On the Identification of Domesticated Emmer Wheat, *Triticum turgidum* subsp. *dicoccum* (Poaceae), in the Aceramic Neolithic of the Fertile Crescent

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Zusammenfassung – - Im vorliegenden Artikel wird der derzeitige Forschungsstand zur Domestikation des Emmers zusammengefasst und diskutiert. Darüber hinaus werden neue Bestimmungskriterien für domestizierten Emmer präsentiert, die der Verfasser in einer Materialstudie erarbeitet hat. Die Morphologie von domestiziertem Emmer (Triticum turgidum subsp. dicoccum) sowie seinem wilden Vorfahren (Triticum turgidum subsp. dicoccoides) aus dem Fruchtbaren Halbmond wurden untersucht. Neben morphologischen Analysen unter dem Rasterelektronenmikroskop wurden Ährchen experimentell verkohlt und mit einem digitalen Mikroskop vermessen. Längsschnitte durch die Rhachis, welche die obere Abbruchnarbe und die ventrale Oberfläche des Internodiums zeigen, ermöglichen eine klare Unterscheidung zwischen domestiziertem und wildem Emmer. Die Morphologie von rauen Narben wilden Emmers ist von der des Domestikats ebenfalls unterscheidbar. Daneben differenzieren zwei der Messstrecken zwischen beiden Unterarten. Diese Bestimmungskriterien wurden anschließend auf verkohlten Emmer der frühneolithischen Fundstelle Chogha Golan (Ilam, Iran) angewendet. Das Material wurde 2009 und 2010 während der Ausgrabungen von einem Team des Tübingen Iranian Stone Age Research Project (TISARP) geborgen. Die Emmerdruschreste datieren auf etwa 9,800 B.P. und beinhalten morphologisch wilde sowie domestizierte Typen, was für Getreidefunde des Akeramischen Neolithikums typisch ist.

Schlüsselwörter – Domestikation; Getreide; Pflanzenmorphologie; Verkohlung; akeramisches Neolithikum; PPN; Zagros Gebirge

Abstract – The present article summarises and discusses the state of research concerning emmer domestication and presents new identification criteria for domestic emmer wheat. General morphological analyses as well as experimental charring and measurements on domestic emmer (Triticum turgidum subsp. dicoccum) and its wild progenitor (Triticum turgidum subsp. dicoccoides) from the Fertile Crescent were conducted to track the main features that distinguish both forms. Wild emmer can be differentiated from domestic emmer using longitudinal sections through rachises. The scar morphology of wild emmer specimens with a rough upper abscission scar is distinct from domestic emmer. In addition, two of the measuring tracks distinguish between domestic emmer and its progenitor. These results were applied to archaeological specimens from the aceramic Neolithic site of Chogha Golan (Ilam Province, Iran), which was excavated in 2009 and 2010 by a team of the Tübingen Iranian Stone Age Research Project. The carbonised emmer rachis remains dating to about 9,800 BP contain morphologically wild and domestic types, which is typical for cereal assemblages from aceramic Neolithic deposits.

Key words – domestication; cereals; morphology; carbonisation; aceramic Neolithic; PPN; Zagros Mountains

Outline

This article is divided into two general parts. The first part gives a basic introduction to the topic of cereal cultivation and domestication in the aceramic Neolithic of the Near East. Phenomena like the "domestication syndrome", the selective pressures behind initial cereal domestication, and the central problems of identifying domesticated cereals among archaeobotanical remains are discussed. A review of the current state of research regarding emmer wheat domestication completes this first part.

The second part of the article presents the morphological analysis of modern and ancient emmer rachises. The structure of this part follows a classical outline including the materials and methods, the results, and their discussion. An identification key for archaeobotanical emmer rachises is provided in the appendix. At the end of the article, a glossary explains the specific botanical and archaeological terms which are used.

Agriculture and Domestication

It was Charles Darwin (1859) who laid the foundation of our understanding of domestication when he first published his theory "*On the Origin of Species by Means of Natural Selection*". He postulated that natural selection gradually accumulates favorable variations, which lead to the emergence of new forms of life. With his second book "*The Variation of Animals and Plants under Domestication*", he specified this theory by illustrating the immense variability among domesticated plants and animals (Darwin 1868). Darwin's ideas about evolution and the descent of species provoked a lot of discussion, even until today. They furthermore encouraged many scholars to search for the origins of our domesticated plants and animals, which were inextricably linked with the emergence of agriculture.

Until the middle of the 20th century, a theoretical framework could be produced which tried to explain how and why hunter-gatherers became sedentary and began to produce food rather

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than solely collecting it. Vere Gordon Childe is undoubtedly the most famous name connected to these early theories. He saw the transition to farming communities as a revolution, mainly triggered by climate change at the end of the last glacial period (Childe 1928). However, his theory could not be tested by archaeological excavations until Robert Braidwood and his staff set out for the Zagros Mountains in Iraq, following the assumption that agriculture must have emerged in the "hilly flanks" of the Fertile Crescent (Braidwood & Howe 1960). Inspired by the successful excavations at Jarmo, several projects were established to excavate Neolithic settlements in the Central Zagros during the 1950's, 60's and 70's. The excavated sites, of which Jarmo, Ali Kosh, and Ganj Dareh are just the most famous ones, revealed the oldest villages of farming communities so far known (Hole et al. 1969; Smith 1974, 1978; Braidwood et al. 1983).

The Islamic Revolution in Iran in 1979 and the Iran-Iraq War from 1980 to 1988 forced scholars to stop fieldwork in the region. The search for the origins of agriculture was mainly continued in the Levant, resulting in an astonishing record of sites dating to the early Holocene, also providing evidence for early food production. New theories arose, which saw the initial emergence of village farming communities in the southern Levant rather than the Central Zagros (e.g. Bar-Yosef & Meadow 1995). A few years later, Lev-Yadun et al. (2000) postulated that southeast Anatolia must also be taken into account, a region where several early Neolithic settlements comparable to sites from the Levant and the Zagros Mountains were found. In view of this geographically widespread record, hypotheses that explained the emergence of agriculture as a multi-regional development with independent centers of domestication emerged (e.g. Willcox 2002; Fuller et al. 2011).

The research on plant domestication was an important part of many of these archaeological projects (for an overview see Zeder 2011). Nevertheless, we are far from understanding the process in which humans initially cultivated and subsequently domesticated plants. As will be depicted below, the reconstruction of the domestication process is hampered by many issues. Tanno and Willcox (2012) made clear that the identification criteria for early domesticated cereals need to be re-evaluated and criticised some criteria which were used in the past. After that, Snir and Weiss (2014) presented a new method to identify domesticated barley by measuring the dimensions of the upper abscission scar. The present study continues the search for new identification criteria of domesticated cereals by analysing the morphology of wild and domesticated emmer wheat. The established criteria will subsequently be tested on archaeobotanical material from the aceramic Neolithic site of Chogha Golan in Iran.

Definitions

The research on domestication and agricultural origins makes use of terms like "gathering", "cultivation", "farming", "agriculture", and "domestication". In the literature, these terms are used in different contexts, implying different meanings. This involves the danger of confusion and misunderstandings (Ladizinsky 1998a). It is therefore necessary to define the above-mentioned terms since they are not self-explaining. This study basically follows the definitions by Nesbitt as they are today generally applied by archaeologists (Nesbitt 2002, 115). Following these definitions, gathering "*is the collection of wild plants from their natural habitat. Modifications to natural habitat, if any, involve low labour, for example burning.*" Cultivation is nothing more than harvesting wild (and semi-domesticated, see below) plants which have been previously sown by humans on prepared ground. This form of plant management is also called "pre-domestication cultivation" (Colledge 2002; Willcox et al. 2008). In contrast, "*farming or agriculture involves (for cereal and pulse crops) the cultivation of domesticated plants.*" According to this, there is an important difference between the pure cultivation of plants and agriculture. The latter is the result of domestication: "*the process in which humans take control of the reproduction of plants and animals, and consciously or unconsciously select for attributes favourable to human use.*" The term "semi-domestication" is occasionally used to refer to traits that presumably emerged under cultivation without human consciousness, like e.g. seed size increase in cereals (Fuller 2007).

The Domestication Syndrome

The domestication of plants resulted in countless forms and varieties, adapted to all kinds of environments and climates. Although plant breeding created such a diversity, even among domesticates which descent from a single wild progenitor, many traits are shared by all of them. For that reason the term "domestication syndrome" was introduced in the early 1980's and defined by K. Hammer (1984):

„Das Domestikationssyndrom ist das Ergebnis eines oft Jahrhunderte oder sogar Jahrtausende währenden Evolutionsprozesses und kann im Extremfall in so ausgeprägter Form vorliegen, daß eine Kulturpflanze sich nicht ohne das Zutun des Menschen auch nur über eine Generation am Leben erhalten kann..."
(Hammer 1984, 12)

Apart from the fact that many domesticated plants are highly dependent on humans because they lost the ability to propagate in nature, the domestication syndrome comprises several morphological and physiological traits which are today well defined (e.g. Gepts 2004; Fuller 2007). They emerged under the selective pressures induced by cultivation and associated practices such as harvesting and processing of the harvest. The development of a weed flora is also associated with the domestication syndrome as many weeds were indirectly domesticated when fields were established (Hammer 1984).

Harlan and his colleagues belong to the first who summarised common features of the domestication syndrome for cereals (Harlan et al. 1973). Many of these traits were already known, but never recognised as a characteristic set, which Harlan and colleagues described as "adaptation syndromes". The most important difference, which separates domesticated cereals from their wild progenitors, is the loss of natural seed dispersal. This means that the dispersal units are shed in the wild species, but remain on the infructescence among the domesticates. Some cereals with panicles such as rice (*Oryza sativa*) retain their grains by preventing the spikelet from shattering the grains (Fuller & Allaby 2009). By contrast, in grasses with spikes, each spikelet represents a dispersal unit. The spike is segmented into rachis internodes which carry the spikelets (**Fig. 1 A**). The rachis internodes of wild species detach at the abscission layers and leave behind characteristic abscission scars (**Fig. 1 B**). However, domesticated cereals like wheat, barley, and rye do not disseminate the spikelets because they developed a tough rachis which does not shatter upon maturity. The ears can thus be harvested entirely without loss of grains. Associated with the development of non-brittle ears is the loss of features which aid natural seed dispersal (Fuller 2007). For instance, wild wheats exhibit haired rachis internodes, long barbed awns, and generally less plump spikelets than domesticated wheats which have bald rachis internodes and short or no awns.

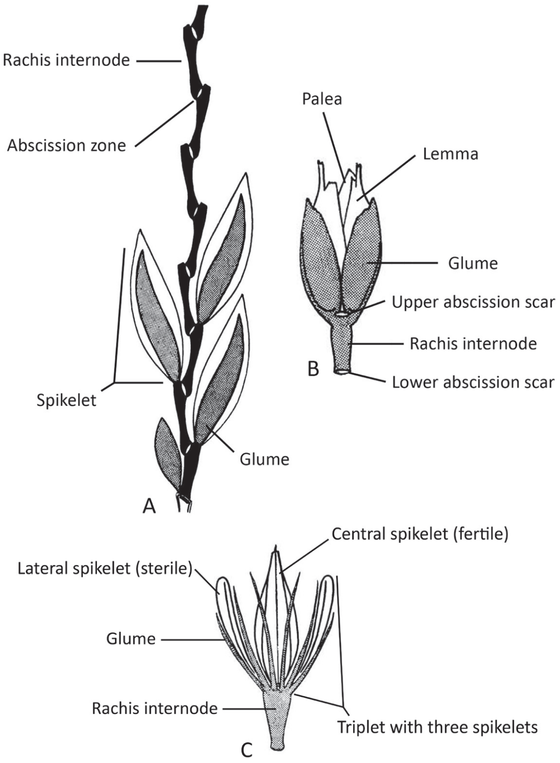

Fig. 1 Terminology of cereal spikes and spikelets. A: a hulled wheat spike composed of the rachis segments and spikelets, B: a single hulled wheat spikelet in ventral view, C: a single two-row barley spikelet in dorsal view (after Helbaek 1969, modified).

The caryopses increased during domestication in terms of both size and number. The most extreme example is maize (*Zea mays*) which is thought to descend from Mexican teosinte (*Zea mays* subsp. *parviglumis*) (Matsuoka et al. 2002). Corncobs of maize are much bigger than seed heads of teosinte and bear multiple amounts of enlarged grains. Another well-studied case is barley whose wild progenitor (*Hordeum vulgare* subsp. *spontaneum*) possesses just one fertile spikelet per rachis segment, the lateral ones are sterile (**Fig. 1 C**). On the contrary, six-row varieties of domesticated barley (*Hordeum vulgare* subsp. *vulgare*) develop three fertile spikelets, and thus, three grains per triplet. The increase in number of grains was therefore reached by converting sterile florets into fertile ones. Apart from that, larger grain sizes as well as changes in grain shape are overall features among domestic cereals.

Another important aspect of the domestication syndrome is the general growth habit (Fuller 2007). Cultivated species show reduced branching in relation to their wild relatives and infructescences are often condensed. This general development towards a more compact growth habit is less distinctive in Near Eastern cereals. It is generally not possible to investigate this feature among archaeobotanical remains since they are too fragmented to reconstruct the culm length or the number of branches. Developments towards condensed inflorescences are analysable when well preserved specimens are recovered.

Unlike grains of wild grasses, cereal grains germinate rapidly when they are exposed to favorable conditions in terms of temperature, light and moisture. The inhibition of germination in wild species is called dormancy and can be described as "*the failure of an intact viable seed to complete germination under favorable conditions.*" (Bewley 1997, 1055). Although morphological alterations are sometimes associated with the reduction of dormancy, e.g. thinner seed coats in legumes, no proceedings regarding this problem have been made in the investigation of cereals (Hillman & Davies 1990; Fuller 2007). The development of synchronous tillering of plants and ripening of seed heads is another physiological adaptation to cultivation. Within a natural population the development of individual plants is not synchronous, and thus, some will produce first fruits while others are still flowering. This variability of maturation is eliminated in domesticated plants. All germinate and flower at about the same time.

When the spatial and temporal scale of domestication is broadened, even more features can be added to the domestication syndrome. With the spread of agriculture outside the Fertile Crescent, varieties thriving under different climatic conditions emerged. One example is vernalisation during the winter months. This means that the flowering of plants is delayed until spring to prevent frost damage (Cappers & Neef 2012). On the other hand, some species need this cold period to flower abundantly in spring (Willcox 1999). With the selection of crops that do not require vernalisation, spring-sown varieties emerged completing a full life cycle from germination until fruit development within a few months. In contrast to morphological adaptations to cultivation, suchlike physiological features cannot be investigated directly. If at all, they can be examined using secondary effects. For instance, Kreuz and Schäfer (2011) suggested the cultivation of summer crops in the Early Neolithic of Central Europe based on their evaluation of the potential arable weeds from settlements of the *Linearbandkeramik* culture. Such conclusions, based on secondary evidences, are less reliable as e.g. recovered weed floras are also influenced by other factors than the sowing time of crops (see Willcox 1999).

The mechanisms behind the evolution of domesticates must primarily be examined by experimental studies rather than the investigation of carbonised plant material. Ethnographic studies as well as experimental cultivation and proceedings in the understandings of plant ecology led to a diverse discussion about the order and time frame in which the domestication syndrome developed, and which selective pressures were the driving forces behind it.

The Selective Pressures behind Cereal Domestication

Most scholars agree that cereal domestication evolved under cultivation and not among wild stands or ruderal communities (e.g. Hillman & Davies 1990; Ladizinsky 1998a; Nesbitt 2002; Purugganan & Fuller 2009; Fuller et al. 2010). The selective pressures behind domestication are therefore induced by the mode of cultivation, which is particularly determined by the sowing and harvesting process. Fuller and Allaby (2009) proposed a scenario, based on archaeobotanical evidences and general assumptions, in which mainly natural rather than conscious human selection favored phenotypes that increasingly dominated the cultivated populations with time. During initial cultivation of wild plants, individuals were favored that lacked dormancy and produced larger seeds. In the second stage, non-brittle mutants increased considerably since selection factors for seed dispersal were eliminated. Associated with this was also the loss of features which aid natural seed dispersal. Physiological adaptations to new climatic conditions evolved in the last stage, when agriculture spread beyond the Fertile Crescent. Apart from this framework, ethnographic and experimental studies imply several distinct forms of cultivation which lead to domestication each in its own way. The exact mode of cultivation in the early Holocene thus remains a controversial subject.

As already mentioned, investigations on the loss of dormancy in cereals did not shed light on its initial appearance. Nevertheless, grains which do not germinate will not contribute to the harvest, and thus, will not be sown in the next season. It is thus plausible to assume that reduction in dormancy occurred very early, when humans initially began to cultivate cereals (Fuller 2007). However, this is only true if cultivation shifted to new locations every year. If grains were sown at the same locality where they were harvested, dormant seeds that were shed could still germinate to become incorporated in the seed stock. Without shifting cultivation, this effect would have hampered the development of several domestication traits (Kislev 1984; Hillman & Davies 1990; Willcox 1999). The second feature, which is thought to predate the emergence of the non-brittle ear, is the grain size increase. Colledge (2001) and Willcox (2004) found that a significant increase in the size range of grains of different cereal taxa occurred at several Pre-Pottery Neolithic A (hereafter PPNA or B) sites of the Levant and the Euphrates valley. In general, scholars suggest that improved growing conditions as well as increased intra-specific competition led to the increase in grain size (2007) referred to studies, which attest that larger seeds produce larger seedlings and that disturbances like deep burial conditions favor these individuals, which have competitive advantages. Although the latter was not observed among cereals, it is demonstrated for closely related genera like *Aegilops*. In this respect, a bias through carbonisation has to be taken into account. Charring possibly altered the size ranges of cereal grains from PPNA sites as it affects grain size and shape significantly (Boardman & Jones 1990; Willcox 2004; Braadbaart & Bergen 2005).

The establishment of the non-brittle ear is thought to be related to the applied harvesting technique and its timing in relation to maturation. Based on ethnographical observations, harvesting practices such as uprooting entire plants, beating grains into baskets, hand-plucking of spikes, and the use of implements like sickles were reported (e.g. Bohrer 1972; Harris 1984; Harlan 1989). Since ears of wild cereals shatter when they are ripe, practices such as uprooting or cutting with sickles favor non-brittle plants, which then accumulate over generations (Hillman & Davies 1990, 1999; Anderson 1999). However, these harvesting methods reduce yield as the ripe spikelets fall to the ground when ears are cut or shaken (Harlan 1999). Kislev et al. (2004) suggested ground collecting of spikelets to avoid loss of grains. In contrast, this would have reduced selection for the tough rachis. Also not favorable for non-brittle ears is the beater and basket method, which reduces loss of grains and is common among indigenous people who harvest grasses (Harlan 1999). In general, all harvesting methods, except of beating seed heads into a basket, can also be conducted when ears are still green. This has the advantage that ears will not shatter during the harvest. Anderson-Gerfaud et al. (1991) found that a remarkable amount of grains, harvested in a fully green state, germinated. For two-grained wild einkorn, germination rates between 80 and 100 % were obtained. By contrast, just 54 % of immature wild barley grains germinated. Germination rates for mature grains of wild barley were also lower than in wild einkorn, which was probably caused by stronger dormancy. These results indicate that harvesting immature grains could have been very attractive in the Early Neolithic, because loss of yield could be avoided and viable grains obtained for the next sowing. Harvesting with sickles or uprooting would then not have favored individuals with a tough rachis, and thus, the domestication process would have been delayed. Indeed, Tanno and Willcox (2006) suggested a slow establishment of the non-brittle ear, after initial cultivation of barley and einkorn wheat began. This assumption is based on a slow but continuous increase of rachis internodes with domesticated-type abscission scars throughout the Pre-Pottery Neolithic. Fuller (2007) supported the results of Tanno and Willcox by compiling an even greater dataset of barley and einkorn rachis remains of PPN sites. Weiss et al. (2006) also expected that pre-domestication cultivation was practiced for at least a millennium without the establishment of the tough rachis. In addition to harvesting practices that discriminate against non-shattering individuals, other factors such as replenishing of the seed stock from wild stands to compensate poor harvests have been discussed to be responsible for the observed patterns (Tanno & Willcox 2006; Willcox et al. 2008). Asouti and Fuller (2013) note that continuous gathering of wild cereals alongside cultivation of early domesticates must in general be taken into account.

