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Ethnoarchaeology and archaeology of rainfed cultivation in arid to hyper-arid lands of North Africa

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Abstract

Rainfed cultivation in drylands, especially arid and hyper-arid lands, is often considered to play a minor role in human livelihood. Understanding the long-term development of this practice will augment knowledge of past land use strategies to inform models of land cover and climate change. Drawing upon the results of an ethnoarchaeological study, this paper presents a review of non-irrigated agricultural practices in the absence of anthropogenic water-harvesting structures, in arid and hyper-arid lands of North Africa. A proposal on how to identify the presence and extent of these practices in the past in world's drylands at large is ultimately presented.

Keywords

Rainfed cultivation, drylands, resilience, Sahara, Al Khiday

1. Introduction

Today, drylands cover some 40% of the world's land area and host roughly 40% of the world's population. According to the UNEP drylands are defined as tropical and temperate areas with an aridity index of less than 0.65, which includes UNCCD hyper-arid drylands



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or deserts, with an aridity index below 0.05 (Safariel & Adeel 2005:626). These areas are especially sensitive to climate change, shifts in precipitation patterns, and the increase in extreme climatic and meteorological events (Huang *et al.* 2017). Nonetheless, drylands have been inhabited for thousands of years and are today home to societies that display a wide array of adaptive behaviours. These behaviours, evidenced by traditional ecological knowledge, are key to the resilience of these communities. In this paper we present a review of rainfed agriculture in the absence of water harvesting structures in arid and hyper-arid lands of North Africa, a surprisingly common practice also in the Sahara, even though this practice is excluded from most maps of current and past land use. On the basis of our observations and the historical record, we argue that (i) this type of rainfed agriculture in arid and hyper-arid lands is an overlooked strategy and holds huge potential for designing effective strategies to cope with current climate-driven, desertification, and that (ii) rainfed cultivation without water harvesting techniques might have played a so far unrecognized role in the development of food production in arid areas, even where rainfall is normally considered too scarce for crop cultivation.

In the Old World, considerable research has been devoted to the study of the Origin of Agriculture, focusing especially on the Near East, the cradle of domestication, and crops such as wheat and barley that provide the foundation for many modern agricultural systems. However, it is clear that past human groups also experimented with a diverse assemblage of crops, some of which are well adapted to areas with water constraints (e.g. millets). Recent work by Winchell *et al.* (2018) has traced the domestication trajectories of African crops such as *Sorghum bicolor* (L.) Moench and *Pennisetum glaucum* (L.) R.Br. However, past cultivation practices related to these crops, including how water was managed, are still under study.

In this paper we first provide an overview of rainfed cultivation of cereals in arid and hyper-arid lands of North Africa (section 2), based upon the study of old reports and ethnographies from the 19th and 20th centuries. In the second part of the paper (section 3) we present the case study of Al Khiday, where a multidisciplinary pilot investigation on rainfed crops has been carried out in 2015-16. The case of Al Khiday has propelled the development of a larger research project (RAINDROPS), featuring an experimental methodology (section 4) aimed at the identification of crop water availability and management directly from archaeobotanical remains.



2. A review of rainfed cultivation in arid and hyper-arid lands of North Africa

In arid lands, irrigation, a permanent water source, or some forms of rainwater harvesting techniques are often deemed necessary for cultivation. However, there are modern examples that testify to the existence of successful rainfed cultivation systems, even under hyper-arid conditions. For the purposes of this paper, in respect to water availability, we use the following definitions:

- (a) Irrigated cultivation: water is provided to crops at regular intervals throughout the growing season by human intervention.
- (b) *Décrue* cultivation: water is provided by natural inundation, typically from major river systems (floodplain cultivation).
- (c) Rainfed cultivation: water is provided by rainfall alone (directly or as run-off) and cultivation occurs far from any permanent water sources (e.g. rivers, wells, lakes, cisterns, etc.) and without any water harvesting.

This last type of cultivation in arid and hyper-arid environments has received comparatively little attention as it is often considered a practice with a minor role in human livelihood. However, although the yield offered by this type of cultivation is lower in respect to irrigated or *décrue* cultivation, its benefits as an adaptive strategy in drylands can be extremely important. Indeed, rainfed crops such as millets and sorghum can offer a considerable contribution to a predominantly pastoral economy as they provide carbohydrates and a high percentage of daily protein and minerals (Gulia *et al.* 2007). Such crops are currently identified as “Future Smart Foods” (Li & Siddique 2018) offering better options for dealing with changing environments, especially the effects of climate change, and supplying affordable and sustainable dietary diversity.

