. P11 and P10 indicated that adhesives are often produced by males. Females used them but rarely engaged in production.

3.4.2. Materials and properties

Participants reported three species for adhesive production: *Euphorbia matabelensis*, *Landolphia parvifolia*, and *Lagenaria* sp. *E. matabelensis* grows in rocky places and is abundant because it is not used for charcoal. In the past, hunters used its exudate to poison arrowheads and spear points, but now poaching laws and fire arms have reduced this practice. The *Lagenaria* sp. fruits are cultivated because their seeds contain cooking oil and the fruit itself is edible. The oil was used in the past to cook, including the exudates employed in the production process of adhesives. This fruit is available around the time of the corn harvesting. Water is used to boil exudates. P12 and P13 replace this home-made oil with vegetable oil that can be purchased on local stores. P12 and P13 indicated that synthetic adhesives do not have the consistency required for bird trapping.

3.4.3. Uses

Adhesives are used in animal traps and repairing objects, including shoes, containers and items with metal and wood components. Adhesive traps are used to catch guinea fowls, small birds and rabbits. The reasons for catching animals are protecting crops, obtaining meat, and hunting games among friends. Children and adults catch animals by covering sticks with adhesives and place them near water sources or crop fields.

3.4.4. Transmission of knowledge

P11 taught her children and grandchildren how to make oil from *Lagenaria* seeds, but it is unclear whether this knowledge was passed down only to female children. P10 shared his adhesive-making knowledge with one of his elder sons, who then taught P12, P13, and his other siblings. P11 did not know about one of the plants mentioned by P10 as adhesive source. The instruction process involves verbal guidance, observation, and practice. Adhesive production also has indirect ties to oral tradition. For example, singing motivational songs is involved in pounding *Lagenaria* seeds to extract oil. Additionally, P10 and P11 explained that in the past, hunters planted *Euphorbia matebelensis* in their residences to foretell hunting success and protect themselves against spirits. After a successful hunt, they would place the prey's head on tree branches and this would settle spirits down after hunting. Spirits would then visit the hunter at night and provide guidance for future hunting activities.

3.4.5. Collection and production

Makers collect the latex from *Euphorbia matebelensis* in the bushes near their residences. Before going to the bushes, they gather a sharp object like a knife and containers to collect the exudates. Collection can be done alone or in groups. P10 indicated that collection can take several hours. For the demonstrations, P12 and P13 gathered the necessary amount of exudate in one day. Collectors hit the *E. matebelensis* trunk with the sharp object and collect the exudates dropping from the wound. To collect enough exudate, P10 explained that collection has to start in the early morning because the exudates drip slowly from the trunk. Makers put oil in their hands to prevent the material sticking to their hands or build containers with long handles and use sticks as spatulas.

Makers start the production by heating the *E. matebelensis* exudate with water in a pot. The mixture in the pot is brought to a boil. Participants take the adhesive out from the water and knead the heated exudate, the adhesive is placed back in the water; this process is repeated several times. While P10 indicated he kneaded using hands lubricated with oil, P12 and P13 used two sticks instead to avoid direct contact with the mixture (Fig. 2C and 2D). Once the mixture becomes soft and plastic, the pot is removed from the fire. Makers extract the exudate from the pot and knead it constantly. The remaining hot water in the pot is discarded, the pot is put back on the heat source and *Lagenaria* seed or other oil is added. The kneaded exudate is added to the pot with oil and cooked. This mixture continues to be frequently kneaded in the pot, and the pot itself is removed and put back on the fire at least a couple of times. After some minutes of repeating this process, the adhesion of the adhesive is tested and then the material is declared ready for use. P10, P12, and P13 consider producing adhesives an easy activity, but regard collecting exudate as the most cumbersome part of the process. Around 20 *E. matebelensis* trees are needed to fill a 1 l bottle of exudate and the amount produced changes depending on their needs. During demonstrations, P12 and P13 collected around 0.5 l of *E. matebelensis* exudate in one day and used this quantity with 0.03 l of commercial vegetable oil to make the adhesives.

