Impetus for sowing and the beginning of agriculture: Ground collecting of wild cereals

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The Agricultural Revolution in Western Asia, which took place some 11,000 years ago, was a turning point in human history [Childe, V. G. (1952) *New Light on the Most Ancient East* (Routledge & Kegan Paul, London)]. In investigating the cultural processes that could have led from gathering to intentional cultivation, various authors have discussed and tested wild cereal harvesting techniques. Some argue that Near Eastern foragers gathered grains by means of sickle harvesting, uprooting, plucking (hand stripping), or beating into baskets [Hillman, G. C. & Davies, M. S. (1999) in *Prehistory of Agriculture: New Experimental and Ethnographic Approaches*, ed. Anderson, P. (The Institute of Archaeology, University of California, Los Angeles), pp. 70–102]. During systematic experiments, we found that archaeobotanical data from regional Neolithic sites support ground collection of grains by early hunter-gatherers. Ground collecting suits the natural shattering of wild species that ripen and drop grains at the beginning of summer. We show that continual collection off the ground from May to October would have provided surplus grains for deliberate sowing in more desirable fields, and facilitate the transition to intentional cultivation. Because ground gathering enabled collectors to observe that fallen seeds are responsible for the growth of new plants in late fall, they became aware of the profitability of sowing their surplus seeds for next year's food. Ground collecting of wild barley and wild wheat may comprise the missing link between seed collecting by hunter-gatherers and cereal harvesting by early farmers.

In attempting to identify the collecting method that triggered humans to begin cultivation, we reexamined the suggested methods of gathering grain by mobile or sedentary late Palaeolithic and preagricultural hunter-gatherers (1–8). Could there have been a technique that provided sufficient grain for summer use, as well as a significant surplus to be stored. A portion of the stored grain would then have been used for raising the next year's crop. Our field and archaeobotanical studies indicate that a formerly overlooked method of collection, gathering from the ground of disarticulated spikelets (Fig. 1) of wild barley and wild emmer wheat by their awns, may provide the key to explaining the start of grain cultivation in the Fertile Crescent.

Materials and Methods

Collecting Methods. Researchers have summarized several possible methods for wild grain harvesting by preagricultural hunter-gatherers. These include sickle harvesting or the uprooting of nearly ripe or unripe stalks, or the plucking (hand stripping) or beating of ripe spikelets into baskets (2, 9-12). However, compared with hand gathering from the ground of wild barley and wild emmer, both of which are found in archaeological sites of the southern Levant, sickle harvesting or hand stripping of whole ears could not have been profitably carried out (12). Even if early humans had found patches with ripe ears, any attempt to strike them with a sickle or to hand strip them would have caused many of the spikelets to fall. Although the harvesting of whole ears of near-ripe wild barley or wild emmer could have theoretically been carried out, they could easily become moldy; or alternatively the dry, hot, desert winds characteristic of the beginning of summer would shatter the ears within 2–3 days (13). Climatic changes of 2–3°C in annual average would not affect our formulation because the diverse east–west topography, together with steep north–south temperature and rainfall gradients, means that vegetation zones would simply have moved a few kilometers to adjust. Using this method of harvesting near-ripe whole ears, early humans could not have collected sufficient grains to last throughout the year. At higher altitudes, however, such as 1,000 m and above (or in exceptionally cold springs, such as that of 2002), ears take longer to ripen and stay intact for a longer period (13). So, upon occasion and in higher localities, hunter-gatherers could have harvested near ripe ears in considerable quantities before disarticulation. In any case, this provides no real advantage, with respect to amounts and convenience, over gathering disarticulated spikelets from the ground throughout the entire summer.