Hillman and Davies (1990, 1999) suggested that, under absolutely ideal conditions, wild cereals could be domesticated in about 20 to 30 years. Other scholars like e.g. Ladizinsky (1998b) argued for a rapid domestication of cereals as well. These calculations pointing towards rapid domestication events are based on speculations like high mutation rates and do not consider the archaeobotanical record. If evidence for pre-domestication cultivation in the PPNA is accepted, the establishment of the non-brittle ear was a rather slow process, delayed by several factors certainly related to cultivation and harvesting practices.

Fig. 2 Comparison between wild and domesticated emmer wheat. A: wild emmer with smooth abscission scars, B: domesticated emmer with a rough surface of the upper scar and a damaged lower end of the internode.

Problems of Identifying Cereal Domestication in Archaeobotany

It is crucial to distinguish between cereal cultivation and domestication in the aceramic Neolithic. Evidence which is used to prove domestication thus needs to be separated from that which is thought to identify pre-domestication cultivation. The appearance and development of a weed flora is to date the most common evidence cited to trace initial cultivation of morphologically wild cereals (e.g. Hillman et al. 2001; Colledge 2002; Willcox et al. 2008; White & Makarewicz 2012; Riehl et al. 2013). Another frequently utilised argument is the appearance of species outside their natural range, e.g. hulled wheats at sites in the Euphrates basin (Willcox et al. 2008). However, it is doubtful whether modern distribution patterns were the same in the early Holocene when climatic conditions were demonstrably distinct (Stevens et al. 2001; Wick et al. 2003; Willcox 2005; Robinson et al. 2006). The probability that wild cereals were indeed cultivated outside their natural distribution thus increases with the distance between their modern wild stands and the site where the species was identified (Nesbitt 2002).

Among the traits of the domestication syndrome of cereals, just two morphological features can be used to distinguish between wild species and early domesticates: (1) the non-brittle rachis indicated by rough abscission scars and (2) grain dimensions. All other traits are in most cases not preserved. Indirect evidence for the domestication of cereals is the appearance of free-threshing wheats as well as naked and six-rowed barley. As these cereals descend from the more primitive hulled forms, they are the most reliable indicators for domestication. However, the appearance of these advanced crops cannot indicate the region nor the time when wild einkorn, emmer and barley were initially domesticated and whether this happened once or several times independently from each other.

Identifying initial domestication of hulled wheats is hampered by another factor, the identification of the species itself. Wild einkorn spikelets closely resemble those of wild emmer in term of morphology. The fragmentation of the archaeobotanical material further increases the problems of identification. Hence, the true frequencies of einkorn and emmer remains are unclear at many sites (Nesbitt 2002). Additional taxa occur within the range of the founder crops and must also be taken into account. Zohary (1969) noted that wild Timopheev's wheat, *Triticum timopheevi* subsp. *araraticum* (=*Triticum araraticum*), today accompanies *dicoccoides* in the central and eastern Fertile Crescent and is virtually undistinguishable from it regarding morphological criteria. The presence of wild wheats other than einkorn and emmer may further complicate the issues of identification.

Grain size and shape

The size and shape of grains was long used to identify the domestication status of cereals. During the last years, several scholars showed that modern grain dimensions were reached by the end of the aceramic Neolithic for barley and still later for hulled wheats (Fuller & Allaby 2009; Purugganan & Fuller 2011; Fuller et al. 2012). Willcox (2004) and Riehl et al. (2012) found that enlarged grains at aceramic Neolithic sites occur together with wild-type rachis fragments. These findings support the assumptions made by Nesbitt (2002), who treats identifications based on grains alone with caution. I therefore avoid identifying cereal domestication in the aceramic Neolithic using grains.

Non-brittle rachis

The ears of domesticated cereals need to be threshed to separate rachis internodes from each other. This results in distinct damage patterns of the upper abscission scar and in a broken lower end of the internode (**Fig. 2 B**). The domesticated hulled wheats possess a semi-tough rachis (Helbaek 1969). Therefore, only the lower rim of the abscission scar exhibits remains of torn tissues, indicating the part where the internodes were connate. In contrast, the spontaneously shattering ears of wild hulled wheats produce abscission scars which have well defined margins and a smooth surface. The lower part of the internode is not broken (**Fig. 2 A**).

Until the late 1980's, scholars were relatively uncritical in identifying domesticated cereals based on finds of non-brittle rachis remains (Nesbitt 2002). This changed with the analysis of the botanical remains from Netiv Hagdud, a PPNA site in the Dead Sea Basin. Kislev et al. (1986) reported the recovery of some barley rachises with rough scars (4.1 % among all barley remains), the earliest evidence for domestic barley so far found in the southern Levant. Kislev (1989) then showed that up to 10 % of the rachis internodes of wild barley exhibit a rough, domestic-type abscission scar because the lower spikelets of the ear do not disarticulate naturally. The interpretation of Netiv Hagdud as a farming village was subsequently rejected.

The number of domestic-type scars present in natural populations was only tested for barley. Many scholars nonetheless applied Kislev's findings to wild cereals in general. The lower spikelets of wild emmer and einkorn also frequently do not disarticulate, but systematic examinations were so far not conducted. Moreover, Kislev (1989) emphasised the difficulty of separating wild from domestic emmer in the PPNA, since both produce similar remains, either through natural shattering or threshing.

Tanno and Willcox (2012) recently further developed the identification criteria for domestic-types among barley and wheat remains. They concluded that more than 90 % of all emmer and einkorn chaff remains from archaeological contexts are not diagnostic concerning the domestication status, while the proportion of diagnostic remains of barley is much higher. Emmer and einkorn possess tough glumes, which are reduced in barley. Thus, grains of hulled wheats are still enclosed in the glumes after threshing, whereas those of barley are separated from the rachis and surrounded by the lemma and palea only. Additional processing of hulled wheat spikelets is thought to result in severe fragmentation of the rachis and damage to the abscission scar, producing tear-off scars. These tear-off scars were indeed used to identify domestication of wheats in the past, for example at Nevali Çori in southeast Anatolia (Nesbitt 2002). However, as Tanno and Willcox show, they are equally present in wild and domesticated hulled wheats and are unsuitable to identify domestication.

The central problems in identifying domestic cereals include the following: cereal rachises are rarely intact, which complicates a determination of their domestication status. Concerning hulled wheats, reliable evidence for initial domestication is in most cases hampered by an extremely small number of diagnostic specimens. Furthermore, a certain amount of domestic-type spikelets must be expected in natural populations. The problem becomes even more complicated, since the non-shattering lower segments of a brittle rachis are more robust and may survive charring in higher frequencies than the upper internodes in the brittle part of the ear (Hillman 1981). This implies that the recovery of more than 10 % of rough scars could be due to taphonomic issues (Hillman & Davies 1999). Establishing morphological criteria, which distinguish between genetically wild rachises showing a rough scar and genetically domestic specimens would thus be a great advantage.

Goals of the Morphological Study

The main goal of the morphological study was to establish additional identification criteria for domesticated emmer wheat from aceramic Neolithic sites in the Fertile Crescent. To reach this, I investigated the morphology of wild and domesticated emmer to define the major morphological differences between them. Entire spikelets were carbonised to analyse the effects of heat on rachis and scar morphology. To test the validity of the developed identification criteria, the results were applied to archaeobotanical remains from the aceramic Neolithic site of Chogha Golan, Iran.

Before I will present this study, the current state of knowledge regarding the biology, ecology, and archaeology of wild and domestic emmer wheat will be summarised and discussed.

The Biology and Ecology of Emmer Wheat

The Genus Triticum L.

The genus *Triticum* L. (wheat) comprises the highest number of domesticates among all cereal taxa and includes tens of thousands of cultivars (~ 25,000 after Feldman et al. 1995). Due to this diversity, it is necessary to clarify the phylogenetic relationships as well as the nomenclature within the genus. Albeit methodological improvements in genetics and molecular biology, no consensus

Common name (ploidy level)	Scientific name
Wild einkorn wheat (2n)	*Triticum monococcum* L. subsp. *aegilopoides* (Link) Thell.
Domesticated einkorn wheat (2n)	*Triticum monococcum* L. subsp. *monococcum*
Wild emmer wheat (4n)	*Triticum turgidum* L. subsp. *dicoccoides* (Körn. ex Asch. & Graebn.) Thell.
Domesticated emmer wheat (4n)	*Triticum turgidum* L. subsp. *dicoccum* (Schrank ex Schübl.) Thell.
Durum wheat (4n)	*Triticum turgidum* L. subsp. *durum* (Desf.) Husnot
Spelt (6n)	*Triticum aestivum* L. subsp. *spelta* (L.) Thell.
Bread wheat (6n)	*Triticum aestivum* L. subsp. *aestivum*

Tab. 1 Taxonomic classification and nomenclature of the most relevant domesticated wheats and their wild progenitors after van Slageren (1994) and van Slageren and Payne (2013).

exists among modern taxonomists concerning the classification of wheat. The distinct species concepts hamper a consistent classification and lead to different designations of the same morphotypes (Ladizinsky 1998a). Publications of archaeobotanical analyses as well as papers on the genetics and ecology of emmer frequently use "traditional" classifications, in which wild and domesticated morphotypes are considered as distinct species (e. g. *T. dicoccoides* for wild emmer and *T. dicoccum* for domesticated emmer). By contrast, I will follow the system after van Slageren (1994). Nomenclature for domesticated emmer is used the way Zohary et al. (2012) and van Slageren and Payne (2013) suggested (**Tab. 1**). Both wild and domesticated emmer are thus considered as subspecies in the species *turgidum*. This comprises all tetraploid wheats sharing BBAA chromosomes and being interfertile with each other (Zohary et al. 2012).

Much attention has been attributed to the phylogeny of wheats. Modern domesticates can be divided into diploid, tetraploid and hexaploid species. Einkorn is the only domesticated diploid *Triticum* species. Emmer and durum wheat are tetraploid, whereas spelt and bread wheat are hexaploid. As recently reviewed by Haider (2013), consensus exists among scholars that the hexaploid *aestivum* (genomic designation AABBDD) descended from the tetraploid *turgidum* (AABB) and that diploid *monococcum* (AA) represents an independent lineage (**Fig. 3**). *Triticum urartu* (AA) is thought to be the donor of the A-genome of *turgidum* and *aestivum*, whereas it is not fully clear from which species the B-genome was obtained. A taxon belonging to the section *Sitopsis* of the closely related genus *Aegilops* is most likely the donor. In the evolution of hexaploid wheat,

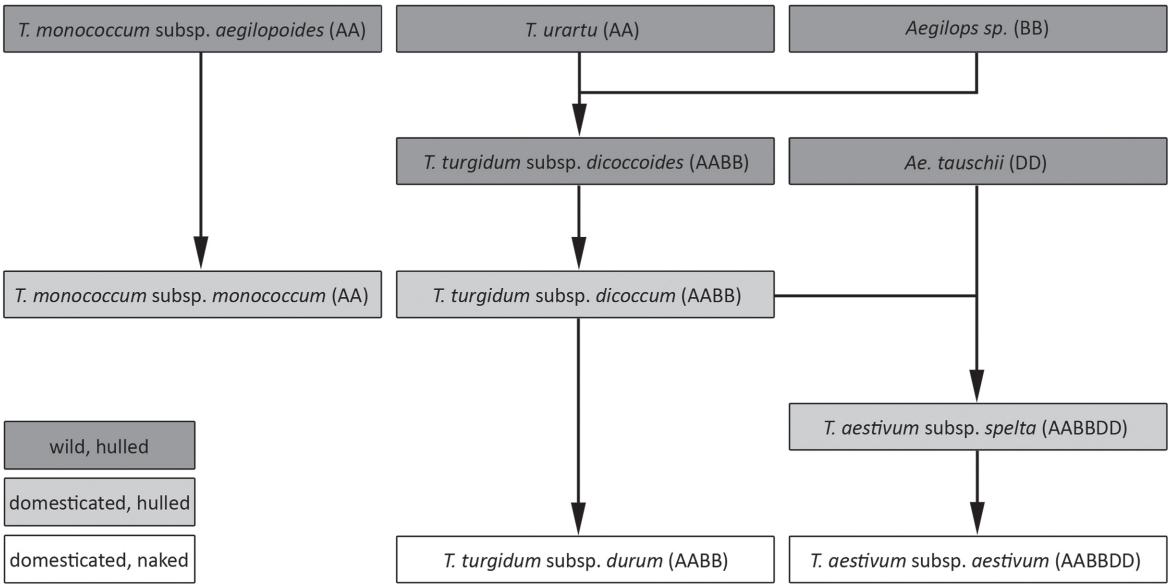

Fig. 3 Phylogeny of wild and domesticated emmer wheat and their most important relatives (after Peng et al. 2011; Haider 2013).

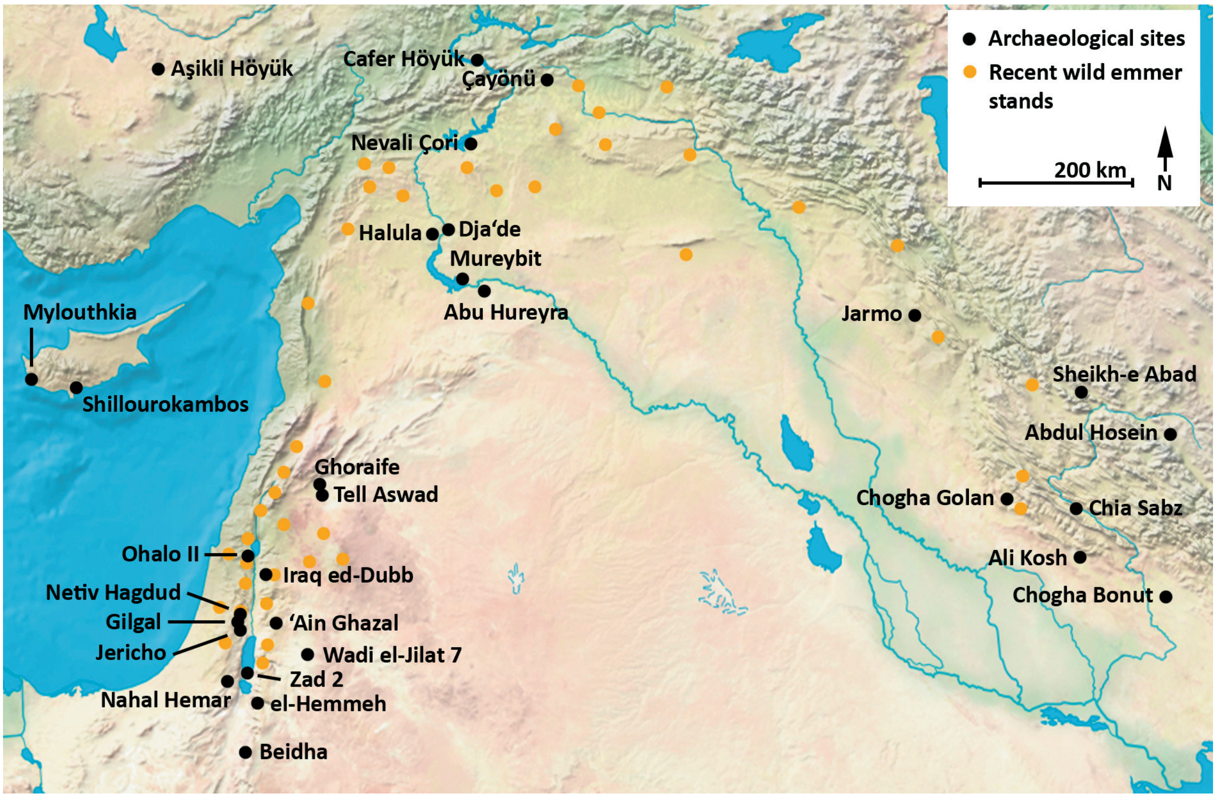

Fig. 4 Distribution of sites dating to the Epipalaeolithic to middle PPNB of the Levantine chronology, for which evidence gfor the presence of emmer is published. Recent distribution of wild emmer after Zohary et al. (2012).

diploid *Aegilops tauschii* (DD) was identified as the donor of the D-genome. According to this, spelt emerged through hybridisation of domesticated emmer and wild *Ae. tauschii* and later developed into the free-threshing bread wheat.

Wild Emmer Wheat

Wild emmer wheat (*Triticum turgidum* subsp. *dicoccoides*) is an annual, predominantly self-fertilizing grass. Upon maturity, the brittle ears shatter into single spikelets, which normally contain two grains each. These are enclosed in tough glumes and will not be released naturally. Thus, every spikelet represents one dispersal unit. The distribution of wild emmer in the Fertile Crescent is discontinuous and patchy (**Fig. 4**). In the catchment area of the northern Jordan Valley, between the Golan Heights and the Mountains of Galilee, the species is most common and forms dense stands (Zohary 1969). There, at the foot of Mount Hermon, A. Aaronsohn discovered wild emmer in the early 20th century (Aaronsohn & Schweinfurth 1906). Other populations occur in Israel, northwestern Jordan, western Syria, southeastern Anatolia, northern Iraq and western Iran. The natural stands in these regions are less dense and semi-isolated to isolated (Nevo & Beiles 1989). Various factors, such as overgrazing, affect wild stands of emmer significantly as already reported by Harlan and Zohary (1966). Consequently, the modern distribution and appearance of wild emmer stands can be misleading. Comparisons with the distribution of Neolithic sites that provided emmer remains should therefore be made carefully, particularly as climate was distinct in the past (Willcox 2005). Wild emmer inhabits environments with distinct climatic conditions. It occurs at 100 m below sea level around the Sea of Galilee and reaches its highest elevation in the Golan Heights and the Zagros Mountains at 1600 m a.s.l. (Zohary et al. 2012). An annual precipitation of 350 mm is thought to represent the minimum amount of rainfall necessary for successful growth and reproduction (Oppenheimer 1963; Peleg et al. 2008). The patchy distribution of wild emmer is partly due to its soil preferences. It is reported to thrive on soils developed on basaltic, limestone and dolomitic bedrocks, but is absent on marls and chalk (Zohary 1969; Nevo et al. 1982). The principal habitat is the herbaceous undergrowth of the oak park-forest belt, which is characterised by *Quercus ithaburensis* in the Levant and *Q. brantii* in southeastern Anatolia and the Zagros Mountains. Furthermore, it inhabits comparable treeless ecosystems dominated by herbaceous species. Secondary habitats like agricultural fields are rarely colonised. Therefore, wild emmer is not regarded as a segetal plant like e.g. wild einkorn (Aaronsohn & Schweinfurth 1906; Harlan & Zohary 1966; Helbaek 1969; Zohary 1969). Whereas in the west, populations are accompanied by wild barley (*Hordeum vulgare* subsp. *spontaneum*) and wild oat (*Avena sterilis*), northern and eastern populations are associated with *Triticum timopheevi* subsp. *armeniacum* and *araraticum*, *T. urartu*, wild einkorn and also wild barley (Zohary et al. 2012).