P11 described the process to obtain oil from the *Lagenaria* sp. as follows. The process starts by drying the seeds. Makers pound batches of dried seeds in a mortar. When a batch of seeds is pounded, the resulting flour is sieved to a container. The cycle of pounding and sieved continues until the desired amount of sieved flour is collected. A fire is made and water is put to heat on the fire. Makers place batches of the sieved flour in the mortar and add small amounts of hot water while pounding each flour batch. This cycle goes until the mixture results in the separation of dough and oil. The dough and the oil are the two products of the process. The dough is used to make food and the oil can be used for cooking or in adhesive production. P11 needs up to 3 h to produce oil and considers the process difficult. Drying and pounding the seeds are the most difficult parts of the process.

4. Discussion

4.1. Flexibility in production of systems of traditional adhesives

We set out to study the flexibility of traditional Zambian adhesive production in terms of the production processes, including the sequence of events, materials used, intended applications; and also in light of cultural, demographic, and environmental differences between people. We found that the production systems of traditional adhesives in Zambia show flexibility, a characteristic common in many complex systems (Fraccascia et al., 2018; Holling, 1973). We found evidence of this capacity in three behavioral aspects of the system: i) the ability to absorb change, ii) the multiple paths to transfer and generate knowledge, and iii) the differences in production between regions and participants groups. In spite of the environmental challenges, such as deforestation of latex-producing trees in Mongu, increased institutional and individual restrictions to hunting in Zambia, and low cost of commercial synthetic alternatives, traditional adhesive technologies operate at a lower scale as before, but they continue to function. These characteristics show the ability of the technological system to absorb disturbances and reorganize when experiencing changing conditions while retaining the same function and structure. Such characteristics are present in complex social-ecological systems (Walker et al., 2004) and modern systems (Ouyang, 2014).

The variability of adhesive production is visible across age and sex, as are the multiple paths to transfer and generate knowledge. All participants learnt and produced adhesives from an early age. Certain materials, such as the exudates from *Euphorbia* species or *Landolphia parvifolia*, are widely distributed in Zambia and are known and used by people of all ages and sexes. However, our research shows that the processes and materials used are not constrained by tradition, and children replace parts of the processes or materials learned from their parents or elders with new steps or materials. Children can also develop their own methods using different species as the one used by elders. These results underline part of previous findings that indicate that skills learned in childhood create foundation for future innovation in adulthood (Lew-Levy et al., 2017; Nielsen et al., 2014). However, our results also indicate that the age at which children start to demonstrate innovative and complex technological behaviors may be earlier than previously documented, occurring during middle and late childhood rather than around adolescence. More (long-term) research on innovation during natural behavior could help clarify this. These results also confirm that children occupy their own 'niche' and their material choices probably reflect an optimization of their foraging strategies (Bird and Bliege Bird, 2000; Bird and Bliege Bird, 2002). For example, in Kitwe, children opted for an alternative approach to adhesive production by disregarding the plants traditionally used by adults. Instead, they utilized fruits, simplifying the production process and eliminating the necessity for a heat source to achieve the desired adhesive properties.

Our findings show the importance of recognizing the diverse roles of men and women in the production and use of these technologies. Interestingly, we observed that same-sex vertical transmission is present, with separated learning spaces, processes, and uses. This result supports previous studies that suggest that many skills are acquired through vertical transmission from same-sex parents (Lew-Levy et al., 2017). However, our study challenges the notion that traditional technology is strictly gender-specific, as we found that both sexes possess knowledge on adhesive technologies, and this knowledge is differentiated based on the various uses or geographical distances rather than sex. Male and female makers may not necessarily be aware of each other's knowledge, even within the same household. Some source materials and the production process were only mentioned by women while others only by men. Our findings are consistent with previous studies that have documented the presence of female and male producers of adhesives in geographically near, but culturally differentiated zones in Ethiopia (Arthur, 2018; Arthur, 2010; Sahle, 2019). Adhesive production has also been observed in Australian aboriginal communities, where women produce adhesives in large quantities while men produce in smaller amounts, using the same kinds of tools (Akerman, 1979; Rots et al., 2020; Love, 1942). These studies suggest differences in the use of traditional technologies by both sexes cannot be extrapolated to restrictions of one sex or the other regarding a particular technology.

