Title: Processing and storage of tree fruits, cereals and pulses at PPNA Sharara, southern Jordan

Author names: Jade Whitlam[1*], Bill Finlayson[1*], Amy Bogaard[1,2], Michael Charles[1] and Cheryl A. Makarewicz[3*]

Affiliations:

[1] School of Archaeology, University of Oxford, 1 S Parks Rd, OX1 3TG, Oxford, UK
[2] Sante Fe Institute, Hyde Park Rd, Sante Fe, New Mexico, 87501, USA
[3] Institute for Prehistoric and Protohistoric Archaeology, University of Kiel, Johanna-Mestorf Straße 2-6, D-24118, Kiel, Germany

***Corresponding author**: jade.whitlam@arch.ox.ac.uk; bill.finlayson@arch.ox.ac.uk; c.makarewicz@ufg.uni-kiel.de

ORCID Whitlam**:** 0000-0001-9769-4704
ORCID Finlayson: 0000-0002-0330-8006
ORCD Bogaard: 0000-0002-6716-8890
ORCID Charles: 0000-0002-9630-7589
ORCID Makarewicz: 0000-0002-1649-336X

ESM 3 Experimental processing of wild barley

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Introduction

Experimental processing of *Hordeum spontaneum* (wild barley) was undertaken with the aim of examining how different processing methods affect the morphology of wild barley chaff and whether it was possible to replicate (i) the ‘ripped’ rachis morphology observed at Sharara and (ii) barley rachis internodes, both with and without palea and lemma attachments. As this was only a preliminary study sample sizes were small and not all variables have been controlled for.

Materials and methods

Experiment 1

Ears of wild barley were hand plucked from wild cereal stands in two locations in Israel in Spring 2022. Ears were selected in various states of ripeness (green to milk-ripe) and then divided into different groups (see Table 1) that were subject to the following treatments:

1. *Sun-drying (S1):* barley ears were left to dry in the sun (recorded temp. 28°C) until they began to disarticulate
2. *Ripping (R1, R2)*: barley ears were manually separated by pulling them apart in a quick downwards motion while still fresh, following the description of similar experimental processing undertaken by C. White (White and Makarewicz 2012)
3. *Control (C1, C2):* barley ears were left in the shade untouched

Table 1. Overview of barley collections and groups subjected to processing as described in text

Location code	Collection date	Number of barley ears			
		Total	Control	Sun dried	Ripped
AMU 03	26/04/2022	75	S1	R1	C1
			25	25	25
ROS 01	02/05/2022	41	n/a	R2	C2
			0	20	21

All barley ears were photographed at the start and end of the experiment and those in the sun-dried group every 30 mins during drying. At the end of the experiment, the various parts that the barley ears had broken down into were described and documented. All material was then stored in separate envelopes and exported to the laboratory at the School of Archaeology, University of Oxford (UK) for further analysis. During this time any remaining green barley dried out.

In the laboratory, the material within each group was examined under a low-powered binocular microscope (Leica MZ75) and all rachis remains were sorted according to scar type and whether palea and lemma material remained attached to the rachis internodes, following identification criteria described in the Main Text and Supplementary Information 2 for archaeological specimens (S2). Where grain remained attached to the rachis, specimens were recorded as spikelets. Lower parts of barley ears where rachis internodes were still connected to each other were rubbed together by hand, to simulating threshing and separate these out to allow an assessment of scar type. If they remained attached after threshing then the abscission scars were recorded as rough (domestic-type) scars, as they would be archaeologically. Results are reported in Table 2.

Experiment 2

The second processing experiment was undertaken in the laboratory at the School of Archaeology, where sub-samples of barley spikelets (*n* = 100) from groups R1 and C2 were pounded for two minutes in a wooden mortar and pestle, using a vertical motion as described by Eitam et al. (2015). A further three sub-samples of barley spikelets (n = 20) from groups S1, C1 and C2 were charred, to see what effect this had on chaff morphology and whether the different morphological types observed at Sharara could be explained as a result of the charring process alone. Charring was undertaken at the School of Archaeology, University of Oxford using a Gallenkamp muffle furnace, following protocols outlined by Fraser et al. (2013). This involved wrapping the material to be charred in aluminium foil and burying this in sand within a glass beaker to simulate reducing conditions. The beaker was then placed in a muffle furnace for 24hrs at 230°C. After charring the spikelets were gently agitated while still wrapped in their foil to simulate a mild degree of post depositional disturbance. Following pounding and charring, the material was then re-examined and re-categorised according to whether the spikelets remained intact, or whether the grain and rachis had separated leaving behind rachis internodes with or without palea and lemma attachments. The presence of broken grains and detached lateral florets were also noted, along with any changes to the appearance of abscission scars. However, these were not systematically quantified. All the spikelets selected for this experiment had smooth (wild-type) abscission scars. Results are reported in Table 3.