Many studies have focused on the genetic diversity of wild emmer and its relation to environmental factors. The goal of this research is mostly the improvement of modern cultivated wheats (e.g. Xie & Nevo 2008). Nevertheless, these studies have important implications concerning emmer biology, ecology and domestication. Nevo and Beiles (1989) concluded that the genetic structure of wild emmer populations reflect their mosaic-like distribution. Alleles occurring in great numbers in one particular population are mostly absent in neighboring localities. Investigations of allozyme polymorphisms showed a high genetic diversity of wild emmer, which is regarded as an adaptation to diverse ecological factors (e.g. Nevo et al. 1988a, 1988b; Li et al. 1999). Topography, water availability, soil type, and solar radiation, investigated at the micro- and macro-scale, are the driving forces behind these adaptations. Aridity stress seems to be one of the major determinants (Peleg et al. 2005, 2008). All studies conclude that natural selection rather than genetic drifts or migration is the main factor leading to high genetic diversity and differentiation in allele frequency. These results are surprising since self-fertilisation is said to reduce genetic diversity within a population (Peleg et al. 2008 and references therein). Golenberg (1987) assumed that gene flow in a natural population of emmer decreases considerably beyond a radius of 5 m. Thus, it can be assumed that limited gene flow is one factor which supports the establishment of spatially restricted alleles.

Based on morphological comparisons and ecological considerations, Blumler (1998) suggested the Levantine race *judaicum* to represent a hybrid between wild emmer and cultivated durum wheat. Luo et al. (2007) did not find evidence for this hypothesis. In contrast, Özkan et al. (2011) supported Blumler's view. Generally, gene flow between domesticated plants and their wild progenitors is common (Ellstrand et al. 1999) and seems to be very likely for emmer wheat.

Domesticated emmer wheat

Domesticated emmer wheat (*Triticum turgidum* subsp. *dicoccum*) is an annual, self-fertilizing crop with ears that do not shatter upon maturity. The abscission layers between the rachis internodes do not fully develop, and thus, threshing is required to disconnect the spikelets from each other and from the straw. The rachis internodes are just partly connate, so we speak of a semi-tough rachis. Two genes (Br2 and Br3) were identified as being responsible for the brittleness of the ears and were localised on the short arms of chromosomes 3A and 3B, respectively (for an overview see Peng et al. 2011). Domestic emmer still possesses tough glumes, which need to be further processed to release the grains. Compared to *dicoccoides*, these are enlarged and germinate rapidly due to the loss of dormancy. Domestic emmer produces less shoots but grows higher than wild emmer and forms larger ears. Most of these features obviously serve the achievement of high yields and created a plant unable to survive autonomously.

Today, the crop is economically unimportant and only cultivated by organic farmers and in marginal environments like in northeastern Turkey. It is less resistant to frost than einkorn but produces almost double harvests (Körber-Grohne 1995). Improvements in wheat breeding since the middle of the last century ultimately outcompeted emmer worldwide. Modern varieties of bread wheat produce multiple harvests and contribute the major portion to the world's wheat harvest (Feldman et al. 1995). Haudry et al. (2007) reported a catastrophic loss of genetic diversity in naked wheats during their domestication history. Although Smale (1997) noted that the relation between this reduced genetic diversity and the "Green Revolution" is not fully clear, Xie and Nevo (2008) argued that modern wheat breeding strategies are the main cause for the genetic erosion. They furthermore emphasised the huge potential of wild emmer for improving modern varieties of cultivated wheats. Zaharieva et al. (2010) assumed this for domestic emmer, and thus, it will hopefully be perpetuated for our future as well.

The Origins of Cultivation and Domestication of Emmer Wheat

Figure 4 shows sites of the Fertile Crescent dating from the Epipalaeolithic to the middle Pre-Pottery Neolithic B of the Levantine chronology that yielded either wild or domesticated emmer remains. Sites with evidence for the domestication status, i.e. presence of rachis remains, are listed in table 2. Note that most sites with domestic-type rachises yielded wild ones as well.

Epipalaeolithic (~ 23,000 to 11,700 cal. B.P.)

Ohalo II, a site at the lakeshore of the Sea of Galilee, provided the so far oldest evidence for the intensive exploitation of cereals in the Near East (Kislev et al. 1992). Grains and few spikelet bases of wild emmer were recovered, accompanied by a much higher number of wild barley remains. It is beyond doubt that Kebaran hunter-gatherers collected these wild cereals along with many other plants about 23,000 years ago (Weiss et al. 2004). Ohalo II is the only Epipalaeolithic site with considerable amounts of charred cereal remains in the Levant. At Iraq ed-Dubb in the Dead Sea Basin, two wheat spikelets of domesticated-type were found in the late Epipalaeolithic levels and are presumably emmer (Colledge 2001). They were not directly dated and are likely intrusive from upper layers (Nesbitt 2002). Therefore, they cannot be accepted as evidence for the use of emmer in the Natufian. Concerning the Epipalaeolithic of the Euphrates basin, Abu Hureyra provided large amounts of charred plant remains whereas emmer is absent (Hillman et al. 2001). Mureybit yielded few emmer grains as well as a domestic-type spikelet fork. Like at Iraq ed-Dubb, the material is undated and thought to derive from later occupations of the site (van Zeist & Bakker-Heeres 1984).

Carbonised plant material as a direct evidence for plant use in the Epipalaeolithic of the Near East is generally very scarce (Rosen 2010). The presence of mortars, pestles, and sickles has been frequently cited as indirect evidence for cereal processing (e.g. Kislev 1984; Bar-Yosef 1998; Feldman & Kislev 2007). However, it is doubtful whether sickles can be used as an indicator for the harvesting of cereals, even when the typical sickle sheen is present. Harvesting of other plants like small seeded grasses or sedges results in similar patterns (Anderson 1999). Although the use of cereals is generally documented for the Epipalaeolithic of the Levant and the Euphrates basin, the scale of emmer exploitation in particular is unclear. Carbonised plant remains are completely absent among the late Pleistocene sites in the Zagros Mountains.

Pre-Pottery Neolithic A (~ 11,700 to 10,700 cal. B.P.)

The archaeobotanical record of the early Holocene is better and considerable amounts of charred plant remains were recovered from many excavations. PPNA sites of the southern Levant provided charred emmer remains in varying frequencies. At Gilgal, situated in the Dead Sea Basin, huge amounts of wild oats and barley were recovered and interpreted as evidence for pre-domestication cultivation (Weiss et al. 2006). Feldman and Kislev (2007) refer to the also numerous grains of wild emmer and add the species to the list of presumably cultivated plants of the site. For the nearby site Netiv Hagdud, cultivation of wild barley was suggested by Weiss et al. (2006). Melamed et al. (2008) argued that rambling vetch (*Vicia peregrina*) could also have been cultivated there. Like at Gilgal, the great amount of recovered grains and seeds is the main argument, supported by the presence of possible weed taxa. Wild emmer was found in low quantities, and thus, it is uncertain whether it was gathered or cultivated at Netiv Hagdud. Hulled wheat spikelets at PPNA levels of Iraq ed-Dubb are of domesticated-type, but undated like those from the Epipalaeolithic contexts (Colledge 2001). Consequently, the evidence is inconclusive and intrusion from upper layers should be considered (Nesbitt 2002). White and Makarewicz (2012) suggested barley cultivation at el-Hemmeh, located southeast of the Dead Sea. This was inferred from the diverse weed flora and the size of barley grains. Emmer remains were found in much lower frequencies than those of barley. Hence, the question whether emmer was cultivated or collected from wild stands remains open. At Zad 2, situated on the Lisan Peninsula of the Dead Sea, the same pattern was observed (Edwards et al. 2004). Cultivation of wild barley was suggested, while the few emmer remains are interpreted as weeds in barley fields. The role of emmer in the subsistence of the early phases at Jericho is not fully clear either. Since flotation was not practiced when the site was excavated in the 1950's, just a limited amount of archaeobotanical remains could be analysed. Asouti and Fuller (2012) noted that it is debatable whether cereals were cultivated at the site, but they assumed cultivation of wild plants during the PPNA occupation. Hopf (1983) reported large emmer and barley grains, which she considered as of domesticated-type. As discussed above, grain size is an unreliable indicator for domestication, but supports the assumption of wild cereal cultivation. In contrast, Nesbitt (2002) treats the PPNA levels at Jericho with caution and refers to the small amount of recovered plant remains. In the end, evidence is not sufficient to plausibly state cultivation of emmer or barley.

This is true for most PPNA sites of the Levant. The most reliable evidence for early emmer cultivation comes from Gilgal. At all other sites, from which charred plant remains were recovered, emmer is never as abundant as other possibly cultivated plants. Edwards et al. (2004) suggest wild emmer to grow as a weed in wild barley fields. Since natural stands of emmer throughout the whole Fertile Crescent are frequently accompanied by wild barley, their combined occurrence in early cultivation may be possible. In the PPNA of the Euphrates basin, emmer is virtually absent whereas wild forms of rye (*Secale* sp.), barley and einkorn are thought to have been cultivated at sites such as Jerf el-Ahmar and Mureybit (Colledge 2002; Willcox et al. 2008; Willcox and Stordeur 2012). At Çayönü in southeastern Anatolia, the presence of emmer in PPNA levels is not certain. This is due to the small amount of wheat spikelet bases, which have not been determined to the species level (van Zeist & de Roller 1994). In the end, a critical assessment of the emmer record does not provide much clear-cut evidence for its pre-domestication cultivation in the PPNA, although Feldman and Kislev (2007) do not doubt it. The main reasons for this are dating problems and the difficulty to interpret emmer remains present in small quantities.

Early Pre-Pottery Neolithic B (~ 10,700 to 10,200 cal. B.P.)

As with the beginnings of cultivation, the earliest appearance of domesticated emmer is far from clear. Until recently, the early PPNB was widely considered to have provided unequivocal evidence for emmer domestication (for summary see Zeder 2011; Zohary et al. 2012). Tanno and Willcox (2012), however, published a critical reassessment of the morphological identification criteria for domesticated barley and hulled wheats and doubted the domestication status of cereals at several sites. Van Zeist and Bakker-Heeres (1982) determined the emmer remains from Aswad as domesticated. By contrast, the new results from Tanno and Willcox show that domestic-type spikelets contribute less than 10 % to the assemblage. Chaff remains were not analysed by van Zeist and Bakker-Heeres, whose assumptions were based on grain size alone. Consequently, the emmer remains of the early PPNB levels at Aswad have been attributed to the wild species. Cultivation is supported by the large domestic-type grains. For a second Levantine site with layers dating to the early PPNB, Nahal Hemar, Kislev (1988) suggested that the domestic-type emmer spikelets are intrusive from layers above.

All einkorn and emmer chaff from Nevali Çori was initially determined as domesticated (Pasternak 1998; Nesbitt 2002). This assumption could also not been verified by Tanno and Willcox, who further investigated the chaff remains. Emmer is not abundant at the site and there is no evidence for its domestication at Nevali Çori. With regard to these results, they questioned the evidence for domestic emmer at Çayönü and Cafer Höyük. Nevertheless, Tanno and Willcox evaluated the determination of the Cafer Höyük assemblage as more reliable. It is thus considered as one of the earliest sites where the presence of domestic emmer is currently likely. An even older emmer assemblage was recovered at Aşikli Höyük in central Anatolia. Based on the proportion of domestic- and wild-type spikelet bases, Tanno and Willcox (2012, 114) regard this population as "*being in the process of domestication*". The contexts from Aşikli Höyük date to 10,250 cal. B.P., the context at Cafer Höyük to 10,000 cal. B.P. (this is already initial middle PPNB, dates according to Tanno & Willcox 2012). As wild emmer does not grow in central Anatolia today, domestic-type emmer appears for the first time outside its natural distribution at Aşikli Höyük. Nevertheless, the evidence is based on a sample of 223 rachis and spikelet remains of which 193 are damaged, and thus, not diagnostic. The amount of the diagnostic fragments should therefore be increased in the future to confirm the results.

Early PPNB levels at Mylouthkia and Shillourokambos, both on Cyprus, also yielded emmer remains outside the distribution of wild stands. Since only grains were recovered, the domestication status could not reliably been determined (Willcox 2000; Colledge 2004; Colledge & Conolly 2007). Together with Aşikli Höyük, the two sites provide evidence for the early spread of emmer cultivation out of the Fertile Crescent. In the Euphrates basin, emmer appeared for the first time in the early PPNB at

Site	Region	Levantine chronology	Emmer rachis remains		Free-threshing cereals	Note on emmer spikelets
			wild	domestic		
Ohalo II	Levant	Epipalaeolithic	X			
Iraq ed-Dubb	Levant	Epipalaeolithic		?		Or einkorn, very few, presumably intrusive.
Mureybit	Euphrates	Epipalaeolithic/PPNA		?		Very few, presumably intrusive.
Netiv Hagdud	Levant	PPNA	X			
Iraq ed-Dubb	Levant	PPNA		?		Or einkorn, very few, presumably intrusive.
el-Hemmeh	Levant	PPNA	X			
Zad 2	Levant	PPNA	X			
Çayönü	southeast Anatolia	PPNA		?		Or einkorn, very few.
Tell Aswad	Levant	early PPNB	X			
Nahal Hemar	Levant	early PPNB		?		Desiccated, probably intrusive.
Dja‘de	Euphrates	early PPNB	X			
Nevali Çori	southeast Anatolia	early PPNB	X			Small quantities.
Çayönü	southeast Anatolia	early PPNB		X		Domestic status recently questioned.
Aşikli Höyük	central Anatolia	early PPNB		X		Based on small sample size.
Cafer Höyük	southeast Anatolia	early/middle PPNB		X		Domestic status recently questioned.
East Chia Sabz	Zagros	middle PPNB		?		Or einkorn, only glume bases.
Sheikh e-Abad	Zagros	middle PPNB		?		Or einkorn, only glume bases.
Beidha	Levant	middle PPNB		X	Barley	Impressions.
Abu Hureyra	Euphrates	middle PPNB		X	Wheat	
Cafer Höyük	southeast Anatolia	middle PPNB		X	Wheat	
Aşikli Höyük	central Anatolia	middle PPNB		X	Wheat and barley	
Jericho	Levant	middle PPNB		X		
Wadi el-Jilat 7	Levant	middle PPNB		X		
Ghoraife	Levant	middle PPNB		X	Wheat and barley	Scar morphology not reported.
Jarmo	Zagros	middle PPNB		?		Impressions, not fully published.
Ali Kosh	Zagros	middle PPNB		X	Barley	
Halula	Euphrates	middle PPNB		X	Wheat	

Tab. 2 Sites of the Fertile Crescent dating from the Epipalaeolithic to middle PPNB of the Levantine chronology from which emmer chaff remains were recovered.

Levantine chronology	cal. B.P.	Events
Epipalaeolithic	~ 24,000 - 11,700	Exploitation of wild emmer in the Levant.
PPNA	~ 11,700 - 10,700	Cultivation of wild emmer in the Levant is likely.
early PPNB	~ 10,700 - 10,200	Appearance at sites in the Euphrates basin, south-east and central Anatolia and Cyprus. First evidences for the domestication syndrome.
middle PPNB	~ 10,200 - 9,500	Domesticated hulled and naked tetraploid wheats, first numerous finds at sites of the Zagros, wild emmer continuously present.

Tab. 3 Archaeobotanical record for the use, cultivation, domestication and initial spread of emmer wheat.

Dja'de. In contrast to the aforementioned sites, domestic-type rachises were not identified (Willcox et al. 2008).

Middle Pre-Pottery Neolithic B (~ 10,200 to 9,500 cal. B.P.)

The middle PPNB provides unequivocal evidence for the domestication of emmer wheat, although determining the domestication status of emmer using rachis fragments is still problematic (Nesbitt 2002). Free-threshing cereals are now present at several sites throughout the entire Fertile Crescent (see **Tab. 2**). As domesticated emmer is the progenitor of naked wheat, the presence of free-threshing chaff proves inevitably its domestication (Nesbitt 2002; Feldman & Kislev 2007; Tanno & Willcox 2012; Zohary et al. 2012). Sites such as Beidha, Ghoraife, Jericho, and Aswad in the Levant as well as Abu Hureyra and Halula in the Euphrates basin and Cafer Höyük in southeastern Anatolia can now be regarded as settlements where agriculture is fully established. The results from Jarmo in the Iraqi Zagros Mountains are unfortunately not fully published. Helbaek (1959, 1966) reported carbonised emmer grains and impressions of spikelets in baked clay. He determined the group of larger grains and some spikelet impressions as of domesticated-type. However, the stratigraphic position and the frequency of the domestic-type specimens remain uncertain, even after their repeated evaluation by Watson (1983). Whether agriculture was established in the aceramic layers at Jarmo is thus still not clear. Ali Kosh in the Deh Luran plain in western Iran provided more convincing evidence. Helbaek (1969) recovered large amounts of charred plant remains due to the very first application of water flotation in the Near East. He reported grains and spikelet forks of domesticated emmer from the lowest levels onwards and emphasised that no remains of the wild species could be found. Since identification criteria in the 1960's were less critical than today, a reevaluation of the material is preferable to confirm Helbaeks results. Nevertheless, there is currently no reason to reject this identification. The presence of domestic emmer in the very lowest levels suggests an even earlier domestication event, probably in the Zagros (Helbaek 1969). Absolute dating of the Bus Mordeh phase at Ali Kosh is unfortunately ambiguous, placing the beginning of occupation at about 9,500 or 8,900 cal. B.P., respectively (Hole 1987; Zeder & Hesse 2000). Whitlam et al. (2013) reported very few glume wheat remains from a context contemporary to the middle PPNB from Sheikh-e Abad. The material is currently under investigation and it will be interesting to hear from the final results since this site has a long occupation history, comparable to Chogha Golan (Zeidi et al. 2012). Evidence from the tells of Abdul Hosein and Chogha Bonut are uncertain as only emmer grains were recovered. With reference to their dimensions, they were determined as domesticated by Hubbard (1990) and Miller (2003), respectively. The presence of emmer at East Chia Sabz is equivocal. Riehl et al. (2012) did not distinguish between emmer and einkorn as only glume bases were recovered.

In summary, wild emmer was certainly used from the early Epipalaeolithic onwards in the Levant. Pre-domestication cultivation during the PPNA in the Dead Sea Basin is likely, but, as evidence for cultivation of wild species in general, not proven. Evidence for emmer domestication in the early PPNB is not as reliable as it has been depicted in the last years. To date, Aşikli Höyük provides the most likely evidence for a partly domesticated emmer assemblage at about 10,250 cal. B.P. Cafer Höyük and Çayönü should be reexamined to establish whether emmer is wild or domesticated in the early PPNB levels. The presence of emmer in central Anatolia and on Cyprus, where it does not grow naturally today, proves its cultivation outside the Fertile Crescent by the end of the 11th millennium. Unequivocal evidence for domesticated emmer, also based on the appearance of free-threshing wheat, comes from sites dating to the middle PPNB. These are located throughout the entire Fertile Crescent. This pattern indicates a stepwise and slow development from initial emmer cultivation, until the traits of the domestication syndrome were genetically fixed (**Tab. 3**).

Following the current state of knowledge derived from carbonised plant remains, emmer domestication took place in southeastern and even central Anatolia. This is surprising since evidence for the use of wild emmer in the Levant is much older and more abundant than elsewhere. Its absence is demonstrated at Epipalaeolithic and PPNA sites of the central and northeastern Fertile Crescent, from where considerable amounts of charred plant remains were recovered: Hallan Çemi, Demirköy, Körtik Tepe, Qermez Dere, and M'lefaat (Savard et al. 2006; Riehl et al. 2012). In the Euphrates basin, the absence of emmer is also proved for sites dating to these periods such as Abu Hureyra, Mureybit, Jerf el Ahmar, and Tell 'Abr (Hillman et al. 2001; Colledge 2002; Willcox et al. 2008; Willcox & Stordeur 2012). As a consequence, a research gap in these regions cannot explain the late appearance of emmer outside the Levant. Instead, a lack of evidence for emmer domestication in the Levant could be due to the scarcity of well preserved emmer assemblages contemporary with sites such as Aşikli Höyük, Cafer Höyük, and Çayönü (true for cereals in general and already suggested by Nesbitt 2002). Levels at Levantine sites dating to the end of the 11th millennium cal. B.P. yielded either wild emmer (Aswad), just grains ('Ain Ghazal, Jericho) or few remains which are considered to be intrusive (Nahal Hemar). For this reason it is possible that, e.g. at Jericho, emmer was in an early state of domestication as well.