The production of adhesives is flexible, allowing for the reorganization of events, and the substitution of materials to achieve the final product. Despite reporting seasonal limitations in material availability related to rainfall, most participants were able to carry out adhesive production processes during the dry season when we visited. Makers also demonstrated the flexibility of the adhesive production systems by collecting materials in places different from their usual locations. Materials can be gathered from nearby locations in case of need. In addition, 10 out of 13 participants mentioned at least two plants from which adhesives can be derived, underscoring that makers possess a multitude of options and they are not bound to a singular material to create adhesives. Participants also indicated that components can be mixed, replaced or left-out depending on availability or time constraints. The cases presented in this study, as well as other case studies in Africa (Sahle, 2019; Wadley et al., 2015), and experimental (Schmidt et al., 2019, 2022, 2016, 2014) and modeling (Fajardo et al., 2022) studies suggest plasticity in technological behaviors associated with adhesive production.

4.2. Archaeological implications

The examination of adhesive technological systems in Zambia reveals that making generalizations about adhesive production processes is challenging. Our observations of production systems and makers are immersed in settings that differ significantly from those of the past, making it difficult to use these ethnobiological examples as direct analogies of prehistoric events (see Schmidt, 2010). Despite these challenges, there are several conclusions to drawn that are relevant for the archaeological study of technology.

4.2.1. On the identification of archaeological adhesives

Most of the adhesives described in this paper are plant based but the variety of plants and different plant parts exploited is striking. The exploited plant exudates include resins, latexes gums, which have diverse molecular signatures (Murthy, 2021). Plant based adhesives made from these materials are also frequent in the archaeological record, and because of their complex organic compositions, an array of techniques targeting the lipid and carbohydrate fractions must be applied in order to identify them.

The oldest known adhesive is a c. 200,000-year-old tar made by distillation of birch bark and used by Neanderthals to haft stone tools (Mazza et al., 2006). In southern Africa, adhesives made with conifer resin date to at least 60,000 years ago (Charrié-Duhaut et al., 2013). Prehistoric adhesives were probably obtained from wood/bark and resins, and evidence for the use of other parts of the plants is scarce. Experimental analysis showed that tar can be obtained from Podocarpus leaves (Schmidt et al., 2022) but to date, the use of tar made specifically from leaves has not yet been identified in the archaeological record. Similarly, no fruit-based adhesives have been found so far, although they are documented in African traditional societies, especially for birdlime-making (e.g. Ramarumo et al., 2020; Schmelzer et al., 2008). Fruits mainly contain carbohydrates and only a small amount of lipids. Compared to lipids, carbohydrates only rarely survive in the archaeological record (Evershed, 1993) and that may account for the absence of prehistoric fruit-based adhesives (cf. Kozowyk et al., 2020).

Another example are hide glues, which are extremely rare in the archaeological record, and their preservation is strictly dependent on the deposition environment. One participant (P8) in Mongu reported the exploitation of collagen adhesives for varied purposes, such as hafting, repairing objects, and woodworking. Currently, there is no evidence for the use of hide glues prior to the Neolithic. The oldest known evidence of animal (collagen) glue comes from a cave in Israel and dates to more than 10,000 years ago (Nissenbaum, 1997). The collagen glue was used as a coating agent for lining/waterproofing baskets and decorating human skulls (Solazzo et al., 2016). Animal based adhesives are thus likely underrepresented in the archaeological record although they may have been an important component of late prehistoric adhesive traditions.