Ethnographic Evidence. It has long been accepted that, shortly after ripening and seed dispersal, spikelets (ear units) of wild emmer and barley are difficult to locate and gather. This alleged disappearance of spikelets was attributed mainly to rodents and the rapid self-burial of the spikelets into the soil (9, 13). Although the gathering from the ground of dispersed grains of grasses and sedges by several groups of hunter-gatherers is known in the ethnographic literature, this collection method was never given serious consideration with respect to preagricultural societies. It was used, for example, by the Tagama, Tawarek, and Tuareg tribes in sub-Saharan Africa (14) to collect *Cenchrus biflorus*, and by the Australian western desert aborigines to collect *Panicum australiense* and *Fimbristylis oxystachya* (15). This method was also practiced by nomadic tribes in Punjab, India, for a variety of fallen grains and dispersal units of grasses, such as *Agrostis scabrifolia*, *Echinochloa colonum*, *Cenchrus*, and *Pennisetum* (16).

In our field research, we discovered that gathering from the ground is plausible in the Levant as well. No local ethnographic data are available because of the total disappearance of hunter-gatherers from the region for probably at least three millennia.

Results

Field Research. Field research carried out in three successive years (2000–2002) demonstrated that dense, easily located patches of dispersed spikelets of wild local cereals are available for gathering from May through October (Table 1). This experiment took place in dense patches of wild barley (*Hordeum vulgare* subsp. *spontaneum*) and wild emmer (*Triticum turgidum* subsp. *dicoccoides*) in three areas in Israel: the grassland of the Upper Jordan Valley, open oak forests on the slopes of the Upper Galilee, and in the Golan Heights. We choose these areas following Badr *et al.* (17), who found DNA markers in wild barley populations from Israel–Jordan that are closer to the gene pool of cultivated barley than those in other populations of wild

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Fig. 1. Thick ''carpet'' of easy-to-collect barley spikelets bearing persistent long awns (Korazim 9.5.2000). The length of the awns, such as those of the horizontal spikelet at the top, measures 20 cm.

barley. Similar DNA results come from southeast Anatolia for emmer (18), although the archaeobotanical evidence (19) still needs verification. On the ground, we observed thick carpets of easy-to-collect large spikelets of wild barley and wild emmer with their 15- to 20-cm-long awns pointing upward (Fig. 1). This find shows the inaccuracy of earlier suggestions (13) that these fallen spikelets disappear due to animal predation and rapid self-burial of the spikelets into the soil. We found that grasping large quantities of the disarticulated spikelets by their awns with the palm of one hand is surprisingly easy. This efficient method could have provided nourishment for hunter-gatherers throughout the summer until the first rains. Related important grasses with smaller grains, such as wild einkorn (*Triticum monococcum* subsp. *baeoticum*), wild rye (*Secale vavilovii*), or a common perennial barley (*Hordeum bulbosum*) could not be collected in this manner because of their comparatively shorter, thinner, and more fragile awns. Our field experience shows that the easiest way to transport and process the collected long-awned spikelets is to break the awns off after collecting them. Transportation and parching, which is the easiest dehusking process, are then much simpler.

Ground Collecting: Evidences and Implementations. The archaeological evidence also speaks for ground-based gathering. Ears of wild cereals mature gradually, with the upper spikelet ripening first. Hence, spikelets fall from top to bottom, with one or two sterile, basal spikelets remaining atop the shattered stalk. Sickled stalks, however, would include the basal spikelets along with the rest of the ear.

Botanical and Archaeobotanical Data. ***The collar.*** The following criteria help us to identify remains of the basal part of the ear in archaeobotanical assemblages and, consequently, to differentiate between harvested ears and ground-gathered spikelets. (*i*) The collar at the top of the stem and the attached, curved, first rachis internode are easily recognized among the other 15–20 rachis nodes of the ear (Fig. 2): it is these first rachis nodes that always bear sterile spikelets (20). (*ii*) The lower internodes of wheat, in transverse section, are somewhat semicircular, whereas the upper ones are flattened and spindle-shaped (21). In Chalcolithic Shikmim [≈6,200 calendar years (cal) B.P.], for example, 60 culm bases, 177 culm nodes, as well as 1,084 normal rachis nodes and 43 basal ear fragments of domesticated barley, including collars, were found in Locus 661, representing harvested nonbrittle ears (22). No basal parts were found in the archaeobotanical remains at three much earlier prehistoric sites: Ohalo II (23,000 cal B.P.), a late Palaeolithic site (23, 24); Netiv Hagdud, a pre-Pottery Neolithic A site (11,400 cal B.P.) (25); and Gilgal I, also pre-Pottery Neolithic A (11,500 cal B.P.) (A.H. and M.E.K., unpublished data). At these sites, the next lowest and fertile spikelets, recognized in barley by their rough disarticulation scars (26), were found in normal concentrations (3.0%–9.9%) (refs. 23–25 and 27, and A.H. and M.E.K., unpublished data). The absence of basal, sterile spikelets in the older archaeological plant assemblages tends to support ground collection *vis-à-vis* sickling of whole ears.