Results

Experiment 1

For the sun-dried group (S1) it took a total of two hours for all the ears to dry out and naturally disarticulate. During this time, the ears were observed to gradually change colour from green to yellow (Fig. 1a). At the end of two hours the ears had broken up into individual spikelets, except for those at the base of the ear where the rachis internodes remained connected (Fig. 1b).

Figure 1. a Wild barley ears drying out in the sun, from left to right at 0 mins, 1 hour and 2 hours. **b.** Sun-dried barley ears naturally disarticulated into individual spikelets after 2 hours, with the base of the ears still intact.

For the ripped groups (R1, R2) the action of pulling the ears apart in a quick downwards motion, resulted in these breaking apart into individual spikelets (Fig. 2a, b). As with the sun-dried group, rachis internodes at the bottom of the ears remained connected, although in this case the grain became detached from these as the ear was ripped apart (Fig. 2c). Detached grains remained fully enclosed in their palea and lemma (Fig. 2d). No ripped scars of the type recorded archaeologically could be observed in the field when the chaff was examined by eye. Finally, for the control groups (C1, C2) there was no change noted to the ears after more than two hours.

Figure 2. a Fresh barley ears before ripping. **b.** Individual spikelets after ripping. **c.** Connected rachis internodes at the base of ripped ears, with grain removed. **d.** Detached grain in palea and lemma with awn attached.

Table 2. Summary of barley material from the sun-dried (S1), ripped (R1, R2) and control (C1, C2) groups, broken down according to scar type and whether the palea and lemma (P + L) material remained attached to the rachis internodes, or the spikelets remained intact

Site code		AMU 03	AMU 03	ROS 1	AMU 03	ROS 1
Group		S1	R1	R2	C1	C2
Total no. ears		25	25	20	25	21
Avg. spikelet/ear		15	16	13	14	14
Scar type	Unit					
Smooth	Spikelet	348	209	142	339	275
	Rachis	1	67	49	-	-
	Rachis with P + L	-	-	-	-	4
Rough	Spikelet	24	22	21	10	23
	Rachis	-	82	38	-	-
	Rachis with P + L	-	1	-	-	1
Non-diagnostic	Spikelet	11	4	8	8	-
	Rachis	-	12	3	-	-
	Rachis with P + L	-	-	-	-	-
Ripped	Spikelet	-	-	-	-	-
	Rachis	-	-	-	-	-
	Rachis with P + L	-	-	-	-	-
Total rachis units		384	397	261	357	303

In terms of abscission scars, smooth scars dominated the sun-dried group (91%) and both control groups (C1 = 95%; C2 = 92%), with low proportions (between 3% and 8%) of rough scars (see Table 2). A small number of non-diagnostic scars were also recorded for S1 (3%) and C1 (2%). No ripped rachises were observed within these groups (Table 2). For ripped ears that had been pulled apart while fresh, smooth scars were also dominant (R1 = 70%; R2 = 73%), although both these groups also yielded higher proportions of specimens with rough scars (R1 = 26%; R2 = 23%). Most of these scars were recorded as rough on the basis of the rachis internodes being connected (even after manual threshing), but when forcibly torn apart it was observed that these typically left behind smooth abscission scars, which were concave with a smooth surface and clearly defined perimeter. A small number of non-diagnostic scars were recorded in the ripped groups (*c.* 4%), but no ripped scars were identified in either the R1 or R2 groups, confirming observations that had been made by eye in the field.