Our current picture of emmer domestication is fairly incomplete and does not allow reconstructing the domestication process reliably. The hypotheses heavily depend on the actual state of research and can be influenced by a few excavations only. For instance, the record of the Central Zagros has not been evaluated by several scholars in the past due to a lack of well preserved botanical assemblages (e.g. Kislev 1984; Nesbitt 2002). This changed with the preliminary analyses of archaeobotanical remains from Chogha Golan, which now provides more data for the Neolithisation process in this region (Riehl et al. 2013). After all, the present knowledge about emmer domestication based on botanical macro remains must be regarded as a result of its complicated research history and needs to be complemented by future investigations.

Evidence from Genetic Studies

Aside from charred plant remains, genetic studies on recent wild and domesticated emmer populations were conducted to reconstruct the place of its domestication. In general, two presumptions need to be considered: First, that the distribution and genetic structure of recent wild emmer populations is similar to the populations in the early Holocene. Second, that gene flow between wild and domesticated emmer during the last 10,000 years was not frequent (Luo et al. 2007). Several studies assume that wild emmer is divided into two major subpopulations, a southern and a northeastern one (Özkan et al. 2002, 2011; Mori et al. 2003; Luo et al. 2007). Although this was not found by Nevo and Beiles (1989), all scholars agree that modern domesticated emmer descended from the northeastern population, which corresponds to the Taurus-Zagros mountain range. Mori et al. (2003) investigated the intraspecific variation of chloroplast DNA and suggested the Kartal Dagi in southeastern Anatolia as the region where emmer was domesticated. Since not all of their domesticated emmer accessions corresponded with this conclusion, they proposed a second domestication event at an unknown locality. Özkan et al. (2005) conducted amplified fragment length polymorphism (AFLP) and found that wild emmer from the Karacadag as well as from the Iraq-Iranian border near Sulaimaniyya are equally close to the tested domesticates. They rejected the hypothesis that Kartal Dag is the place of emmer domestication, as did Luo et al. (2007). Luo and his colleagues used restriction fragment length polymorphism (RFLP). They disagreed with the suggestion that emmer was domesticated from the wild stands in the Central Zagros. Instead, they supported a monophyletic origin with the ancestral population being located in the Karacadag. Genetic studies are thus partly contradictory, but generally agree that domesticated emmer emerged in southeastern Anatolia. Özkan, Willcox and colleagues reviewed

Accession	Taxon (according to IPK database)	Origin
TRI 584	*T. dicoccon* subsp. *dicoccon* convar. *dicoccon* var. *dicoccon*	Turkey
TRI 3424	*T. dicoccon* var. *immaturatum*	Israel
TRI 5860	*T. dicoccon* subsp. *dicoccon* convar. *dicoccon* var. *rufum*	Iran
TRI 11501	*T. dicoccoides* convar. *dicoccoides* var. *dicoccoides*	Turkey, unknown location
TRI 11502	*T. dicoccoides* convar. *judaicum* var. *safedicum*	Turkey, unknown location
TRI 16621	*T. dicoccoides* convar. *dicoccoides* var. *aaronsohnii*	Israel, Mount of Beatitudes, near mean sea level
TRI 16626	*T. dicoccoides* convar. *judaicum* var. *safedicum*	Israel, Golan Heights, unknown altitude
TRI 16633	*T. dicoccoides* convar. *dicoccoides* var. *kotschyi*	Israel, Mount Hermon, unknown altitude
TRI 18498	*T. dicoccoides* convar. *dicoccoides* var. *aaronsohnii*	Israel, near Yehud, approx. 45 m a.s.l.
TRI 18506	*T. dicoccoides*	Syria, near Al-Zabadani, 1240 m a.s.l.
TRI 18521	*T. dicoccoides*	Turkey, Karacadag , 1400 m a.s.l.

Tab. 4 The analyzed wild and domestic emmer accessions (T. = Triticum). Sampling locations of wild emmer wheat accessions used in the study. No detailed information concerning the location of TRI 11501 and TRI 11502 from Turkey are available.

the available evidence from archaeobotanical and genetic analyses and hypothesised that wild emmer from the Karacadag region is most likely the ancestor to the modern domesticates (Özkan et al. 2011). However, they follow the presumption that emmer was taken into cultivation at several places and was presumably domesticated more than once, independently from each other. Özkan and colleagues suggested that the "dispersed-specific" model could explain this discrepancy between the archaeobotanical and genetic record, although they did not further develop it. According to this model, a species was taken into cultivation at one place and dispersed during the phase of pre-domestication cultivation. Independent domestication events occurred then at distinct places. This could explain why domesticates emerged at geographically distinct places but belong to a single genotype. Current evidence from Aşikli Höyük supports this hypothesis. Tanno and Willcox (2012) concluded that emmer at this site is in an early state of domestication, although outside the natural range of wild emmer today. If this assumption will be verified in the future, the dispersion of cultivated but not fully domesticated emmer out of the Fertile Crescent is demonstrated. Evidence from Cyprus may further support the model. By contrast, possible emmer domestication in the southern Levant most likely occurred among local populations as these are more abundant in the Dead Sea Basin where the archaeobotanical record shows a long tradition of emmer consumption. Independent domestication events, which are not supported by genetic studies, are principally explainable by the extinction of domesticates. In light of the drastic disappearance of crop varieties since the colonial era and again since the Green Revolution, the loss of domesticates is always at risk, in particular as crops depend on propagation by humans. Throughout prehistory, several factors like climatically catastrophic times or competition with other varieties are conceivable causes for crop extinction.

Morphological Analysis of Wild and Domesticated Emmer Wheat

The analyses included the following steps: (1) quantifying scar types among the spikelets of wild and domestic emmer accessions. (2) Measuring spikelets of four accessions (see below), which were subsequently (3) carbonised and (4) re-measured. (5) Longitudinal sections of both uncharred and charred spikelets were analysed using scanning electron microscopy (SEM). (6) Finally, the identification criteria were applied to the archaeobotanical emmer chaff from the aceramic Neolithic site of Chogha Golan.

Material and Methods

Accessions of Wild and Domesticated Emmer Wheat

Modern material of wild and domesticated emmer wheat was obtained from the Genebank of the *Leibniz-Institut für Pflanzengenetik und*

Kulturpflanzenforschung (*IPK*) *Gatersleben*. Samples of eight populations of wild emmer and three samples of domesticated emmer from different locations within the Fertile Crescent could be analysed. All samples of wild emmer derived from southeastern Anatolia and the Levant, domesticated emmer was available from Israel, Turkey and Iran (**Tab. 4; Fig. 5**). Samples from natural stands in the Zagros Mountains could not be obtained. Since only single spikelets were received from the IPK Gatersleben, the location of each spikelet within the ear is unknown. Note that the *IPK* uses a traditional taxonomic classification, which differs from the one used in this study (see **Tab. 1**). *Triticum dicoccoides* corresponds to *T. turgidum* subsp. *dicoccoides* and *Triticum dicoccon* corresponds to *T. turgidum* subsp. *dicoccum*.

Accessions acquired from the *IPK Gatersleben* originally derived from botanical expeditions in the Near East. Unfortunately, how the populations were originally sampled and which harvesting method was applied is unknown. Since then, seeds have been cultivated by several scientific institutes around the world. The *IPK* cultivates both wild and domesticated emmer under local climatic conditions in western Saxony-Anhalt. Fields are separated from each other to avoid hybridisation between the domesticate and its wild progenitor. As soon as wild emmer becomes mature, employees go through the fields several times to avoid loss through shattering of the ears. Attention is paid to reduce loss of spikelets as much as possible. The ears are harvested by hand-plucking. Spikelets which are then still attached to each other are disarticulated by hand. Domesticated emmer is reaped entirely and bound to sheafs. To separate spikelets and culms, sheafs are processed using a *Stiftendrescher*. This harvesting method does not utilise heavy machines, and thus, can be regarded as traditional (Grau, personal communication).

Spikelets of wild emmer accessions were categorised into specimens showing smooth upper abscission scars, scars with protruding torn tissues at the surface (domestic-type), and tear-off scars (after Tanno & Willcox 2012). Between 200 and 288 spikelets were examined, except for accessions 16621 (*n* = 95) and 11501 (*n* = 90) due to limited availability. I categorised accessions of domesticated emmer into spikelets with rough scars and tear-off scars. Sample size for domesticated emmer was limited and varied between 102 and 128 per accession. Frequency of terminal spikelets was determined for both wild and domestic emmer, as their number should increase with reduced ear brittleness (Tanno & Willcox 2012). The morphology of the rachis internode and upper scar was analysed by producing longitudinal sections using ordinary razor blades.

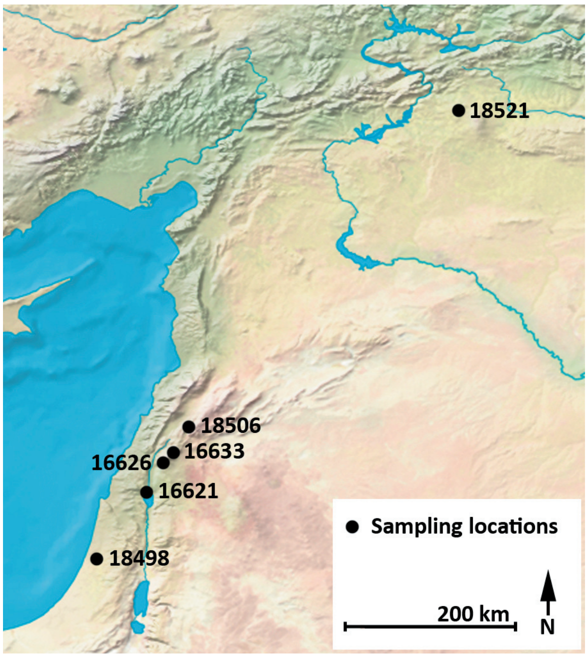

Fig. 5 Sampling locations of wild emmer wheat accessions used in the study. No detailed information concerning the location of TRI 11501 and TRI 11502 from Turkey are available.

The Aceramic Neolithic Site of Chogha Golan

Archaeobotanical emmer rachises from Chogha Golan were analysed in order to test the validity of the identification criteria. Chogha Golan is an aceramic Neolithic site in the foothills of the Central Zagros Mountains in Iran (**Fig. 6**). Members of the Tübingen Iranian Stone Age Research Project (TISARP) and the Iranian Center for Archaeological Research excavated the site in 2009 and 2010 (Zeidi et al. 2012). Chogha Golan is situated near the right bank of the Konjam Cham River at an elevation of 485 m a.s.l. in the Amirabad Plain. The tell is 7 to 8 meters high and has an extent of about 3 hectares. An area of 2 x 4 m in the center of the site was excavated to a depth of about 1.5 m below the surface. In addition, a looter's pit 5 m from this excavation area offered the opportunity to study the entire stratigraphy of the mound. The looter's pit was extended by 1.5 x 1.5 m and excavated into sterile sediments consisting of silty material which represent the paleosurface below the tell. In this deep sounding, about 8 meters of cultural deposits were divided

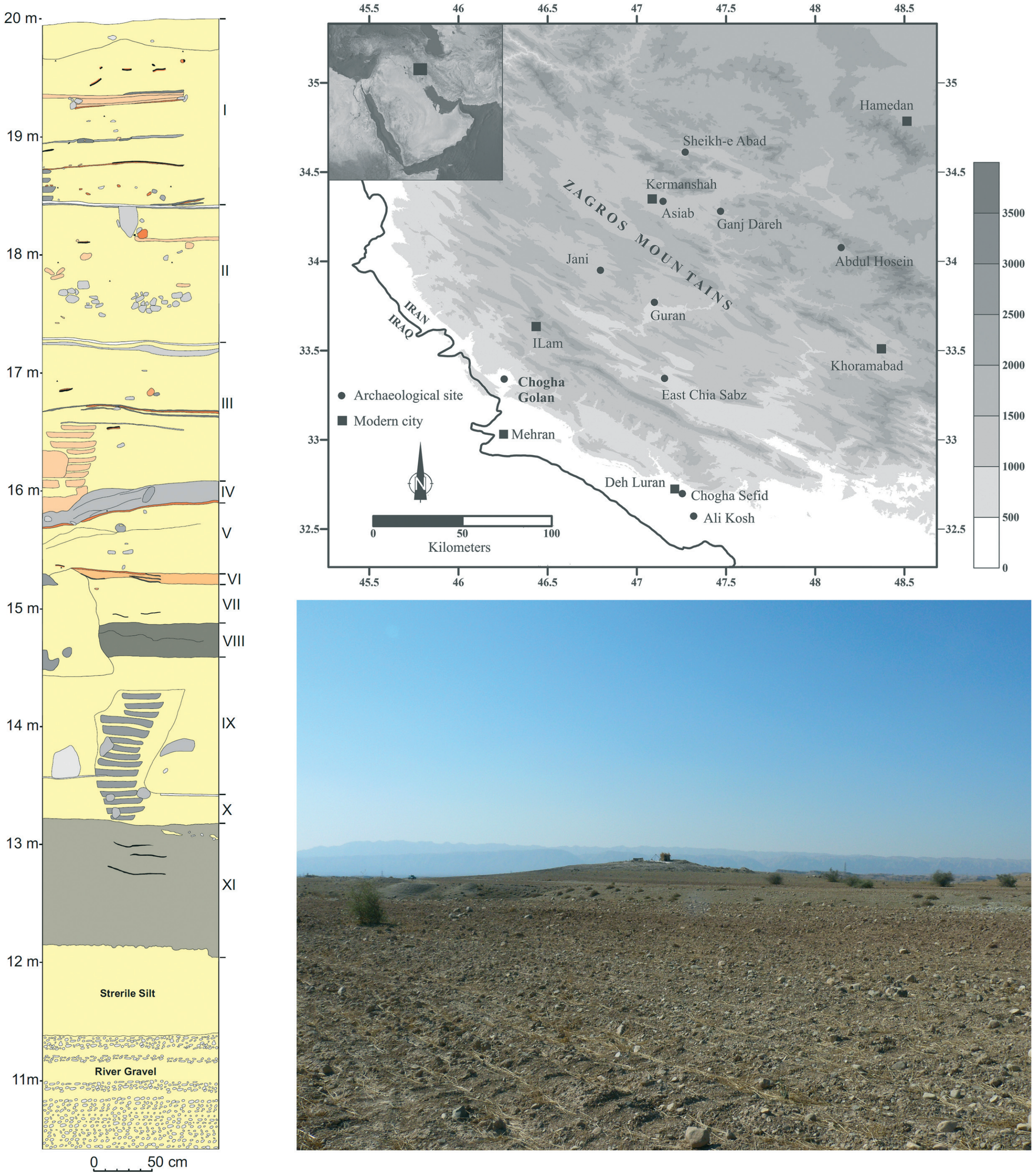

Fig. 6 The aceramic Neolithic site of Chogha Golan. Left: South profile of the deep sounding; top: location of Chogha Golan, map by M. Zeidi.; bottom: photo of the tell, M. Zeidi 2009.

into eleven Archaeological Horizons (AH I-XI). Radiocarbon dates are available from AH I, II, III, IV, VIII and XI, suggesting occupation from 11,700 to 9,600 cal. B.P. (**Tab. 5**). Occupation at Chogha Golan is thus contemporary with sites of the PPNA to middle PPNB of the Levantine chronology.

Architectural features are present throughout the entire stratigraphy. Walls were mostly made up of packed mud and are regularly associated with stone structures. Mud brick walls were also recorded as well as plasters and compact surfaces indicating living floors (Zeidi et al. 2012). Fairly detailed reports on the artifact assemblages are available for the two uppermost horizons. The chipped stone assemblage represents the most numerous categories of inorganic artifacts. It is mainly a bladelet industry with chert as the main raw material and some artifacts made of obsidian (Zeidi & Conard 2013). Within the whole

AH	Dated material	Labcode	B.P.	Cal. B.P.	Cal. B.C. (2σ)
I	Charcoal	Beta-336508	8690 ± 40	9637 ± 54	7790 - 7600
II	*Triticum*-type	Beta-336510	8800 ± 40	9831 ± 82	8020 - 7750
III	Poaceae	Erl-14840	8805 ± 38	9839 ± 81	8181 - 7731
IV	*Hordeum spontaneum*	Erl-14839	8887 ± 37	10037 ± 94	8234 - 7938
VIII	*Hordeum spontaneum*	KIA43836	9425 ± 45	10656 ± 53	8814 - 8602
XI (upper)	*Hordeum spontaneum*	KIA44944	9690 ± 45	11054 ± 129	9274 - 9119
XI (lower)	*Hordeum spontaneum*	KIA45647	10125±45	11740±187	10042 - 9651

Tab. 5 Radiocarbon dates from Chogha Golan after Conard & Zeidi (2013).

stratigraphy, significant changes in the chipped stone tool assemblage are not visible (Zeidi, personal communication). Altogether 59 ground stone tools such as mortars, pestles, grinding slabs, handstones and pounders were recovered from AH I and II. They are primarily made of locally available limestone. However, few exceptions are made of chert, sandstone and basalt (Conard & Zeidi 2013). Besides, Zeidi et al. (2012) describe miscellaneous objects which complement the assemblage of inorganic artifacts. Among them are human clay figurines, clay cones and stone beads.

The faunal assemblage is currently under investigation. Therefore, no final results can be described here. A variety of taxa including caprines, wild boar, gazelle, equids, large bovids as well as microfaunal, fish and bird remains is attested (Zeidi et al. 2012).

Preliminary analyses of the archaeobotanical material from Chogha Golan showed that the site has a huge potential to contribute to the current state of knowledge concerning the emergence of agriculture. Riehl et al. (2012, 2013) published first results and discussed the main questions concerning the subsistence strategy. The work of Karakaya (2013) contributed to the available knowledge about plant husbandry at Chogha Golan. From AH XI onwards, the plant assemblage contains a considerable amount of wild progenitors of the Neolithic founder crops. Most abundant is wild barley (*Hordeum vulgare* subsp. *spontaneum*), which occurs together with goatgrass (*Aegilops* sp.), lentil (*Lens* sp.) and other large-seeded pulses (*Lathyrus*, *Pisum*, *Vicia*). Taxa frequently interpreted as arable weeds are numerous throughout the sequence and possibly indicate pre-domestication cultivation. Their development coincides with that of the wild progenitor species. A direct indicator for the cultivation of wild barley is the increase in barley grain size from AH VIII to IV. Samples from AH V to III are dominated by small-seeded grasses, which outnumber all other taxa by far. This phenomenon raises the question, whether a shift in subsistence occurred at that time or whether the low proportion of wild progenitors can be explained by taphonomic processes. The final occupation phases (AH II and I) are again characterised by a domination of large-seeded crops accompanied by arable weeds. Goatgrass and emmer wheat dominate the cereals whereas wild barley is less abundant.

Archaeobotanical Material

In order to test the application of the identification criteria developed on modern material, 24 flotation samples from 296 liters of sediment were scanned for emmer chaff. Sediment samples had a mean volume of 10 liters. They were floated on-site by using two buckets and a sieve with a mesh size of 200 µm. Altogether, sampled sediments were relatively homogenous and commonly included ashy deposits deriving from numerous events of burning (Zeidi, personal communication).

Botanical remains are, with few exceptions, preserved through carbonisation. Only some specimens belonging to species of the borage family (Boraginaceae) survived without charring. The carbonised material comprises remains of vegetative organs as well as of fruits and seeds. In general, preservation is good and the amount of recovered plant remains extraordinary. Riehl et al. (2013) reports the identification of about 21.000 plant remains from 203 liters of sediment.

Concerning hulled wheat remains, parts of the rachis internodes as well as spikelet fragments were recovered. Glume bases are by far most numerous as their solid tissues primarily preserve. Complete and fragmented *Triticum* caryopses are very rare. Fragmented grass awns are present but have not been determined so far. Culm fragments were not recognised.