Because we found that people extensively mix and work their adhesives, it may be more fruitful for archaeologists to document the variability in materials and production processes, rather than focus on one particular hypothetical material or technique as unique explanation for how the adhesive technology was produced in the past. For example, exudates from Euphorbiaceae can be mixed with *Colophospermum mopane* bark—that have diterpenes (Mebe, 2001) and other metabolities (Cheikhyoussef et al., 2023; Reiter, 2002)—or with vegetable oil to form an adhesive (Blayo, 2002). As a result, the compound adhesives, have such diverse chemical signatures, that it hampers chemical characterization of (variation in) production processes and materials. Terpenes and terpenoids are a case-in-point. Triterpenes occur in different African latex bearing plant families (El-Kashef et al., 2015; Salomé-Abarca et al., 2021) and individual triterpenes are hardly unique for any species or genus. For example, the triterpenes euphol and tirucallol are amongst the most prominent triterpenes in the *Euphorbia* genus (Amtaghri et al., 2022; Duong et al., 2019; Fernandez-Arche et al., 2010; Li et al., 2021; Wawer, 2008), but are also found in members of another plant family, the Moraceae (Emenonye and Nwabueze, 2016; Kuete et al., 2011). Such markers were identified in the adhesive lump dating back to 40,000 years ago, found in Border Cave (d'Errico et al., 2012). Based on chemical comparisons of modern *E. tirucalli* and on previous research on common compounds of Euphorbiaceae (Seigler, 1994) it was suggested that archaeological triterpenes derived from *E. tirucalli*. Nevertheless, the current lack of comparative phytochemical footprint of the exudates from the genus *Euphorbia* and the diversity of components and mixtures we found in Zambia, indicate that more studies are needed to confirm the use of specific species in adhesive production.

4.2.2. Connecting to function in the past

Another aspect of interest that emerges from this study is the exploitation of latex for its adhesive properties. Euphorbiaceae plants are a usual source of latex, and some are used as poisonous ingredients in arrow points in the African continent (Bisset, 1989; Bradfield et al., 2015). A 40,000-year-old lump of organic residues containing beeswax at Border Cave, South Africa, is probably made with *Euphorbia* sp. latex and proteinaceous material (perhaps egg). It was interpreted as a hafting adhesive (d'Errico et al., 2012) or as a "poisonous adhesive" (Wadley et al., 2015, p 4.). From the same site, a wooden stick dated to c. 240,00 years BP showing traces of ricinoleic and ricinelaidic acids, a component found in mature castor beans (*Ricinus communis* L.), was interpreted as poison applicator (d'Errico et al., 2012). Three adhesive lumps from Boomplaas Cave, South Africa, dated to the final Late Stone Age (LSA) display traces of *Euphorbia* sp. latex mixed with and exudate from *Ammocharis* sp., and a ricinoleic acid-containing plant product (Veall, 2019). These results demonstrate that the exploitation of toxic plant substances dates to at least the Middle Stone Age. Moreover, material evidence from Border Cave was used to establish a close parallel between San's practices of poisoning arrows and the prehistoric use of poisoned weaponry (d'Errico et al., 2012). Our findings show the use of latex for other purposes than hafting and poisoning, such as traps, woodworking, adhering paper, gluing objects, and sealing seams canoes.

Despite participants being aware of the toxicity of some *Euphorbia* exudates, they still use it because of its material properties. In Ethiopia, Hadiya hideworkers use exudates from *Euphorbia abyssinica* as the primary adhesive ingredient for hafting obsidian scrapers (Sahle, 2019). Additionally, as with many other toxic plants, *Euphorbia* species have medicinal applications (Coates Palgrave, 2002; Neuwinger, 1996), and the dose and preparation determine whether a product is a medicine or a poison (Bradfield et al., 2015, p. 31). Thus, *Euphorbia* exudates in traditional societies have a wide range of applications, and that may also have been the case for prehistoric adhesives. Euphorbiaceae may have been exploited in the past for its poisonous, medicinal, and adhesive properties. When *Euphorbia*-rich mixtures are found in the archaeological record, some caution for the interpretation is required, as there may not always be a unique link with poisoned adhesives for hunting weapons. In archaeological *Euphorbia*-rich mixtures, all the ingredients must be carefully considered before making any conclusions. The other ingredients may have been blended because they add to the medicinal properties, to increase or decrease toxicity, or to influence the adhesive's texture; their chemical identification can thus aid the functional interpretation.