Experiment 2

Following pounding as described above, just over half of the spikelets in the original sub-samples remained intact (R1 = 60%; C2 = 63%). The remainder had separated into their grain and rachis components. Rachis internodes both with and without palea and lemma attachments were represented in this assemblage (Table 3). Pounding also generated a large number of detached lateral florets and broken grains, as well as causing damage to abscission scars (see Fig. 2). Damaged abscission scars took the form of non-diagnostic scars, smooth scars which had cracks across them, and scars that had been torn off completely and which appeared morphologically similar to the 'ripped' rachis remains identified from Sharara. In comparison, charring followed by gentle agitation, caused grains to become detached from the majority of spikelets (60–80%). Most of the resulting rachis internodes retained their palea and lemma attachments (Table 2). Charring also generated a large number of detached lateral florets, but no broken grains. All the abscission scars on the charred specimens were still intact and clearly identifiable as smooth scars (Table 3; Fig. 2)

Table 3. Summary of barley remains in sub-samples of smooth scared spikelets from groups R1, C2, S1, C1 and C2 after pounding or charring. After pounding a small number of rachis specimens were unquantifiable and thus the combined total of the different units after pounding does not equal the original 100 spikelets

Treatment	Pounded		Charred		
Site code	AMU 03	ROS 1	AMU 03	AMU 03	ROS 1
Group	R1	C2	S1	C1	C2
No. spikelets in sub-sample	100	100	20	20	20
Unit					
Spikelet	60	63	4	8	4
Rachis	21	20	-	-	6
Rachis with P + L	13	7	16	12	10
Detached lateral florets	Yes	Yes	Yes	Yes	Yes
Broken grain	Yes	Yes	No	No	No
Damaged abscission scars	Yes	Yes	No	No	No

Discussion

In the preliminary experiments carried out for this study, pulling unripe ears apart failed to recreate the type of ripped rachis morphology identified at Sharara. This does not discount the results of previous experiments where this morphology has been shown to be created in this way (White and Makarewicz 2012). However, the rationale for pulling unripe ears apart by hand also requires explanation, as drying green ears in the sun results in their disarticulation within a short period of time and without the labour input as shown in this experiment. Furthermore, after being ripped apart, additional processing would still be required to clean the grain and separate it out from the remaining chaff. If this involved pounding it would be necessary to wait until the barley had dried out to avoid creating a 'mush'. It is possible that people could have ripped apart barley ears while fresh in order to consume the grain immediately, but in the case of Sharara this explanation doesn't hold as most of the ripped barley rachis was found in a room where plants were clearly being processed and where a cup-hole mortar was installed. Ripping ears apart also failed to produce any detached lateral florets or any broken grain, both of which are present in the archaeological assemblage. Ripping also produced only a single rachis internode which still had its palea and lemma attached. Instead, ripping the ears apart generated relatively high proportions of rachis internodes without these attachments.