The material analysed in the study derives from AH II in the deep sounding (between 18.32 and 17.88 m, one sample from 17.73 m, see **Fig.**

T. monococcum subsp. *monococcum*

T. turgidum subsp. *dicoccum*

Fig. 7 Ears and terminal spikelets of domesticated einkorn and emmer. Note that the uppermost spikelet in einkorn is vestigial (arrow) whereas it is fully developed but twisted in emmer. The wild subspecies possess the same types of terminal spikelets (figures of ears from Neef et al. 2011).

6). Within the sequence at Chogha Golan, AH II represents the remains of one of the last phases of occupation. An AMS date of 9,831 ± 82 cal. B.P., which was obtained from a *Triticum*-type caryopsis, places the deposition of the analysed sediments at the end of an at least 2,000 year long settlement history. The investigated samples are therefore contemporary with levels at aceramic Neolithic sites such as Ganj Dareh in the Central Zagros, Çayönü, Nevali Çori and Cafer Höyük in southeastern Anatolia and Tell Aswad in the Levant (for a comparative chronology see Zeder 2011 and references therein).

Matthews (2010) recommended the examination of taphonomic processes in archaeobotany by studying the depositional context of plant remains via micromorphology. For Chogha Golan, this was done by A. Zanoni, who analysed thin sections from the entire stratigraphy of the deep sounding (Zanoni 2014). Unfortunately, samples of mud bricks were not available. These would have been informative as cereal plant components were used as tempering material in the aceramic Neolithic (Willcox & Stordeur 2012). Parts of a pisé wall from AH VII could be analysed, but this has no relevance for the present study. From the upper sequence, Zanoni analysed one thin section of the transition from AH III to AH II, which included one gypsum plaster floor (**Fig. 6**). In addition, a dung tempered mud plaster floor could be identified in combination with possible midden or occupation deposits containing charcoal and burnt bone fragments. The mud plaster floor exhibited plant pseudomorphs, which indicate the decay of uncharred botanical material included in the plaster as temper. Although the examined thin section derived from an area more than 50 cm below the level from which the analysed flotation samples were taken, it indicates that the building debris of AH II are intermixed with occupation deposits.

All laboratory work was conducted in the Institute of Archaeological Sciences at the University of Tübingen. Flotation samples were dry screened with mesh sizes of 2, 1, 0.5 and 0.2 mm in order to separate charred plant remains of different sizes. Cereal rachis and spikelet remains were primarily found in the 1 mm and 0.5 mm fractions. The 2 mm fraction yielded very few but well preserved rachis and spikelet remains. Fragments recovered from the 0.2 mm fraction were scarce, very small and hardly identifiable. A Euromex binocular with 10x to 60x magnification and the botanical comparative collection as well as the analysed accessions were used to identify the archaeobotanical cereal chaff.

Identification of Emmer Specimens

Separating rachises and glume bases of emmer and einkorn can be problematic (cf. Hillman et al. 1996). The most secure feature used in this study is the lifted upper abscission scar, whose lower portion protrudes from the ventral internode surface (see below). This appearance is typical for domestic emmer and could not be observed among the domestic einkorn accessions of the botanical comparative collection at the University of Tuebingen. Therefore, the identification of the domestic-type emmer rachis fragments is regarded as secure. More difficult is the identification of the wild-type rachises, as they lack the lifted scar. I assigned them to wild emmer because a clear evidence for einkorn chaff in the analysed material could not be detected. The recovered glumes are characterised by relatively thin primary and poorly developed secondary keels (cf. Jacomet 2006). In contrast, the glume bases are very thick. There is no great variation regarding these features and, at this stage of the analysis, the glume bases cannot be separated into two or more morphotypes. This was suggested by Hillman et al. (1996) to approach the problem of separating einkorn from emmer. In addition, the quite high number of terminal spikelets diagnostic for tetraploid wheats supports the assumption that the assemblage mainly consists of emmer. The uppermost spikelet of an ear in diploid wheats is vestigial. By contrast, tetraploid wheats have a fully developed terminal spikelet, which is twisted and does not exhibit an upper abscission scar (**Fig. 7**). When a greater amount of hulled wheat chaff is analysed, the question of whether einkorn is present in the material from AH II can be answered more accurately. Morphotypes of wild einkorn did definitely appear with single finds in AH XI, V and IV at Chogha Golan, but as the present study does not focus on these horizons, there is no need to discuss them.

Experimental carbonisation, measurements and scanning electron microscopy

Accessions 16633 (Israel), 18506 (Syria) and 18521 (Turkey) were selected from the available wild emmer populations, accession 584 (Turkey) from domestic emmer. From each accession 60 specimens were chosen for the analyses. Complete spikelets were placed on sand in open chamotte crucibles and exposed to heat in a Nabertherm N 60 H muffle furnace. Temperature was increased slowly to 60°C within 1 hour and reached maximum temperature after two hours. This avoided puffing of the specimens due to high moisture content. I decided to carbonise the already measured spikelets at 250°C for 480 minutes. Thus, effects of exposure to heat over a long span of time were examined rather than effects of increased temperatures. Following Boardman and Jones (1990), potentially detected

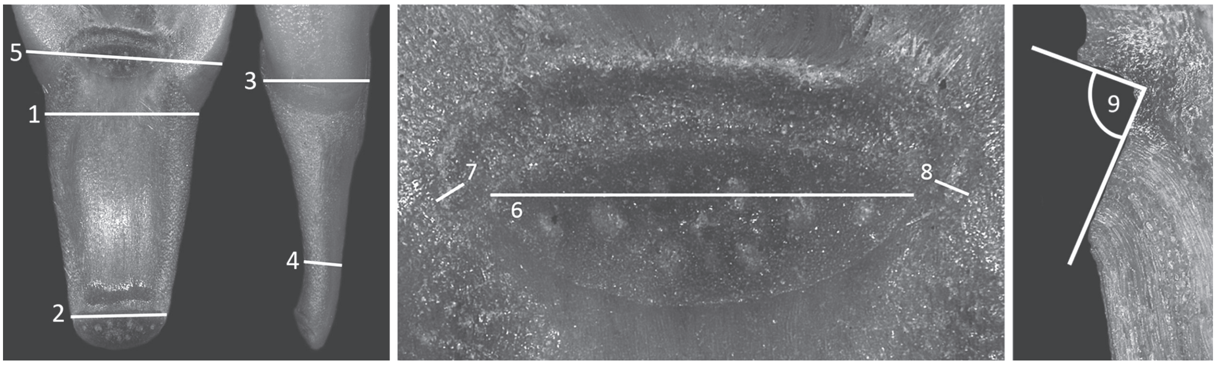

Fig. 8 Measuring tracks. 1: Maximum internode breadth; 2: Minimum internode breadth; 3: Maximum internode thickness; 4: Minimum internode thickness; 5: Spikelet breadth; 6: Scar breadth; 7/8: Thickness at ends of bulge around the scar; 9: Scar orientation.

Measurement	Unit	Description
Max. internode breadth (1)	mm	Breadth of internode, taken directly below the lower glume base
Min. internode breadth (2)	mm	Breadth of internode, measured along the upper rim of the lower scar
Max. internode thickness (3)	mm	Thickness of internode in lateral view, taken directly below the upper scar
Min. internode thickness (4)	mm	Minimal thickness of internode in lateral view, measuring track rectangular to dorsal side of rachis
Spikelet breadth* (5)	mm	Breadth of spikelet, measuring track oriented at lateral edges of abscission scar
Scar breadth (6)	mm	Maximum breadth of upper scar, measured between lateral edges of scar
Breadth of left bulge end (7)	mm	Breadth at end of bulge at left side of upper scar
Breadth of right bulge end (8)	mm	Breadth at end of bulge at right side of upper scar
Scar orientation (9)	°	Angle between scar surface and bulge above the scar

* Breadth of the upper scar relative to the breadth of the spikelet at the same level was calculated.

Tab. 6 Description of measurements.

effects should be less marked when exposure to heat is shorter.

Measurements were conducted with a Keyence VHX-500FD Digital Microscope with 20x to 200x magnification. All specimens were measured before and after carbonisation in order to analyse the effect of carbonisation in the different areas of the spikelet forks. Ordinary razor blades were used to remove hairs along the rachis internodes of the uncharred spikelets. In total, nine measuring tracks were defined (**Fig. 8; Tab. 6**). Maximum internode thickness could not be measured for complete uncharred domestic emmer spikelets because the broad glume bases cover the internodes in lateral view. Measurements of uncharred rachises were therefore taken from longitudinal sections of 25 additional specimens (due to a limited number of received spikelets, it was not possible to measure additional 60 specimens) and subsequently compared to the values of the 60 charred spikelets. We generally measured scar orientation of charred rachises using longitudinal sections. Effects of carbonisation were evaluated by using values from 25 longitudinal sections of uncharred spikelets from each accession (quantity also based on restricted amount of material). The obtained values were then compared to the values of 25 charred spikelets per accession.

Measurements of the archaeobotanical specimens were oriented on the significant differences between the charred wild and domestic accessions. The amount and condition of the recovered rachis fragments limited the number of measureable specimens (see results).

I studied the morphology of the upper part of the rachis internodes in lateral view using SEM micrographs. Longitudinal sections were made using ordinary razor blades. The specimens were coated with an ultra-thin layer of platinum for 90 seconds in a BAL-TEC Model SCD 005/CEA 035 Sputter Coater. Micrographs were taken with a LEO Model 1450 VP SEM.

Statistical Methods

All statistical tests were performed in JMP (© 2013 SAS Institute Inc. 11). Separate analysis of variance (ANOVA) models were used to test for differences between the measured features of the spikelets. With the Shapiro-Wilk test I tested whether data were normally distributed; homogeneity of variances was tested with Levene's test. An ANOVA was used when assumptions for parametric tests were fulfilled (*F* test). A Welch test was performed for normally distributed data with unequal variances. In the case of non-parametric data, the Kruskal-Wallis test was applied. Using post-hoc analyses I tested all possible pairings concerning one measuring track. Tukey's HSD test assumes parametric data and was conducted in combination with an *F* test. A Steel-Dwass test, which does not assume parametric data, was performed after a Welch test or a Kruskal-Wallis test, respectively. Outliers were not excluded in order to analyse the true biological variance within and among all samples. When outliers were the result of measurement errors, I repeated the measurements.

Results

Morphology of Wild and Domesticated Emmer Wheat

Wild emmer forms an abscission layer between each internode allowing the ear to shatter into single spikelets upon maturity. This leads to a straight and smooth surface of the scar, which has in most cases a relatively steep orientation (**Fig. 9**

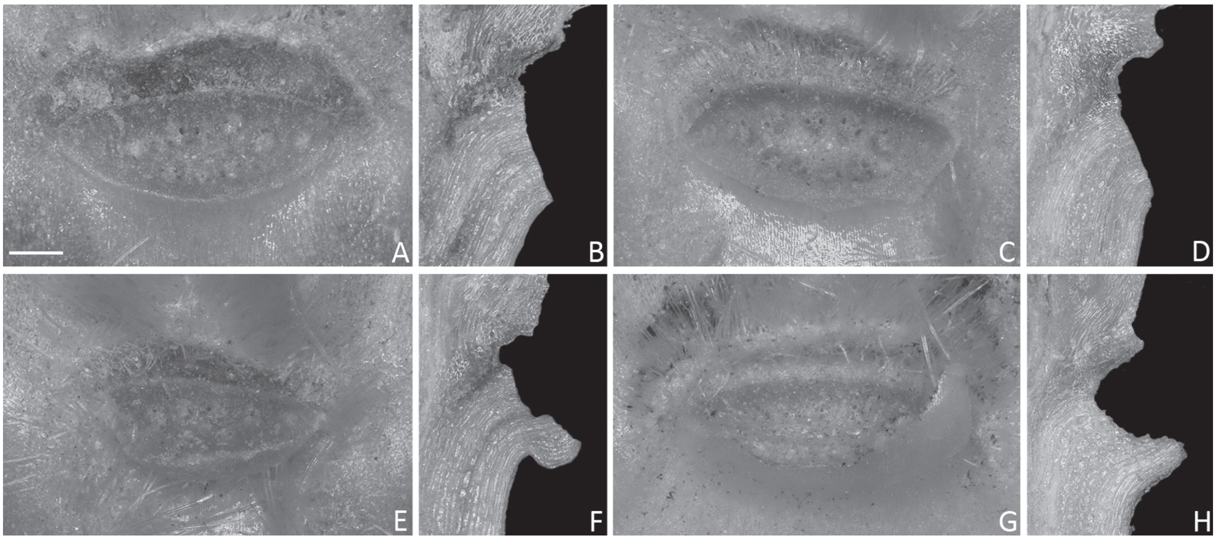

Fig. 9 Upper abscission scars of wild (A-F) and domesticated (G-H) emmer in frontal view and longitudinal section. A-B: TRI 18521 (Turkey); C-D: TRI 16633 (Israel); E-F: TRI 16633 (Israel); G-H: TRI 3424 (Israel). Bar indicates 250 µm.

A-D). The ventral surfaces of the internodes of all accessions are straight except for the part directly below the scar. There, the internode surface forms a curve before it meets the scar surface. This curve was prominent in several specimens from accessions 11502 (Turkey) and 18506 (Syria) (**Fig. 10 B, E**). However, accessions 16626 (Israel), 16633 (Israel) and 18521 (Turkey) do not frequently show this marked curve (**Fig. 10 C-D, F**). Most specimens from these accessions display a virtually straight internode surface or, like accessions 16626 and 16633, an internode with a very slight curvature directly adjacent to the scar. There is considerable variability among wild emmer regarding these features. The variation between populations is greater than within a population.

Domesticated emmer does not develop a complete abscission layer. The internodes thus remain attached upon maturity (**Fig. 11 A-B, E-F, I-J**). After separating them, the lower part of the scar shows remains of torn tissues, indicating where the internodes were connate (**Fig. 9 G-H**). The accessions from Israel (3424) and Iran (5860) exhibit apparent rough surfaces (**Fig. 11 G-H, K-L**). In contrast, many spikelets of the Turkish (584) accession have relatively smooth scar surfaces. Remains of torn tissues at the lower rim of the scar were visible but very short (**Fig. 11 C-D**). Morphology of the ventral surface of the internodes is more distinct from wild emmer. The curve below the scar is marked in domestic emmer and is not located directly adjacent to the scar (**Fig. 9 H; 11 G-H, K-L**). Specimens from the Turkish accession have a clearly bent internode surface, which is thus also distinct from the wild accessions (**Fig. 11 C-D**). In general, the lower parts of the scars protrude from the internode, leading to a straightened rachis axis. In contrast, transitions between the single internodes of wild emmer are less fluent (compare **Fig. 10 A with 11 A-B, E-F, I-J**).

Specimens with a rough scar from genetically wild populations are distinguishable from genetically domesticated specimens by the above mentioned features. Moreover, the lower end of an internode from wild emmer exhibits a knee (designation after Morrison 1994), i.e. a rounded extension below the lower abscission scar (**Fig. 9 E-F; 12**). This knee is visible in domestic-type specimens from all analysed natural populations. Genetically domesticated emmer does not show this feature.

Table 7 shows the frequencies of the different scar types among the wild and domestic populations. A few specimens in which two or three spikelets did not detach were present in almost every wild population. The frequency of terminal spikelets generally differed between 1 and 8.4 %. Both extremes were obtained from Israeli accessions whereas the Syrian and Turkish accessions lay between these values. However, results for accessions 16621 (Israel) and 11501 (Turkey) should be treated cautiously since sample sizes were less than half of the other samples. By

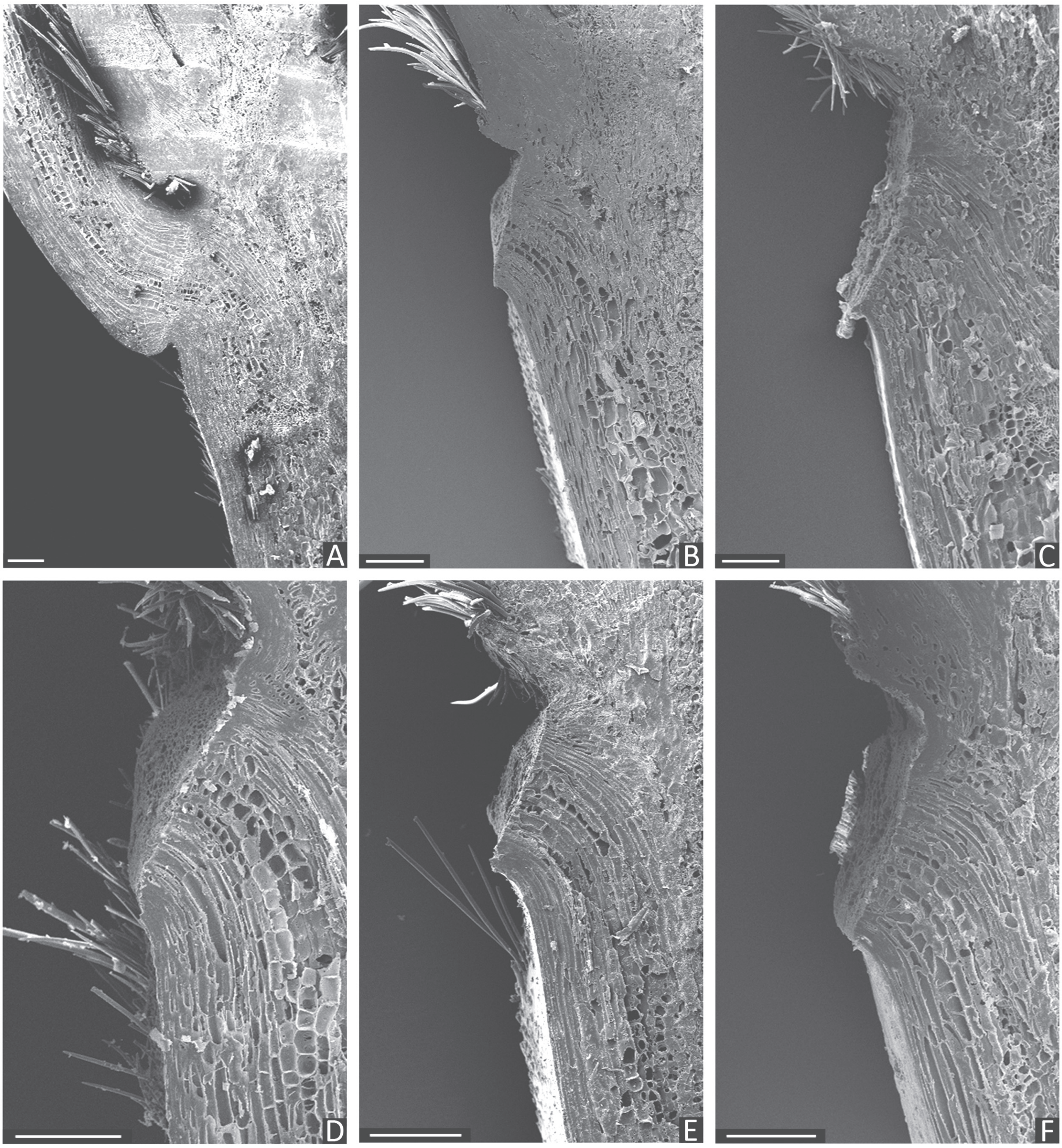

Fig. 10 SEM micrographs of longitudinal sections through the rachises of wild emmer showing the morphology of the abscission zone. A: specimen from the lower part of the ear with the following internode still attached to the scar (botanical comparative collection, Tübingen); B: TRI 11502 (Turkey); C: TRI 16626 (Israel); D: TRI 16633 (Israel); E: TRI 18506 (Syria); F: TRI 18521 (Turkey). Bars indicate 200 µm.

excluding both, high values for terminal spikelets correlated positively with high proportions of rough scars (**Fig. 13**).