Our findings also suggest that functional interpretations may explain the endurance of certain technologies. The persistence of a traditional knowledge is often attributed to social factors (Panich, 2013). For example, the desire of people to maintain or expand existing social networks it is linked to periods of heightened creativity and also active resistance to change (Catherine, 2021). Nevertheless, the significance of material properties cannot be underestimated in the adoption or maintenance of technologies and ways of life. A recent study of archaeological adhesives found that some of the last hunter-gatherer populations in Lesotho adopted novel resources from the landscape created by the Basotho and the European colonial rule, enabling people of ultimately hunter-gatherer origin to maintain certain aspects their traditional ways of life (Veall and Mitchell, 2023). In Zambia, traditional adhesives used in bird trapping are an example of a persistent technology in the face of modern adhesive synthetic materials. However, the traditional adhesives' unique combination of adhesive properties, such as tackiness, viscosity, and elasticity are reportedly absent in synthetic adhesives available to the participants. The implication for archaeology is that some of these enduring technologies, including adhesives, may owe their persistence to material properties that render them highly effective for specific tasks. Consequently, since some of these material properties can be directly tested through experimentation (Kozowyk and Poulis, 2019), it becomes worthwhile to investigate whether the primary reason for technological continuity is better explained by the distinctive properties of the materials themselves rather than solely by social factors.

4.2.3. Inorganic additives

Only two participants reported the use of inorganic additives as loading agents in their adhesive mixture. Those inorganic ingredients are sand and pounded shells. P5 in Sinazongwe mixes these ingredients with charcoal, black beeswax, and *Colophospermum mopane* resin to create an adhesive utilized to fix and mend objects. She also reports using sand in combination with other plant exudates to produce cement-like material for house construction. A striking difference with the archaeological record is the absence of the addition of ochre powder (iron oxides), or 'red clay' as it is sometimes referred in historical records (Webley, 1994), as an adhesive component. The use of ochre in prehistoric adhesives is widely documented across continents (Bradtmöller et al., 2016; Helwig et al., 2014; Lombard, 2007; Rots et al., 2011), and its intentional addition to the mixture may have served both symbolic and functional purposes. Laboratory test demonstrated that the addition of ochre as a loading agent impacts the performance of resin adhesives increasing strength and workability (Kozowyk et al., 2016; Zipkin et al., 2014). But archaeological examples showed that ochre can be replaced by other inorganic fillers such as quartz, sand, or clay (Rots, 2008). Adhesives made of a conifer resin loaded with quartz sand were identified at Elands Bay Cave and Diepkloof Rock Shelter, South Africa (Charrié-Duhaut et al., 2013; Charrié-Duhaut et al., 2016). Experiments suggested that fine-sized quartz grains improve adhesive shear strength (Zipkin et al., 2014). The effects of other mineral loading agents on adhesive mixture are not well researched as for ochre and quartz, but it is likely that they also affect the material proprieties of the adhesive. However, the relevance of other mineral additives in prehistoric adhesive traditions is challenging to estimate. First, clay, sand, and quartz are often natural components of archaeological sediments and may be contaminants rather than additives. Second, when left on a tool's surface after the organic components decayed ochre is easily identified compared to other inorganics. The overrepresentation of ochre-loaded adhesives in the archaeological record may also be explained by considering ochre's symbolic value. The use of other mineral fillers by traditional makers in Zambia highlights that ochre may not be essential component of adhesive mixtures and can probably be replaced with other ingredients. For prehistoric populations, ochre may have been imbued with symbolic connotations accounting for the preferential choice of this inorganic component over the others.