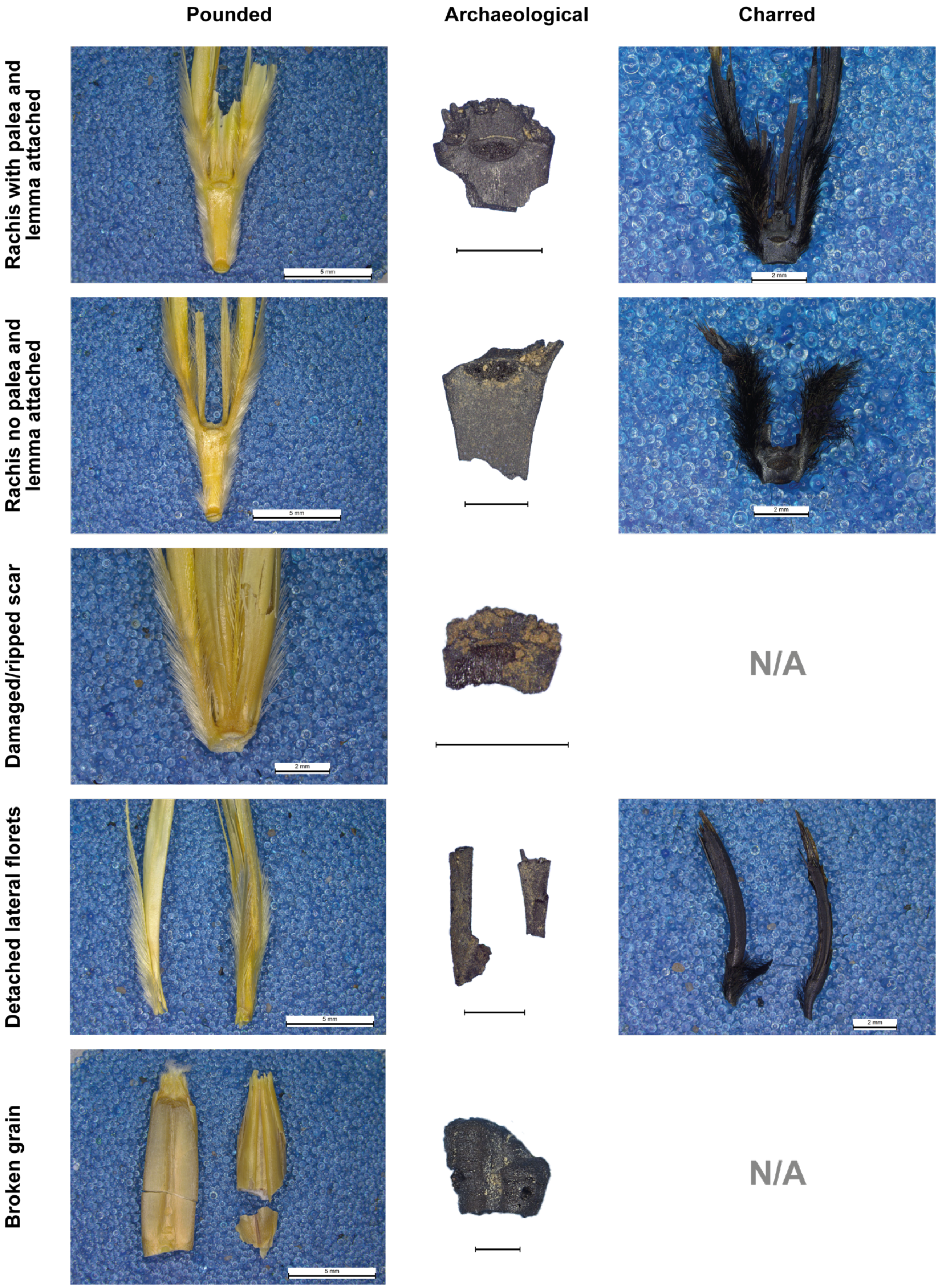

Figure 3. Comparison of different parts of wild barley spikelets remaining after pounding (left) and charring (right) as described in text. Archaeological specimens from Sharara (middle) shown for comparison, unlabelled scale bars 1mm.

In comparison to tearing ears apart manually, pounding dried barley spikelets (whether previously ripped apart or not) created all the types of barley that were recovered archaeologically. This included rachis internodes with non-diagnostic and ripped abscission scars, rachis internodes with and without palea and lemma attachments, detached lateral florets and broken grain. Rachis internodes with palea and lemma attachments bear some similarity to those of two-row naked barley (Hordeum vulgare convar. distichon var. nudum) (Bogaard et al. 2013: Fig. 7.4), although the latter are more robust and, as a domestic species, have exclusively rough abscission scars.

Charring whole spikelets also generated some of these types but had no impact on scar morphology and failed to generate any broken grain. Grains that break after charring also have a different morphology to grains that are broken before charring, displaying a distinctive oozing of their endosperm and bulging-smooth appearance of the grain at the broken surfaces (Willcox 2002, Valamoti 2011). This can be clearly observed in archaeological specimens from Sharara (Fig. 3). Furthermore, if the barley remains recovered at the site were simply the result of ears/spikelets charring we would expect to find comparable proportions of grain and chaff within the same deposits, which is not the case at Sharara where barley rachis dominates the cereal assemblage (see Main Text).

Conclusions

Based on the results presented above we argue that pounding offers the best mechanism to explain the barley assemblage recovered at Sharara. In particular, it offers one route by which ripped rachis morphologies could have been created and agrees with previous arguments made by Tanno and Willcox (2012) for pounding creating ‘tear-off’ scars on glume wheats. However, it is worth highlighting the fact that the ripped rachises recovered at Sharara and el-Hemmeh (White and Makarewicz 2012) are variable in their morphology and may not result from a single process. We also emphasise that the experiments reported on here were preliminary and involved limited samples and sample sizes. Many variables were not controlled and other methods of processing, such as flailing, trampling, and beating were not tested. As the objective of these experiments was limited to demonstrating what types of remains can be created through different forms of processing, we also caution against quantitative comparisons of different types of barley rachis generated experimentally to those documented archaeologically.

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