Carbonisation resulted in two principal alterations of the spikelets. First, charred spikelets were smaller than the uncharred ones. Second, carbonisation significantly distorted parts of the spikelets. The upper ends of the husks were twisted and the lower parts of the rachis internodes bent. In contrast, the more massive, upper parts of the internodes and the glume bases did not show signs of distortion. The general morphology of the upper abscission scars was not affected in charred specimens of wild emmer. The scar surfaces were almost undamaged except for about 10 % of the Israeli population, in which the uppermost cell layers were destroyed. By contrast, carbonisation affected scar morphology of domestic emmer.

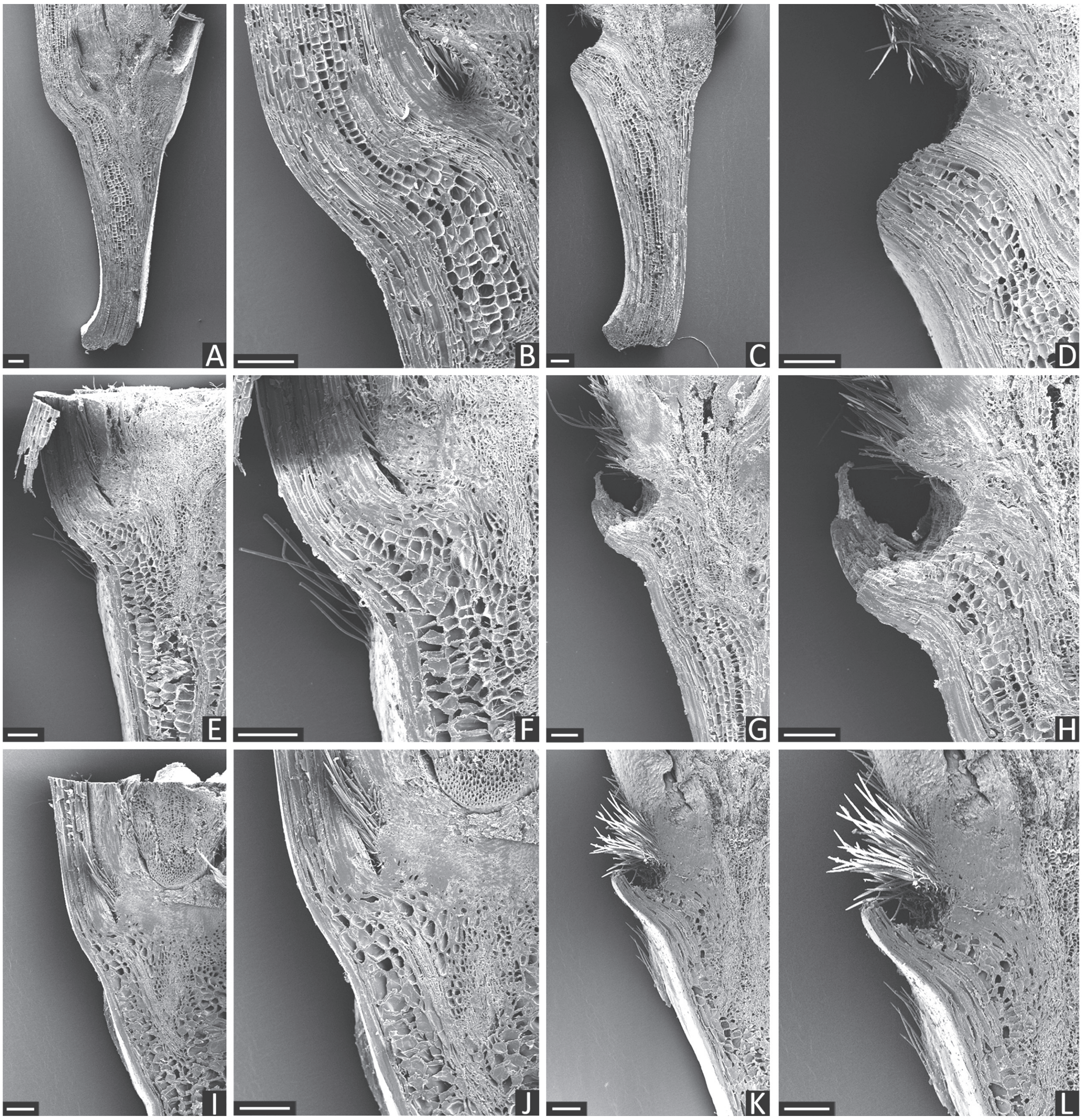

Fig. 11 SEM micrographs of longitudinal sections through the rachises of domesticated emmer showing the morphology of the abscission zone. A-D: TRI 584 (Turkey); E-H: TRI 3424 (Israel); I-L: TRI 5860 (Iran). Bars indicate 200 µm.

Particularly the torn tissues in the lower part of the scar are bent towards the rachis in varying degrees. The general appearance of the scar and ventral surface of the rachises was not affected.

Measurements

Measuring rachis and scar morphology did not provide a consistent pattern concerning differences between the accessions, except for maximum internode thickness and scar orientation (**Tab. 8**). Before carbonisation, maximum internode thickness was significantly different between the domesticate (size range: 0.89-1.37 mm) and the Israeli (Steel-Dwass test, $p < .0001$; 0.96-1.46 mm), the Syrian (Steel-Dwass test, $p < .001$; 0.85-1.53 mm) and the Turkish (Steel-Dwass test, $p < .0001$; 1.1-1.43 mm) accessions. These differences were still significant after carbonisation (Steel-Dwass test, all wild accessions: $p < .0001$; size range domesticate: 0.56-1.04 mm, Israel: 0.72-1.16 mm, Syria: 0.83-1.29 mm, Turkey: 0.85-1.18 mm).

Regarding scar orientation of the uncharred spikelets, domestic emmer (46-109°) differed

Accession	Spikelets				Total	% Rough scars	% Terminal
	Smooth	Rough	Tear-off	Terminal			
584 (Turkey) ^{d}		110	13	2	125		1.6
3424 (Israel) ^{d}		86	14	2	102		2
5860 (Iran) ^{d}		108	13	7	128		5.5
16621 (Israel) ^{w}	83	3	1	8	95*	3.2	8.4
16626 (Israel) ^{w}	180	9	3	8	200	4.5	4
16633 (Israel) ^{w}	176	15	1	8	200	7.5	4
18498 (Israel) ^{w}	193	5		2	200	2.5	1
18506 (Syria) ^{w}	196	1		3	200	0.5	1.5
11501 (Turkey) ^{w}	81	7		2	90*	7.8	2.2
11502 (Turkey) ^{w}	257	12	4	15	288	4.2	5.2
18521 (Turkey) ^{w}	191	3		6	200	1.5	3

^{d} accessions of domestic emmer; ^{w} accessions of wild emmer.

Tab. 7 Frequency of different scar types and terminal spikelets among wild and domestic emmer accessions.

from the Syrian (Steel-Dwass test, *p* < .0001; 91-115°) and Turkish (Steel-Dwass test, *p* < .0001; 88-122°) accessions, however, not from the Israeli one (Steel-Dwass test, *p* = 0.144; 81-113°). Nevertheless, an angle of 90° was defined as a threshold to distinguish between at least some of the wild and domestic emmer rachises. The three smallest values from the wild accessions, but about 40 % of the domestic specimens had an angle smaller than 90° (**Fig. 14 A**). After carbonisation, scar orientation of domestic emmer (71-115°) was significantly different from all wild accessions (Steel-Dwass test, Syrian [94-134°] and Turkish [97-141°] accessions: *p* < .0001, Israeli accession [90-136°]: *p* < .001). It must be taken into account that the uncharred specimens were not carbonised and re-measured since scar orientation was measured using longitudinal sections. In general, angles between the scar surface and the bulge above the scar increased during carbonisation.

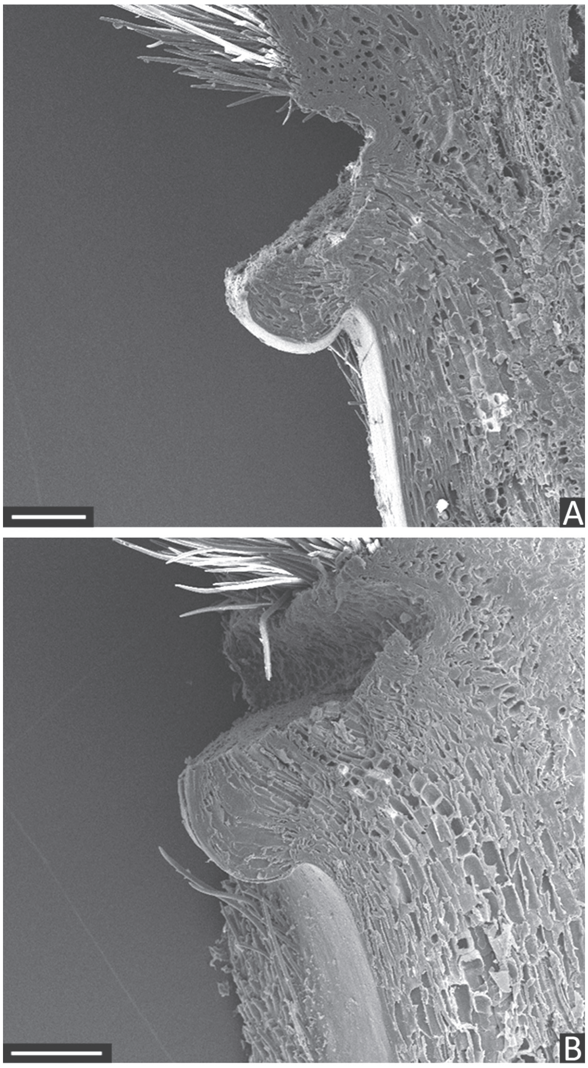

Fig. 12 SEM micrographs of longitudinal sections through rough scars from wild emmer. A: TRI 16633 (Israel); B: 11502 (Turkey). Bars indicate 200 µm.

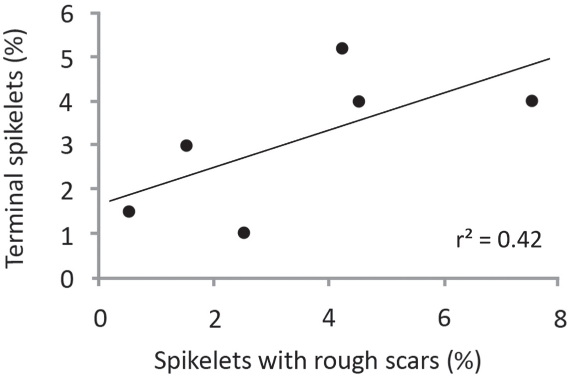

Fig. 13 Correlation of frequencies for spikelets with rough scars and terminal spikelets among wild emmer accessions. TRI 11501 (Turkey) and TRI 16621 (Israel) were both excluded due to their small sample size.

A threshold of 100° was defined to distinguish between charred wild and domestic emmer. One specimen of each wild emmer accession gave a value smaller than 100° whereas two-thirds (~67 %) of the domestic emmer specimens were below this threshold (**Fig. 14 B**).

It is important to note that the amount of shrinkage differed between the accessions (**Fig. 15**). The dimensions of accessions 16633 (Israel) and 584 (Domestic) were most affected by carbonisation; accessions 18506 (Syria) and 18521 (Turkey) decreased less in size. Overall shrinkage patterns were comparable between the accessions and the response to heat of domestic emmer was not distinct from that of wild emmer. The amount of shrinkage of the single features was not equal, and thus, relative spikelet dimensions were altered by charring.

Emmer Wheat from Chogha Golan

Table 9 shows absolute counts of the identified emmer chaff fragments. The ubiquity of the remains is 95.6 %; find density is 1.97 fragments per liter soil. Glume base fragments dominate the assemblage but are not diagnostic regarding the domestication status. Rachis remains in which parts of the scars are preserved make up 17.8 % of all analysed emmer chaff. Specimens with undamaged scars are virtually absent. The determination of the domestication status is therefore mostly based on incomplete scars. However, the fragmentation of the material allowed the analysis of "naturally" occurring longitudinal sections. Altogether, nine terminal spikelets were recovered, constituting 1.6 % of all fragments. The true number of terminal spikelets

Measurement/	*p*-values < 0.05					
Index	Israel		Syria		Turkey	
Max. int. breadth	X		X	(X)	X	(X)
Min. int. breadth			X	(X)	X	(X)
Max. int. thickness	X	(X)	X	(X)	X	(X)
Min. int. thickness	X					(X)
Scar breadth				(X)		(X)
Breadth l. bulge*		(X)		(X)		
Breadth r. bulge*		(X)		(X)		
Scar orientation		(X)	X	(X)	X	(X)
Scar/spik. breadth				(X)	X	(X)

* not measurable before charring due to low contrast.

Tab. 8 Significant differences between domestic emmer and wild accessions before (X without brackets) and after (X in brackets) carbonization.

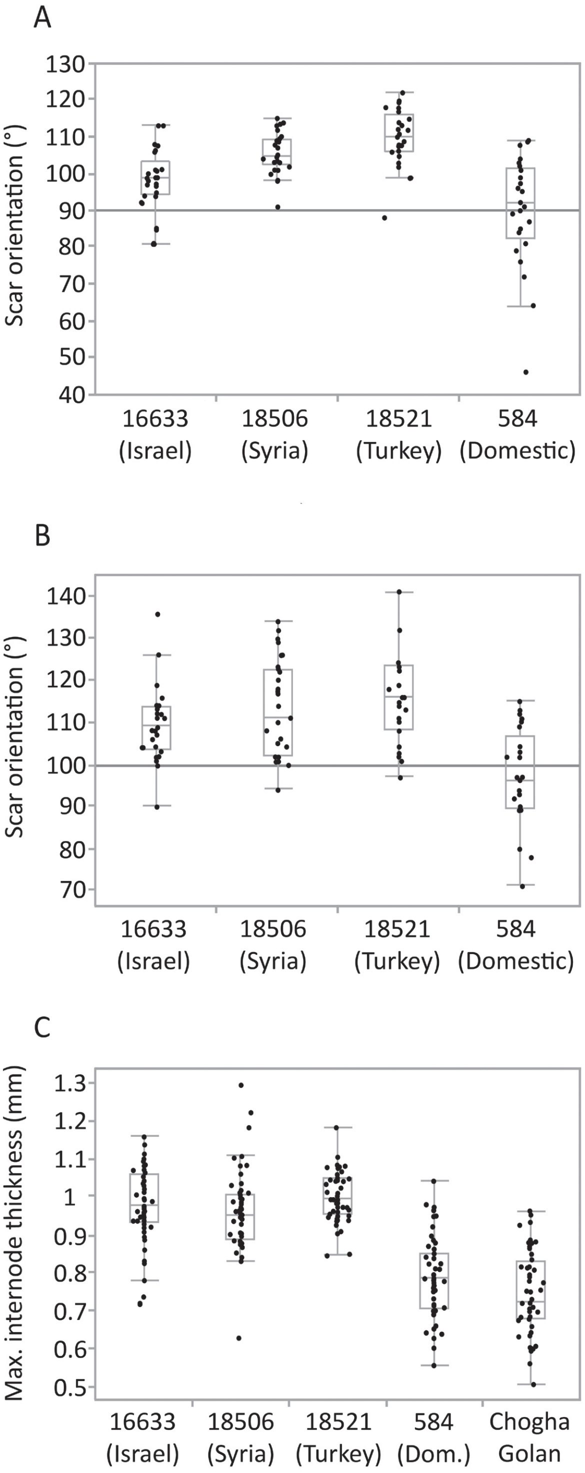

Fig. 14 Box plots illustrating differences between the analyzed emmer accessions. A: Scar orientation of uncharred wild and domestic emmer accessions; the threshold of 90° (horizontal line) allows one to separate about 40% of domestic spikelets from wild spikelets. B: Scar orientation of charred wild and domestic emmer accessions; the threshold of now 100° (horizontal line) allows one to separate about 67% of domestic spikelets from wild spikelets. C: Maximum internode thickness among charred accessions including the Chogha Golan assemblage.

Fragments	*n*	% of all fragments
Glumes	453	80.6
Rachises*		
domestic-type	9	1. 6
wild-type	7	1. 3
*not diagnostic***	84	14.9
Terminal spikelets	9	1.6
Total	562	100

* without fragments of lower ends; ** including tear-off scars (cf. Tanno & Willcox 2012).

Tab. 9 Frequency of emmer chaff fragments from AH II of Chogha Golan.

should be higher since only well preserved fragments can be determined as the uppermost spikelet. Fragments of the lower ends of the internodes are also present in the material. No effort has been undertaken so far to differentiate between the lower scars of *Hordeum* and *Triticum* specimens. These remains are therefore not considered in this study.

Only 16 out of 100 rachis fragments allowed the evaluation of the domestication status. Nine of these 16 specimens possess morphological features associated to the scar and ventral surface of the internode which are distinctive for the analysed domestic emmer accessions (**Tab. 9**). The internode surfaces of these domestic-type specimens display neither a marked curve directly adjacent to the scar nor are they straight. Some specimens show a slightly curved surface, whereas others have a distinct curve which is clearly distant from the scar (black arrow in **figure 16 A**). Only one fragment exhibits the characteristic protruding tissues indicating the connation of the rachis internodes. This rough scar, however, does not exhibit a knee typical for domestic-type specimens from genetically wild populations (black arrow in **figure 16 B**). The morphology of the remaining seven diagnostic fragments is more similar to the analysed wild emmer accessions. Some specimens have a virtually straight ventral internode surface without a marked curve directly below the scar (black arrow in **figure 16 C**). If a curve is present, it is small and located directly adjacent to the scar surface. These wild-type specimens are clearly distinct from the domestic-type rachises. The variability of morphological features present in the Chogha Golan emmer assemblage is relatively high. All analysed wild and domesticated emmer accession were more uniform regarding these features.

The measurements for maximum internode thickness support the assumption of a partly

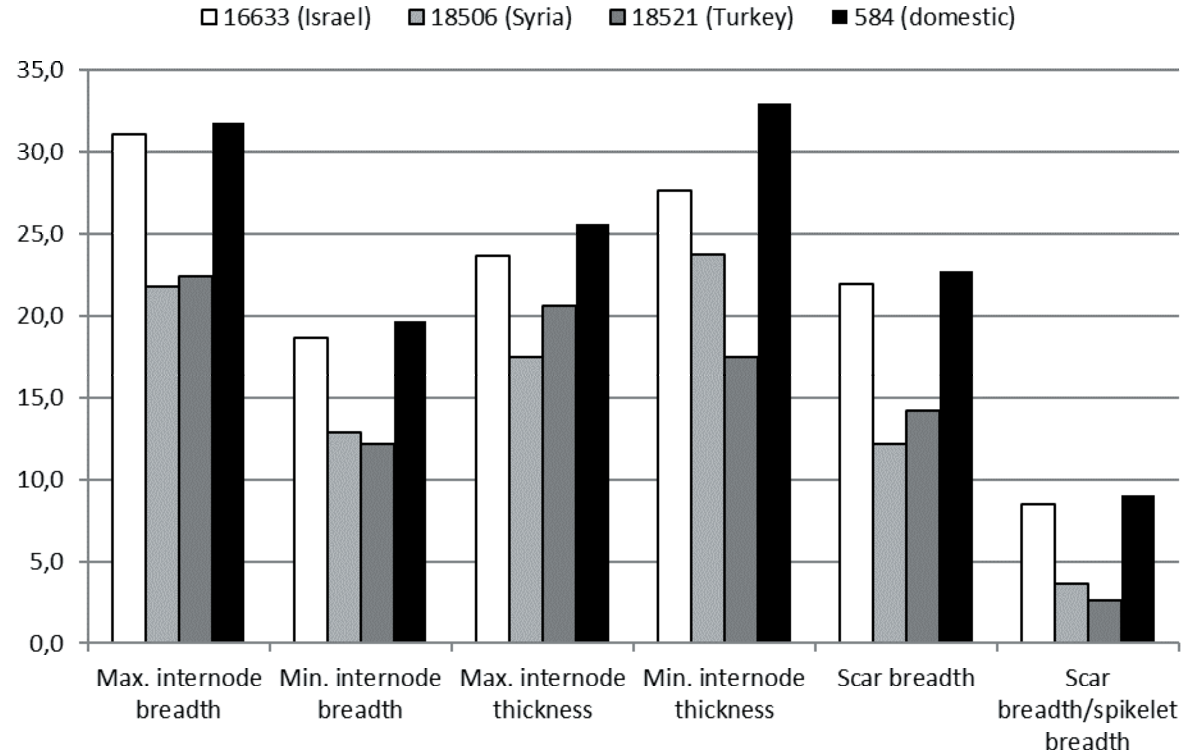

Fig. 15 Mean shrinkage of the measured features expressed as percentage.

domesticated emmer population at Chogha Golan. The measured Chogha Golan specimens (n = 56) are significantly distinct from all wild accessions (Steel-Dwass test, $p < .0001$ each) but not from the domestic accession (Steel-Dwass test, p = 0.266; **Fig. 14 C**).