4.2.4. Storage of adhesives in the archaeological record

Our study sheds light on another aspect of the adhesives' life which is poorly represented in the archaeological record: storage. Most of the participants of this study reported that the adhesives could be stored for about a year. Hadiya hideworkers in Ethiopia also create rounded lumps of remaining adhesive and store it (Sahle, 2019). Storage sticks, also referred to as adhesive/poison applicators, are known from ethnographic accounts (Bleek, 1928; Deacon, 1992; Goodwin, 1945) and collections (e.g., Fig. 8A in Bradfield et al., 2020, Fig. 1 J-K in Isaksson et al., 2023). The Naron people from central Kalahari, for instance, stored and transported poisonous mixtures by compressing them around wooden sticks (Bleek, 1928). However, there are only a few archaeological examples of adhesive storage. One of the oldest pieces of evidence of storage of a general mixture comes from Blombos Cave, South Africa, and dates to 100,000 years ago. At the cave, an ochre-rich compound, interpreted as a painting mixture, was produced and store in two abalone shells (Henshilwood et al., 2001). Concerning stored adhesives, we can mention the 40,000-year-old lump found in Border cave (d'Errico et al., 2012)) and a wooden stick with a reserve of adhesive, dated to the LSA, found at Melkhoutboom Cave, South Africa (Deacon, 1976). A similar function was attributed to at least one adhesive lump with wood fragments from Boomplaas Cave dated to the final LSA (Deacon, 1984). A peculiar mastic object from Steenbokfontein Cave, dated to the final LSA (c. 2,200 cal BP), may have served a similar purpose. This cigar-shaped mastic object may have represented a reserve of adhesive to be used for fine applications, such as repairing arrows, basketry, mending strings, and gluing decorative objects (Jerardino, 2001). A mastic object from Elands Bay Cave, South Africa, dated to the LSA, may be interpreted as a lump of adhesive collected around a stick for storage and transportation or a mastic handle. Due to the symmetrical finished shape of the object, the authors lean towards the latter option (Charrié-Duhaut et al., 2016). Outside Africa, five 'tar cakes' were found in the Mesolithic site of Star Carr, England, together with birch bark rolls that may have represented a storage of raw material for birch tar production (Clark, 1954; Fletcher et al., 2018). Additionally, two large balls of birch bark tar (100 g and 8 g) were found at the Neolithic site of Montpezat-Grotte Murée, France. These adhesive lumps display textile impressions on their surface, suggesting that they were stored and transported wrapped in clothes (Rageot et al., 2021). Lastly, an amphora from the Changning site, Northwest China, dated to c. 4,000–3,500 BP, was either used to store or produce birch bark tar (Rao et al., 2019). Pottery with tar and resin residues are also well-known from Europe (Breu et al., 2023). It is possible that more lumps of adhesive or tar-stained containers that have been found can connect with adhesive storage and transportation. From the ethnographic record emerges that adhesive storage is a common aspect of the life cycle of an adhesive, especially because some of the ingredients are collected far away from the village or harvested only during specific seasons. Therefore, storing the raw materials or the processed ones is necessary to ensure the availability of the desired products throughout the year. Similarly, prehistoric hunter-gatherers may have wanted to store their surplus of adhesives for future uses considering the investment in terms of time (for collection and production) and resources for adhesives production. That may have been particularly relevant during inclement periods (e.g., MIS4 and MIS3) characterized by cold climates, scarcity of vegetation, shortage of raw materials, and extreme residential mobility (cf. Niekus et al., 2019).

4.2.5. On bees, bee products and nature inspired innovation

Participants reported the use of animal-based adhesives made of beeswax or collagen. Beeswax is used by different groups in Zambia as a component of compound adhesives or as a pure material to repair objects and seal canoe seams. Bee products have a long exploitation history. Evidence of the use of mixtures containing beeswax for hafting purposes is found in South Africa, and dates back to the Stone Age (d'Errico et al., 2012; Villa et al., 2012), and in Europe dates to the Paleolithic (Degano et al., 2019). Beeswax was supposedly added to the adhesive mixture as a plasticizer, and mechanical tests demonstrated that it greatly influences the performance of the adhesive by reducing brittleness (Kozowyk et al., 2016). Moreover, evidence of pure beeswax for hafting is also documented in Europe (Baales et al., 2017). Prehistoric accounts of beeswax adhesives are not limited to hafting but also include sealing and waterproofing pottery (Rageot et al., 2016), and gluing objects (Luo et al., 2012).