Table 1. Yields of gathering barley and emmer spikelets by their awns, North Israel

Date of gathering	Location*	grams/hr†
5/28/2000	Mount of Beatitudes	373
5/28/2000	Korazim	387
8/14/2000	Korazim	506
9/5/2000	Korazim	583
6/3/2001	Korazim	184
6/3/2001	Mahanayim	175
5/26/2002	Korazim	234
5/26/2002	Kefar Ha-Nasi	244
5/27/2002	Allonei Ha-Bashan	322
5/27/2002	Wadi Reihan	313
9/26/2002	Korazim	254

*Korazim, Kefar Ha-Nasi, Mount of Beatitudes, and Mahanayim are located in grassland in the Upper Jordan Valley, 9, 13, 19, and 21 km north of Tiberias, respectively. Wadi Reihan, Upper Galilee, and Allonei Ha-Bashan, Golan Heights are in open oak forests, 29 km north and 38 km northeast of Tiberias, respectively.

†Grams of dehusked grain per worker.

Our fieldwork has also demonstrated, however, that hand stripping of whole, nearly ripe ears also leaves the basal spikelets on the stalk. Thus, the absence of basal spikelets in the archeological material cannot eliminate hand plucking of ears as a harvesting method used by early human groups. Here, other archaeobotanical evidence must be brought to bear.

The grain. It is known that ripe grains are smooth when dry, whereas unripe grains are wrinkled. Wheat and barley ripen in three stages: ''milk-ripe,'' in which the grains are milky in color and soft in texture; ''yellow-ripe,'' in which the fluid within the grain is yellow and sticky; and ''full-ripe,'' in which the grain is dehydrated and reduced in size (21). Because of differences in water content, differentiating between these ripening stages is relatively straightforward. In fact, cereal grains found in early sites are mostly full-ripe. Their carbonized grains do not exhibit signs of puckering, which is characteristic of younger, unripe grains (25). At Netiv Hagdud, there are only 15 unripe grains out of 556 (2.7%) mature wild barley grains (25). Because the vast majority of grains were full ripe, it would be difficult to assume that they were from sickle-harvested ears, which would have had to have been collected before ripening was complete. Hence, these archaeobotanical findings support our claim that early people did not harvest grains during their short ripening periods, because obtaining sufficient quantities would not have been practical. Humans probably gathered from patches of fallen ripe