Scar orientations of the six measured specimens from Chogha Golan lay between 78 and 129°. The two lowest values lay below the defined threshold of 100° that allowed the separation of charred wild from domesticated emmer. Both these specimens exhibited morphological features similar to the domesticated emmer accessions. The other two domestic-type specimens gave angles of 110 and 117°. The largest angle was obtained from a wild-type specimen.

Discussion and Conclusions

Identifying Domesticated Emmer Wheat

The requirements to reconstruct the domestication of cereals reliably are observations made on modern plants both from natural stands and cultivated fields. Kislev (1989) reported that up to 10 % of the barley rachises from two wild populations in Israel exhibited rough abscission scars after artificially detaching them. The majority of the domestic-type rachises derived from the lower parts within the ears. By analysing the tissue anatomy of the abscission zones, he concluded that domestic-type rachises from a genetically wild population could be distinguished from genetically domesticated barley. He further emphasised the problem of reconstructing initial emmer domestication as wild and domestic emmer are very similar in appearance. The analysis of wild emmer accessions from Israel, Syria, and Turkey in the present study showed that rough scars occur with a considerably fluctuating frequency between 0.5 to 7.5 %. In contrast to Kislev's study, the examined emmer spikelets were obtained from the *IPK Gatersleben* and not collected in nature. However, no information about the original sampling process were available. Whether the percentage of domestic-type spikelets among the analysed accessions reflects genetic variation rather than differences in the harvesting strategy needs to be confirmed by experimental studies.

The inconsistent proportions of terminal spikelets among the wild accessions (1 to 5.2 %) may be explainable by the fact that employees harvested mainly ripe ears rather than significant portions of green ones (Grau, personal communication). The number of terminal spikelets included in the harvest possibly varies from year to year, depending on the state of maturity when the ears are harvested. On the other hand, variable proportions of terminal spikelets could indicate differences in brittleness between the accessions. The number of terminal spikelets correlated positively with the amount of rough scars. Nevertheless, further investigations during the harvesting process are

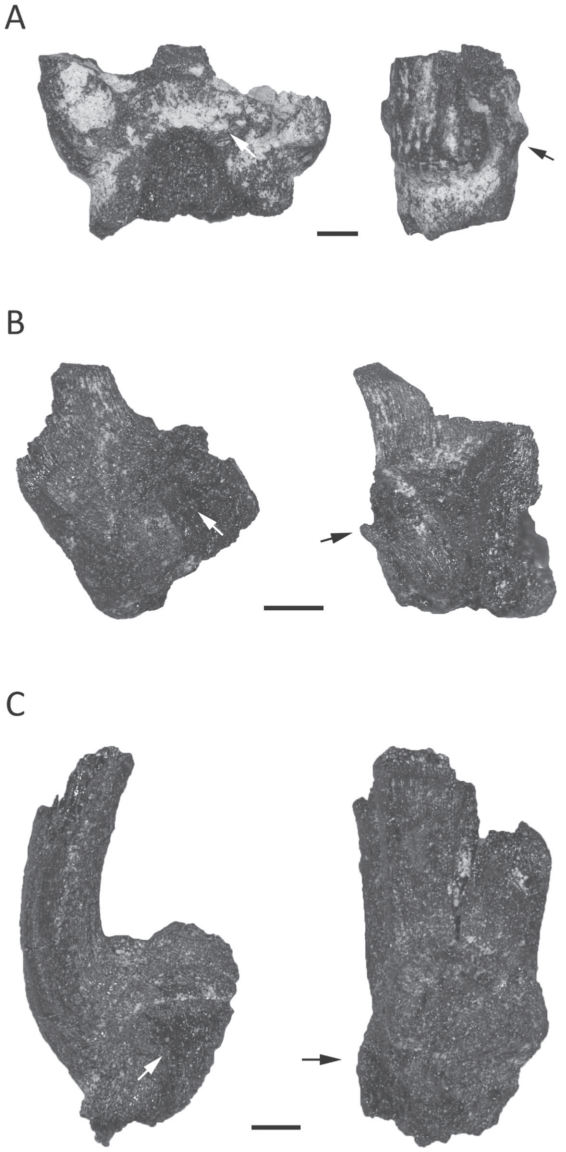

Fig. 16 Carbonized emmer rachis fragments from AH II of Chogha Golan in frontal (left) and lateral (right) view. A: domestic-type rachis with a scar clearly lifted from the internode surface (black arrow); B: domestic-type rachis showing adhering tissues at the scar surface which are straight (black arrow); C: wild-type rachis whose scar is neither lifted nor showing adhering tissues in the lower portion (black arrow). White arrows indicate the lower margin of the scar in ventral view. Bars indicate 250 μm.

necessary to verify this hypothesis.

Unexpectedly, proportions of terminal spikelets for the accessions from domestic emmer were neither higher nor more consistent than those for wild emmer. They ranged from 1.6 to 5.5 %. Theoretically, terminal spikelets should be more numerous among domestic emmer since their ears do not shatter (Tanno & Willcox 2012). This was not the case and the reason is hardly explainable as I did not attend the harvest and threshing process. The values are presumably biased by the small number of available spikelets, so the ambiguous results cannot be further interpreted. Damaged scars, which would hamper the identification of the domestication status, were rarely present among the wild accessions (tear-off scars, about 1 %). They were certainly produced by artificially detaching ears which did not shatter entirely. The few specimens with torn scar surfaces are unlikely to bias archaeobotanical results and can therefore be neglected. Higher but still moderate values were obtained from domestic emmer (10.2 to 13.7 %). This supports the suggestion that dehusking and carbonisation rather than threshing primarily destroys the upper abscission scars. Again, concerning domestic emmer, the small sample size should be considered.

Among the scar types present in wild emmer accessions, the domestic-type specimens exhibiting remains of torn tissues in the lower part of the scar are of special concern for the identification of genetically domestic emmer. With regard to a study by Frank (1964), Kislev (1989) showed that domestic-type barley rachises of genetically wild populations can be distinguished from domesticated barley by the short cells in the abscission zone. The reduced abscission layer among domestic barley is said to be indicated by the lack of these short cells. Although a detailed analysis of the tissue structure of emmer spikelets was not conducted in the present study, genetically wild and domestic specimens with rough scars could be distinguished. The torn tissues which adhere to the scar surface of domestic emmer rachises are straight. In contrast, the protruding tissues on scars of wild emmer have a distinctive knee-shaped appearance (cf. Morrison 1994). These knee-shaped tissues are not present among domestic emmer and allow a clear-cut differentiation between both subspecies. Kislev's illustrations (Kislev 1989, Fig. 2-3) show that wild barley also possesses a well developed knee, although Morrison (1994) states that this feature is most prominent in *Triticum* taxa. Preliminary observations, made on material from the Tübingen reference collection, indicate that *Hordeum vulgare* subsp. *distichum* may also be distinguishable from its wild progenitor by using this criterion. In addition, Morrison shows a *Triticum urartu* rachis section, which coincidentally exhibits a domestic-type scar (Morrison 1994, Fig. 5.5a). A section of undetached wild einkorn rachises is depicted as well (Morrison 1994, Fig. 5.7b). Both species possess the same morphological features as wild emmer, i.e. the knee-shaped protruding tissues. Like for barley, I briefly surveyed the Tübingen reference collection for spikelets of domesticated einkorn. They seem to have a knee, which is not as prominent as in the wild specimens. Based on these brief observations, I suggest that domestic-type rachises from wild cereal populations are generally distinguishable from domestic cereals. Further research regarding this issue is required and promises further advances in the identification of carbonised cereal chaff remains.

These findings have important implications for the identification and evaluation of emmer assemblages from PPNA and PPNB sites. By using Aşikli Höyük, it was already exemplified that the number of diagnostic emmer specimens can be vanishingly low due to preservational and taphonomic issues, and the same is true for the so far analysed emmer remains from Chogha Golan. A comprehensive quantification of the proportion of domestic-type specimens is thus impossible. Considering suggestions made by Hillman (1981) and again by Hillman and Davies (1999), the lower, most robust spikelets of an ear, which frequently produce rough scars, possibly survive charring in higher frequencies than the upper, brittle spikelets. This implies that taphonomic issues possibly bias the frequency of domestic-type specimens, which can lead to wrong determinations of the domestication status. In other words, when just a dozen out of hundreds of rachis fragments are diagnostic and show a rough scar, these scars could theoretically derive from the lower parts of wild emmer ears, or other cereals, and erroneously indicate domestication. Whether this was ever the case is by no means verified, but it has to be taken into account. The identification criteria presented in this study are suited to approach this problem, as they distinguish between rough scars of wild and domestic emmer.

Due to the fragmentation of hulled wheats, entire scars are often rarely preserved. Therefore, the application of the above discussed method could be hindered. I showed that wild and domestic emmer is also distinguishable by analysing the ventral surface of the rachis internode directly below the scar. Domestic emmer possesses a lifted scar, whose lower portion is protruding from the internode surface. By contrast, wild emmer has a straight internode surface that is, if at all, curved directly adjacent to the scar. This part may exhibit the diagnostic traits when the scar surface is destroyed.

Overall rachis and scar dimensions from the material of four accessions were measured in order to establish additional differences between wild and domestic emmer. The results showed that the variability of the material from natural stands was high, and thus, dimensions of domestic emmer always fell within this range. This was to be expected as molecular biological research demonstrated high genetic diversity among and within wild emmer populations (e.g. Nevo et al. 1988a, 1988b; Nevo & Beiles 1989; Li et al. 1999; Peleg et al. 2005, 2008). The general morphology of *dicoccum* rachises is obviously little distinctive and does not allow a clear-cut differentiation from its wild progenitor, as already stated by Kislev (1989). Only maximum internode thickness and scar orientation are suited to support the identification of domestic emmer.

It was not possible to analyse the variation of all these morphological features within an ear. But since the morphological variation within the accessions was much smaller than between accessions, I expect the position of a spikelet to be of minor significance. This, however, requires further analyses.

The Effects of Carbonisation on Rachis and Scar Morphology

Botanical remains from aceramic Neolithic sites are almost entirely preserved by carbonisation (Zohary et al. 2012). It is therefore crucial to consider the effects of heat on the survival and the morphology of plants and their different organs. Experimental carbonisation of plant parts, which are frequently found in archaeological contexts, resulted in three major conclusions. First, temperature and duration of heating are the most important factors that influence the carbonisation process, second, an increased amount of available oxygen negatively affects the temperature range under which plant tissues become carbonised rather than burned, and third, different taxa as well as different organs respond to the exposure to heat in different ways (e.g. Boardman & Jones 1990; Wright 2003; Braadbaart & Bergen 2005). Few exceptions however exist such as grains of *Panicum miliaceum*, which preserved better under oxidizing conditions (Märkle & Rösch 2008).

In this study, whole spikelets of wild and domesticated emmer were carbonised under one general treatment (250°C for 8 h in open chamotte crucibles). The main conclusions are that (1) most features diagnostic for the domestication status of emmer were not significantly affected by carbonisation, (2) the amount of shrinkage among the accessions was not equal, and (3) the measured features did not shrink consistently. In contrast, the general shrinkage pattern of the spikelets was comparable between the accessions and charring effects on domesticated emmer were not significantly distinct from those on wild emmer.

A temperature of 250°C can be regarded as the lower border of the range in which grains and chaff of cereals become successfully carbonised. Boardman and Jones (1990) charred whole spikelets as well as free grains and glumes of einkorn, emmer, and spelt under varying conditions and showed that temperatures between 250 and 550°C successfully carbonised the material. Between three to three and a half hours were needed to reach carbonisation under reducing conditions at 250°C whereas grains and chaff were destroyed within one hour at 550°C. Oxidising conditions led to a more rapid carbonisation but also to a reduced temperature range that allowed some plant tissues to survive. Grains survived charring better than glumes and distortion of plant organs increased with higher temperatures and length of heating.

It is to be expected that carbonisation at higher temperatures significantly affects the morphological features, which allow the identification of domesticated emmer. In the present study, apparent distortions were visible on the lower parts of the internodes and the upper parts of the husks. The latter preserve only under special circumstances and do not play an important role in the research on cereal domestication. A more pronounced bending of the internode will certainly lead to its fragmentation, which does also not affect domestication features as long as the upper scar and the adjacent internode surface are not destroyed.

About 10 % of the scar surfaces of the Israeli accession and the scars of virtually all domestic emmer specimens were affected by heating. Scars from the wild accession lacked the uppermost cell layers. Concerning the domesticate, the torn tissues which protrude over the scar surface were always bent towards the rachis. Since scar morphology exhibits the main features to distinguish between wild and domestic emmer, the effects of more destructive charring conditions need to be analysed by further investigations. Tanno and Willcox (2012) reported that the far majority of hulled wheat rachis fragments lack an intact scar and attributed this to crop processing practices. The results of this study indicate that carbonisation itself could be another agent, which significantly damages the abscission scars. SEM micrographs show that the outer tissues of rachises are composed of thick-walled sclerenchyma cells. The scar is thus the only part of the internode surface where vascular bundles and parenchyma are exposed and which is affected by heating at first.

Tanno and Willcox (2006, 2012) and Fuller (2007) interpreted the damaged lower scars of hulled wheats from aceramic Neolithic sites as evidence for initial domestication. These conclusions were based on the fact that threshing of non-brittle ears damages the lower parts of rachis internodes. However, the above mentioned effect of heat on scar preservation places doubt on the reliability of this feature to identify the domestication status. It must also be taken into account that burial conditions as well as recovery techniques such as flotation might further affect the preservation of charred plant remains. As a consequence, I suggest not using the condition of the lower parts of the internodes to differentiate between wild and domestic cereals.

The amount of shrinkage due to carbonisation was different between the accessions and between the single features which were measured, but the overall shrinkage patterns were comparable. Differences in the response to heat between plant taxa can generally be attributed to the chemical and physical properties of their tissues as well as the moisture content before carbonisation (Wright 2003; Märkle & Rösch 2008). Some differences in the consistency of the tissues of emmer carbonised in this study exist and resulted in distinct amounts of shrinkage, although all accessions belonged to one species. Varying effects among the single features can also be interpreted as a result of different anatomical structures among the organs of a spikelet. This is indicated by the comparison of the decreased rachis dimensions and the glume bases, which withstood charring. The question how exactly rachis anatomy and the arrangement of tissues are related to the shrinkage process was beyond the scope of this study.

Finally, some general problems regarding the experimental carbonisation on plant components remain. The charring process is always simulated under artificial conditions using a muffle furnace or comparable instruments rather than a real fire. The validity of the gained results is thus not clear (Wright 2003; Märkle & Rösch 2008). Willcox (2004) as well as Braadbaart and Bergen (2005) pointed out that experimental carbonisation hitherto failed to reconstruct charring conditions that prevailed in prehistory. Therefore, the application of the results to ancient plant remains and the reconstruction of charring processes as suggested by Boardman and Jones (1990) should be made carefully. Besides differences in charring conditions between the past and modern laboratories, we have to consider the ongoing evolution of plants during the past millennia. Since different taxa respond to heat in different ways, crops from the Neolithic, the Middle Ages and from today may also behave distinct under the exposure to heat, although we place them into the same species or even subspecies.

The Emmer Wheat Remains from Chogha Golan

The application of the defined identification criteria to the emmer remains clearly proved the presence of wild-type as well as domestic-type specimens. In total, 562 carbonised fragments were recovered of which the far majority were glume bases. Only 100 fragments exhibited a part of the rachis including the abscission zone, which was destroyed in most cases. Finally, nine specimens could be identified as of domestic-type and seven as of wild-type. This is a relatively high proportion of diagnostic rachises, compared to other aceramic Neolithic sites (**Tab. 10**). The ratio between both types is about 44 to 56 %. Whether these values are representative is doubtful as the major portion of the available fragments was severely damaged. The frequencies of spikelets showing a tough rachis from recent wild emmer populations are therefore useless for interpreting the material from Chogha Golan. All the more important is the presence of one specimen with the morphology of genetically domestic emmer, i.e. a protruding scar with torn tissues lacking the knee typical for wild cereals. The remaining eight domestic-type specimens are distinguishable from the wild-types by their distinctive scar morphology. Based on these observations, I assume that domesticated emmer spikelets are present in AH II of Chogha Golan, dating to about 9,800 cal. B.P. This hypothesis is supported by two values for scar orientation of domestic-type rachises, which clearly lay beyond the threshold that differentiates between wild and domestic

	Nevali Çori	Tell Aswad	Aşikli Höyük	Chogha Golan	Seker Aheimar	Salat Cami	Tell el-Kerkh
Date (cal. B.P.)	10,500	10,500	10,200	9,800	9,300	8,300	8,200
Taxon	Einkorn[1]	Emmer	Emmer	Emmer	Emmer	Emmer	Emmer
Domestic rachis	3	7	9	9	2	42	11
Poss. domestic rachis*	38	50	-	-	-	12	23
Wild rachis	64	170	11	7	1	1	19
Indet. rachis	2285	1262	193	84	70	1268	860
Terminal spikelet	6	27	4	9	2	18	27
Glume fragment	5312	568	200	453	179	1848	621
Total	**7708**	**2084**	**417**	**562**	**254**	**3189**	**1561**
% terminal spikelets	**0.1**	**1.3**	**1**	**1.6**	**0.8**	**0.6**	**1.7**
% diagnostic rachises**	**2.8**	**12.3**	**9.4**	**16**	**4.1**	**3.3**	**3.4**

[1] presence of emmer indicated by terminal spikelets, * category not used for Chogha Golan, ** excluding poss. domestic rachises

Tab. 10 Comparison of Chogha Golan to other aceramic Neolithic sites (data after Tanno & Willcox 2012).

emmer. Mean maximum internode thickness of 56 measured rachises from Chogha Golan differed significantly from all wild accessions, but not from the domesticate. This represents a further evidence for the domestication status of the assemblage. However, the number of diagnostic rachises is still low. To confirm the presence of domesticated emmer, the number of diagnostic specimens needs to be increased by future research. Another limitation of the presented evidence is that the criteria have been applied to material from only one site. To confirm the validity of the criteria developed and applied here, it is necessary to test them using archaeobotanical remains from sites where emmer domestication is already proven.