The discovery of adhesive making in the past may have occurred by observing other species' behavior. According to an informant's remark (P6), beeswax is a main component in some adhesive mixtures, and it is a natural adhesive mixture made by bees. This explanation is supported by studies documenting tree exudate components being used by bees to build and protect their nests (Leonhardt et al., 2011; Howard, 1985; Simone-Finstrom and Spivak, 2012; Shanahan and Spivak, 2021). There is a current research trend where modern technological innovation takes inspiration from nature (Shin et al., 2022); trends like these may have deep behavioral roots and may have played a role in the discovery and development of early human materials and technologies. The observation that materials are inspired by the living world, together with the transmission of knowledge among children, women, and men suggest redundancy in the mechanisms of knowledge transmission, providing the system with the ability to continue in the event of losing one of the transmission mechanisms. Models that approximate knowledge transmission in archaeology may, therefore, benefit from incorporating interactions of structured and non–hierarchical populations in their approach. This inclusion will allow to account for the possibility that past societies may have had organic organizations for knowledge transmission.

4.2.6. Distribution of plants and human activities

The distribution of plants exploited as adhesive sources and human activities in southern Africa may offer valuable insights about the evolution of vegetation and current landscapes. Some adhesive recipes are similar throughout the ecosystems in Zambia, while others are very specific to certain locations because of material availability. The production processes to make adhesives from Euphorbiaceae and Moraceae species in the Zambezi mopane, dry miombo (Sinazongwe and Kafue) and wet miombo (Kitwe) ecosystems are similar. Similar materials, steps, users, and uses, including the setting of chembwe traps, are also reported for adhesive produced in a semi-arid to arid region of

Zimbabwe (Mpala et al., 2015). Nevertheless, adhesive makers in each region have their own preferences for specific exudates and are aware that others may use different exudates. Some participants avoid certain species due to toxicity, while others do not consider the same plant toxic, or use it in spite of its toxicity. These choices between different plants for adhesive production might vary not only in space but over time. For example, *Diplorhynchus condylocarpon* and *Euphorbia tirucalli* are used by contemporary makers as adhesives in southern Africa (Veall, 2022), while only *E. tirucalli*, has been suggested to be used in ancient times (d'Errico et al., 2012). Despite their wide distribution and abundance, *Diplorhynchus condylocarpon* and *Euphorbia tirucalli* are only sporadically used in Zambia today. These observations imply that examining the distribution of plants used in technology like adhesives and the locations of ancient human activities can provide insights into potential human-induced changes in landscapes. For example, Dominance of plant species long used by humans (Levis et al., 2017) and changing anthropogenic landscapes (Gnecco and Aceituno, 2004) have been documented in tropical areas. Investigating the correlation between current and historical species distribution linked to adhesive production in southern Africa may unveil the influence of small-scale societies on local landscapes.

5. Conclusion

Adhesive makers use a wide range of materials and production techniques to overcome challenges related to resource availability and environmental concerns. Furthermore, the transfer of adhesive technological knowledge could have occurred across generations through various distinct avenues, including parallel vertical transmission among same-sex individuals, horizontal transmission among individuals of same and different ages who possessed diverse knowledge, and also though observed behavior of other species. These mechanisms collectively played a pivotal role in sustaining the technological system. When looking closely, the archaeological record is equally diverse in adhesive types, and it is likely that currently some adhesives are underrepresented in the archaeological record. Drawing inspiration from our ethnographic observations we may also expect flexible production and flexible recipe strategies in the past. A better understanding of ancient adhesives starts with mapping current traditional practices. In combination compositional analysis, physical reconstructions, and testing of material properties, we can build inferences about the evolution and impact of technological behaviors.

Author contributions statement

Conceptualization: SF, GL, TA.
Investigation: SF, JZ, CM, TM, MK, GL.
Writing original draft: SF, JZ, MK, AA, GL.
Writing, review & editing: SF, GL, TA, JZ, AA, MK.
Data curation: SF, JZ.
Formal analysis: SF, JZ, AA.
Methodology: SF, GL, TA.
Visualization: SF.
Resources: GM, CM, GL.
Project administration SF,GL.
Funding acquisition: GL.
Supervision: SF, GL, TA, GM.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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