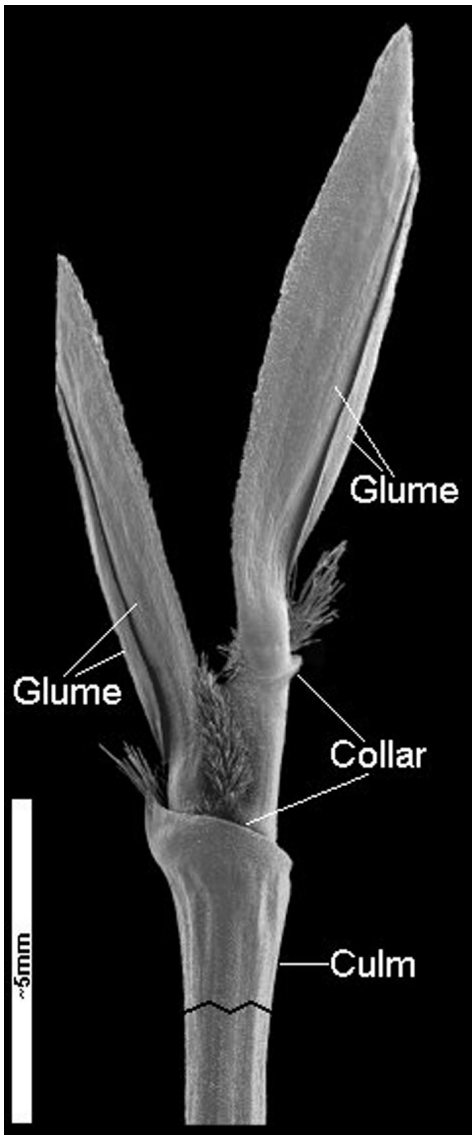

Fig. 2. Collar: an organ that is found in sickle-harvested products but not in hand-collected yields. The photograph shows a culm of modern wild emmer bearing two sterile spikelets after shedding all fertile ones. Each spikelet has two attached glumes. The culm's uppermost node, and to some extent the lowest node of the rachis, is extended into a collar. The zigzag represents the highest harvesting point. The image was taken with a scanning electron micrograph.

grains, which we have demonstrated would have been readily available for several months.

Experimental Data. We found that hand gathering of wild barley and emmer spikelets from the ground in Korazim and Mount of Beatitudes (Israel) is simple and efficient. About 0.25–0.5 kg (0.337 kg on the average) of pure grain could be gathered per hour by a single person, which provides on the average between a half and a whole day of the nutritional requirements for an adult individual. Similar weights of glumes, awns as well as rachis fragments, and sometimes also two more parts of dry culms and leaves were collected with the grains. Several factors influenced the yields of our gathering outings. These include the density of the stands, which determines the density of the spikelet carpet; foliage cover on the ground, which prevents easy gathering; and winter rainfall (2001 was a drought year) (Table 1).

Discussion

Our results are in accordance with Harlan, who, after experimental hand stripping of pre-full-ripe ears of wild einkorn at Karacadağ, southeast Turkey, claimed that in three weeks, a family group could gather more grain than it could possibly consume in an entire year (28). However, as noted above, in the southern Levant, collecting in this way is limited to a few days in most years, and therefore it is not a reliable long-term collecting technique.

Conclusions

The significance of recognizing the practicality of spikelet gathering from the ground is that the gathering of large-seeded cereals as a staple food is not restricted to early summer. Rather, it can continue throughout the summer into the autumn, July through October, when the first heavy rains arrive and the dispersed grains begin to sprout. In other words, the collecting of grains from the ground would supply hunter-gatherers with a ready source of vegetal food until October, when acorns, their second most important plant resource, matured (29). The availability of acorns in October enabled them to invest part of the harvested grains for sowing. Moreover, stored grains and acorns would have provided nourishment until the following summer. There would then have been no period of vegetal food shortage due to seasonality of the two major harvests that helped support human groups in Western Asia at least from the beginning of the Upper Palaeolithic.

The arrow-shaped dispersal units of wild cereals enable them to insert their large grains into the soil. When gathering spikelets toward the end of the season, humans could have easily observed that the remaining spikelets are responsible for the next year's growth. Furthermore, the sowing of spikelets requires no tools or tillage. After the first rains, the soil becomes muddy, enabling the scattered arrow-shaped spikelets to penetrate easily into the ground and germinate. With our gathering method, there would have been no shortage of grains at the end of the summer, which would have tended to forestall the initiation of sowing. Thus, the beginning of sowing is better understood if the transition took place from the gathering of fallen spikelets throughout the summer, than from the harvesting of ears early in the summer.

Cereals were the first crops to be taken into agriculture in Western Asia. Wild barley and wild emmer are common annual grasses that combine large, durable seeds (30), with prolonged availability on the ground, and long, persistent awns. Other grasses, which have short or deciduous awns, could not be easily collected by hand from the ground. Wild barley and wild emmer were, therefore, the easiest grasses to exploit. Indeed, seeds of many other grasses were collected before the cultivation and eventual domestication of cereals, but the advantages of emmer and barley, and the fact that humans could collect them throughout the long summer season, made them preadapted candidates for domestication.

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