The proportion of terminal emmer spikelets at Chogha Golan is relatively high. This becomes particularly apparent by comparing the remains with other aceramic Neolithic sites (**Tab. 10**). Because the identification criteria for domestic hulled wheats were revised recently, most publications from the last decades do not describe wheat chaff remains in sufficient detail. The number of sites available for a comparative analysis is therefore small. Data published by Tanno and Willcox (2012) include sites dating from 10,500 to 8,200 cal. B.P., spanning the period in which emmer was domesticated. At Chogha Golan, terminal spikelets make up 1.6 % of all emmer fragments. Only Tell el-Kerkh in northwest Syria, for which emmer domestication is demonstrated by the end of the 9th millenium, has a higher value (1.7 %). The currently oldest reliable evidence for domestic emmer comes from Aşikli Höyük, dating to about 10,200 cal. B.P. There, terminal spikelets contribute just 1 % to all fragments. Tanno and Willcox (2012) suggested that increased proportions of terminal spikelets indicate the successive establishment of the non-brittle ear, although values may be biased as terminal spikelets in archaeobotanical assemblages are easily overlooked. In addition, the amount of terminal spikelets in the analysed wild emmer accessions correlates positively with the number of domestic-type spikelets, and thus, reduced brittleness. The high percentage of terminal spikelets at Chogha Golan therefore supports the assumption of an at least partly domesticated emmer population. Only the relatively high value of 1.3 % from Tell Aswad, that yielded a far majority of wild-type scars, advises caution in interpreting the percentages in this way. Generally, high frequencies of terminal spikelets from wild populations can be explained by certain harvesting practices (Willcox 1999). If wild cereals are harvested in an unripe state, all known harvesting methods will lead to an accumulation of terminal spikelets. The proportions at Tell Aswad can be interpreted in this way. By contrast, Salat Cami in southeastern Turkey yielded a value as low as 0.6 %, although emmer is clearly domesticated. This again shows that the proportions of terminal spikelets can be misleading. Why such few terminal spikelets were recovered at Salat Cami is unclear. Preservation issues could be an explanation. The number of single glume base fragments, whose position within the ear cannot be determined, is very high. Fragmented terminal spikelets are possibly included in these remains.

Explaining the co-occurrence of brittle and non-brittle spikelets

The identified emmer remains from AH II are composed of specimens exhibiting a wild-type as well as a domestic-type morphology. This co-occurrence of brittle and non-brittle spikelets is common among aceramic Neolithic sites (Helbaek 1969; Tanno & Willcox 2006, 2012; Fuller 2007; White & Makarewicz 2012). In the literature, four major hypotheses aimed to explain this. First, the persistence of brittle individuals is due to cultivation and harvesting techniques discriminating against non-shattering ears (Kislev 1984; Hillman & Davies 1990; Willcox 1999; Fuller 2007; Fuller & Allaby 2009). Second, although early farmers selected for tough rachis mutants, wild cereals invaded the fields as weeds and thereby contributed to the harvest (Helbaek 1969; Nesbitt 2002). Third, wild cereals were gathered in order to replenish seed stocks after poor harvests (Tanno & Willcox 2006; Willcox et al. 2008). Fourth, continuous gathering in wild stands alongside cultivation of domestic crops resulted in intermixed chaff remains recovered from midden deposits (Asouti & Fuller 2013). There is to date no established approach allowing a differentiation between these scenarios.

Cultivation and harvesting techniques can be reconstructed by analysing associated implements combined with use-wear analyses. Nevertheless, even if sickles exhibit use-wear patterns that are attributable to cutting cereals, it is unclear whether they were harvested from fields or natural stands (Anderson 1999). Instead, contextualising the material is a more promising approach, particularly through the reconstruction of processing and storage practices (Fuller et al. 2010; Asouti & Fuller 2013). If wild cereals had been growing in fields, suggesting an incompletely domesticated population or weedy forms, brittle spikelets should be found together with non-brittle ones in storage facilities. The case of storage finds that contain solely brittle or non-brittle spikelets, but the respectively opposite types were recovered from either another storage context or midden deposits, would indicate separate origins of wild and domestic cereals. Unfortunately, primary storage finds are rare. Weiss et al. (2006) reported the recovery of hundreds of thousands of wild barley and oat grains from a granary at Gilgal. The storage did not contain chaff remains except for oat awns. Despite the absence of such *in situ* storage finds, Willcox and Stordeur (2012) argue that grains as well as chaff of wild barley, rye, and einkorn were stored at Jerf el Ahmar. They analysed find densities and found that small cells in communal buildings yielded relatively high values for either grain or chaff, each belonging to one of the mentioned taxa. In addition, building earth remains exhibited numerous impressions of rachises and husks, indicating chaff storage for tempering material. Since straw impressions were rarely observed, threshing was presumably not conducted at the site (Asouti & Fuller 2013). Although domestic cereals were not found at Jerf el Ahmar, analysing find densities combined with contextualised sampling seemed to provide a valuable tool for tracing cereal storage, even though apparent storage facilities were not excavated. Find densities are rarely calculated for sites of the Fertile Crescent. In order to get a better understanding of the interaction between cereal cultivation, utilisation, processing techniques, and domestication, approaches like the one described above should be increasingly applied in the future (Fuller et al. 2010; Asouti & Fuller 2013).

Since we have no detailed information regarding the contexts from which the emmer remains of Chogha Golan derived, their general patterns throughout the sequence may reveal hints concerning the origin of brittle and non-brittle specimens. Hulled wheat remains are scarce in levels dating to the 11th millennium B.P., but increase quite spontaneously in the upper horizons. Emmer is dominant in AH II as well as AH I, and displaced wild barley as the major cereal (Karakaya 2013; Riehl et al. 2013). A look at the modern distribution map for wild emmer shows that known natural stands in the Zagros are rare. *Triticum turgidum* subsp. *dicoccoides* is much more abundant in the western and northwestern Fertile Crescent and has its core area in the northern Dead Sea Basin. By contrast, *Hordeum vulgare* subsp. *spontaneum* is much more widespread and forms massive stands in its primary habitats throughout the Zagros (Harlan & Zohary 1966; Zohary 1969). It is of course not certain whether these distributions match those 10,000 years ago (Nesbitt 2001; Willcox 2005). But the patterns from Chogha Golan generally imply that natural stands of barley were an important food resource, perhaps also for replenishing seed stocks for its cultivation, whereas the scarcity of emmer prior to AH II indicates the absence of wild stands near the site. Emmer yields more grains per spike, and thus, it is not explainable why the inhabitants should have gathered or cultivated wild barley but ignored wild emmer. Based on this, I suggest that the brittle spikelets were not collected from wild stands of the local environment. The occurrence of wild emmer as a weed seems unlikely due to the same reason. These considerations point to an incomplete establishment of the tough rachis in an entirely cultivated emmer population at Chogha Golan.

Implications for the Local Aceramic Neolithic

The identification of morphologically domesticated emmer at Chogha Golan dating to about 9,800 cal. B.P. has important implications for the aceramic Neolithic. Regarding the Central Zagros, profound archaeobotanical studies are available for Ganj Dareh in the uplands and Ali Kosh in the lowlands. AMS dates for Ganj Dareh indicate a quite short occupation slightly after 10,000 cal. B.P. (Zeder & Hesse 2000). The site is thus roughly contemporary with the upper horizons at Chogha Golan. The lowest level of Ali Kosh dates to about 9,500 or 8,900 cal. B.P. Zeder and Hesse emphasised that the younger date is supported by two AMS dates of charred bone. Regardless of these problems, the aceramic layers of Ali Kosh are younger than the upper sequence at Chogha Golan.

Ganj Dareh yielded barley remains from all horizons, other cereals were not recovered (van Zeist et al. 1984). Whereas the percentage in the lowest level E was as small as 2.3 % (if a sample with a very high amount of grains is ignored), it increases to 50 % in level B. The far majority are grains, accompanied by very few rachis fragments. Among them, smooth as well as rough abscission scars are present. In addition, grain dimensions cover ranges from thin, *spontaneum*-like specimens, to thick, domestic-type ones. It is worth mentioning that van Zeist and colleagues emphasised the difficulties of identifying the domestication status of a cereal based on grain dimensions. Nevertheless, they assume that domesticated two-row hulled barley was cultivated, possibly alongside gathering in wild stands. The wild-type specimens could also have been weeds or reflect the uncompleted domestication of the cultivar. At least, van Zeist and colleagues underline the absence of emmer and argue for some kind of isolation of the site within the Fertile Crescent. This conclusion was inevitable, since they followed the general assumption that agriculture emerged in a Levantine "core-area", from where it spread eastwards into the Taurus-Zagros mountain range (cf. Kislev 1984).

For Ali Kosh, Helbaek (1969) reported the presence of domestic emmer from the earliest occupation onwards and assumed that it was domesticated in the uplands of the Zagros, where it thrives naturally. Numerous finds of hulled barley grains were also recovered, unfortunately not accompanied by the same amounts of rachis fragments. To evaluate the barley remains of the site, one particular statement in Helbaek's detailed report must be considered: "*...barley internodes are generally utterly rare in the Tepe Ali Kosh material. They are thin, sharp, and certainly not suggestive of any nutritive value whatsoever. Even so, one of the Mohammad Jaffar phase samples, containing 218 of them, proves that they did not automatically disappear in winnowing. It might be noted, although slightly out of place, that about 10 to 15 per cent of these internodes show fractures characteristic of a tough axis...*" (Helbaek 1969, 401). These lines are of special concern rather than out of place. They imply that hulled two-row barley from a pottery-bearing layer cannot belong to the domestic subspecies, as the percentage of domestic-type rachises is too low. The presence of domestic two-row barley in the aceramic levels is thus very unlikely. Although Helbaek mentioned the recovery of wild barley even earlier (Helbaek 1966), a domestic status was assumed recently (e.g. Nesbitt 2002; Charles 2007). I suggest that domesticated emmer was cultivated at the site whereas wild hulled barley was either collected from natural stands or it grew in the fields as a weed. This pattern resembles the situation in the upper levels of Chogha Golan (Karakaya 2013; Riehl et al. 2013). In light of Helbaek's suggestions, that emmer was domesticated in the Zagrosian uplands and later brought to the lowlands, we should again have a look at the results from Ganj Dareh. Whether barley from the site was wild or domesticated cannot be examined further, but the absence of emmer does not point towards a domestication event in the uplands, prior to its appearance at Chogha Golan. Only the evidence from Abdul Hosein and Jarmo indicates the presence of domestic emmer in the Zagros Mountains. But since both sites are younger than Chogha Golan, they cannot explain its emergence in the lowlands.

In the end, whether emmer was taken into cultivation as a wild plant at Chogha Golan and then subsequently domesticated, or if it was introduced as a partially domestic cultivar from further away, is currently unclear. The absence of emmer prior to its sudden appearance may indicate that grains from a wild or semi-domesticated population were introduced and then cultivated. This hypothesis coincides with the "dispersed-specific" model of Özkan et al. (2011). According to this model, a wild plant was taken into cultivation in one place and then dispersed as a pre-domesticated cultivar. It was subsequently domesticated at several sites, independently from each other. This scenario is currently the most probable one and is supported by the current state of knowledge concerning both archaeobotany and genetics. Once emmer was domesticated, it seemed to have become an important part of the subsistence economies among later Zagrosian sites, as it was frequently recovered along with barley. In addition, lentil is the third important crop species that is characteristic for the local aceramic Neolithic (Charles 2007). Besides Chogha Golan and Ganj Dareh (van Zeist et al. 1984; Karakaya 2013; Riehl et al. 2013), lentils are present at sites such as Abdul Hosein, Jarmo, and Chogha Bonut (Helbaek 1959; Hubbard 1990; Miller 2003). For Ali Kosh, just very few lentils were recovered (Helbaek 1969).

The scarcity of emmer at Chogha Golan prior to its cultivation is striking. Then, barley as well as one or some *Aegilops* species dominated the large-seeded grasses (Karakaya 2013; Riehl et al. 2013). The patterns observed at Ganj Dareh may be thus a survival of "traditions" still persisting in the uplands, despite *Aegilops* remains were not recovered. Concerning this issue, the results of J. Whitlam, who currently analyses the assemblage from Sheikh-e Abad, will be interesting. So far, preliminary results point to an abundance of barley and lentil but very scarce remains of hulled wheats, in layers dating to about 10,000 cal. B.P. (Whitlam et al. 2013). A lack of barley chaff so far hinders the identification of the domestication status. The preliminary data indicate the expected patterns that pre-date the emergence for domesticated emmer in the Zagros, but we should wait for the final results.

This brief survey of archaeobotanical data from aceramic Neolithic sites in the Zagros demonstrates that distinctive patterns seem to exist. The record for the 11th millenium is poor, however, data from Chogha Golan and Sheikh-e Abad indicate the exploitation of wild barley and lentils along with a diversity of edible plants. Domesticated emmer seems to appear as soon as 9,800 cal. B.P. Contemporary Ganj Dareh in the uplands lacks emmer. This suggests that domestication did not inevitably occur in the range of natural stands. Sites post-dating Chogha Golan yielded emmer, although its domestication status is not always certain. The results from the present study support the assumptions of Hubbard (1990) and Miller (2003) that emmer grains from Abdul Hosein and Chogha Bonut belong to the domestic subspecies. The current state of knowledge concerning the emergence of agriculture in the Central Zagros is now richer than a decade ago, when Nesbitt wrote his well-known paper about the appearance of domestic cereals in the Near East (Nesbitt 2002). Future investigations will show whether the current patterns are reliable or an artifact of the state of research.

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Glossary

This glossary explains the botanical and archaeological terminology which is used in the article. Words written in italics are explained elsewhere in the glossary.

Abscission layer – The layer of cells which enables the *rachis* to break upon maturity.

Abscission scar – The *rachis* of a cereal *spike* is divided into segments. After disarticulation, these rachis segments display an upper and a lower abscission scar. These scars indicate where the rachis segments were attached to each other.

Accession – Plant material that was collected and then stored in a scientific collection for further research.

Aceramic Neolithic – The first phase of the *Neolithic* in the Near East that lacks ceramic vessels. In the present article, it is used as a chronological unit instead of "*Pre–Pottery Neolithic*", which was described in the Levant and is also associated with a distinct cultural setting.

Allele – A variant of a gene. Different alleles of a gene can result in different traits of the *phenotype*.

Allozyme polymorphism – The diversity of different enzymes which are coded at a single genetical locus.

Awn – A long appendage at the *lemma* of a grass *spikelet*.

Caryopsis – The grass fruit, commonly called grain.

Chaff – Threshing remains of cereals, mainly composed of husks but also of rachis segments.

Chloroplast – An organelle of plant cells, in which photosynthesis takes place. Chloroplasts contain their own DNA, because they originate from unicellular organisms that once lived autonomously.

connate – Specific adjective for organic tissues which are grown together.

Cultivar – Here, equivalent to *variety* or landrace. In general a domesticated plant species.

diploid – see *ploidy*.

Dispersal unit – The unit that is dispersed for the purpose of seed dispersal. It can be a single seed or a compound structure such as a *spikelet* containing grains.

Domesticate – A domesticated plant or animal species.

Epipalaeolithic – The final period of the Palaeolithic in the Near East, equivalent to the Mesolithic in Europe.

Fertile Crescent – A crescent-shaped geographical area which includes the Levant, southeast Anatolia, and the Zagros Mountains of northern Iraq and western Iran. Due to sufficient precipitation, rainfed agriculture is possible in this region.

Floret – A single flower within a *spikelet*.

Genome – The entirety of genes of an organism.

Genotype – A distinct *genome*.

Glumes – The two lowermost *husks* of a *spikelet*.

Habit – The overall appearance of a plant.

hexaploid – see *ploidy*.

Hulled cereals – Cereal species whose *spikelets* possess tough *husks* that enclose the grains, e.g. emmer, einkorn and hulled barley. The opposite are the *naked cereals*.

Husk – Modified leaf. Husks are part of a *spikelet* and enclose the *florets*. After fruit development, they enclose the *caryopses*.

Inflorescence – The entirety of flowers which are grouped together on a plant.

Infructescence – The entirety of fruits which are grouped together on a plant.

Kebaran – An archaeological "culture" of the southern Levant that dates to the early *Epipalaeolithic*.
Lemma – The lower one of two *husks* enclosing a *floret* or *caryopsis*, respectively.

Morphotype – The set of observable morphological traits of an organism. See *phenotype*.

Naked cereals – Cereal species whose grains are not enclosed by tough *husks*, e.g. bread wheat or naked barley. The opposite are the *hulled cereals*.

Natufian – A well investigated archaeological "culture" which was distributed throughout the Levant. The Natufian represents the last phase of the local *Epipalaeolithic*.

Neolithic – The last period of the Stone Age that is characterised by the development of sedentism and agriculture.

Palea – The upper one of two *husks* enclosing a *floret* or *caryopsis*, respectively.

Panicle – A multi-branched *inflorescence*.

Phenotype – The overall appearance of an organism, including its anatomy and physiology, which is determined by genetic and environmental factors.

Phylogeny – Study of the evolutionary relationships between organisms.

Ploidy – The number of chromosome sets. A *diploid* organism has two sets of chromosomes, a *tetraploid* organism has four sets, and so on.

Pre–Pottery Neolithic (PPN) - see *aceramic Neolithic*.

Rachis – In botany, a rachis is the main axis of a leaf or an *inflorescence*. Here, it is the segmented axis of a cereal *spike*. These segments are commonly called *rachis* internodes, although they are composed of an internode between two nodes.

Ruderal plant – A plant which grows in disturbed habitats, e.g. an abandoned settlement.

Segetal plant – A wild plant which grows in cultivated fields, commonly called a weed.

Spike – A specific type of *inflorescence* typical of many grasses. It consists of a central *rachis* and *spikelets*, which are directly attached to this rachis (without a stalk). Among cereals, a spike is commonly called an ear.

Spikelet – A compound of flowers common among grasses. A spikelet includes a variable number of single *florets* (depending on species) which are enclosed by *husks*.

Spikelet base – This term is conventionally used to refer to a *rachis* internode with the *glume* bases preserved. An equivalent term is "*spikelet fork*".

Spikelet fork – see *spikelet base*.

Taxon – A category in the classification system of organisms, e.g. a genus or species.

Taxonomy – The classification of organisms.

Tell – A mound which has been formed by the accumulation of anthropogenic sediments, i.e. building debris, midden deposits etc. This type of settlement is common throughout the Near East.

tetraploid – see *ploidy*.

Triplet – Barley *rachis* segments carry three *spikelets* each. This compound of spikelets is called a triplet.

Variety – It is used in its broadest sense, i.e. a distinct type of domesticate that differs in some traits from other types of the same domesticate. An equivalent is "landrace". The specific *taxonomic* rank is not meant.

Weed flora – see *segetal plant*.

About the author:

Alexander Weide studied Prehistoric Archaeology and Biology at the University of Marburg. He completed his Bachelor's degree with a thesis on Early Iron Age ceramics found near Niederweimar in Hessen. In autumn 2011, he went to the University of Tübingen to focus on archaeobotany.

During that time, Alexander Weide conducted archaeobotanical field work on excavations in South Africa and Anatolia. In his Master's thesis he worked on improving identification methods for domesticated emmer wheat in the aceramic Neolithic of the Near East. He recently started his dissertation project "The development of plant use and exploitation at the aceramic Neolithic site of Chogha Golan, Iran". This also includes experimental studies on wild and domesticated cereals to gain a better understanding of their morphological differences.

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Appendix: Identification key for archaeobotanical emmer rachis fragments

A secure identification of the domestication status of a carbonised emmer rachis is possible by analysing the longitudinal section. The following features are distinctive for the genetically wild or domestic subspecies of *Triticum turgidum*, respectively:

1) Appearance of upper scar in longitudinal section:
- flat, steep orientation (mostly > 100°): *dicoccoides*
- lifted from internode, less steep orientation (often < 100°): *dicoccum*

2) Surface of upper scar:
- smooth, no adhering tissues: *dicoccoides* (or *dicoccum*)
- rough, adhering tissues present: *dicoccum* (or *dicoccoides*)

3) Protruding torn tissues at scar surface:
- knee-shaped in longitudinal section: *dicoccoides*
- straight in longitudinal section: *dicoccum*

Attention must be paid to the morphological variability of both the wild and domestic subspecies. Most scars of *dicoccum* are clearly lifted from the internode surface, but the transition to *dicoccoides* is occasionally fluid. This is also true for the abscission surface of the upper scar. Whereas up to 8 % of genetically wild spikelets exhibited rough scar surfaces, quite a few specimens of the domestic accession from Turkey had virtually smooth scars. Therefore, the shape of the protruding tissues adhering to the scar surface is the most secure feature indicative of the domestication status. We never observed the knee-shaped type of *dicoccoides* among *dicoccum* rachises. In general, combining all preserved features including measurements of internode thickness and scar orientation will lead to the most secure identifications.