Most of North Africa is occupied by the Sahara, often considered ‘inactive’ from an agricultural point of view (Rockström & Falkenmark 2015). Indeed, land use models and maps of North Africa normally characterize the Sahara and its margins as a huge empty area stretching from the northern edge of the Sahel up to the Mediterranean coast and the Atlas Mountains (Rockström & Falkenmark 2015). Similarly, current technical reports and studies on food production in drylands tend to regard the Sahara as devoid of cultivation (Portmann *et al.* 2010).

The perceived dominance of pastoralism, together with the idea that hot deserts are unsuitable for raising crops, seems to have eclipsed the role that cultivation has had over time. It is therefore not surprising that the extent of rainfed agriculture in the Sahara is poorly understood. Yet, notes published over the last two centuries suggest the occurrence



of this practice in different parts of this desert (fig. 1). In central Mauritania, in the Moudjeria area, where average rainfall is 170mm/y, rainfed crops were observed in the early 1960s and so-called pastoral communities were reportedly growing cereals without irrigation (Toupet 1963). In the Ahaggar Mountains, where rainfall varies between 0 and 100mm/y, millet (without further specification) was grown in the nineteenth century (Duveyrier 1864:372). Nicolaisens & Nicolaisens (1997:251) reported the existence of a specific word (“*tawgest*”) to designate non-irrigated plots of land cultivated by the Tuareg along the valleys of the Ahaggar. Similarly, in the Air massif, where average precipitation is 120mm/y, Rodd (1926:133) observed that rain-grown cereals could be grown most years. The engagement of nomadic Tuareg groups with rainfed cultivations is further confirmed by Nicolaisen & Nicolaisen (1997:250-251) who observed rainfed wheat and millet/sorghum fields in the Tassili n’Ajjjer in the early 1950s. This last report for cultivation is rather surprising given the very low (and mostly uneven) rainfall of this area, ranging between 0 and 40mm/y. Cultivation was also recorded in the Tadrart Acacus massif in the Libyan south-west (di Lernia *et al.* 2012), and around the city of Ghat (Bourbon del Monte di Santa Maria, 1912), where annual rainfall is less than 20mm. In the Tibesti range (SE Libya), close to the Guezendi area, rainfed cereal plots were observed in the 1940s in areas with less than 50mm/y of rainfall (Desio 1942). This clearly shows that cultivation of rainfed crops did complement pastoral and foraged resources in the Sahara.

3. The case study of Al Khiday

In 2015-2016 our team carried out ethnoarchaeological surveys in the area west of Al Khiday in Central Sudan (fig. 2), aimed at investigating the late prehistoric and historical landscape of the region as well as Traditional Ecological Knowledge (TEK) of current populations. The area today is arid (according to both the Koppen–Geigen and the CGIAR–CSI classifications, Zomer *et al.* 2007, 2008) with an aridity index of 0.0765, a yearly average rainfall of c. 100mm (concentrated in July, August and partially September) and widespread sandy aridisols. A part of this region is licensed to Donatella Usai who has been conducting archaeological investigations there since 2001 (Usai 2018 and references therein). In 2015, we noted a great number of regularly spaced, aligned rows of tufts c. 30km inland from the Nile River where no farms, no wells, and, obviously, no permanent rivers are present (fig. 3). The following year, more systematic fieldwork led to the



identification of several rainfed fields of pearl millet [*Pennisetum glaucum* (L.)R.Br.] between 15km and 30km west of the White Nile left bank.

Millets, and specifically pearl millet, are key crops in drylands because of their short growing season and the high productivity under aridity and high temperatures. They can also be used as fodder (both the entire plant before grains mature or the by-products from grain processing), and are therefore perfectly suited for mixed agro-pastoral systems. Pearl millet is a critical West Africa domesticate (D'Andrea & Casey 2002) and the Sahel zone south of the Sahara is an important area for its domestication (Winchell *et al.* 2018). Pearl millet is a very suitable rainfed crop for hyper-arid areas, well adapted to soil with low fertility and to high temperatures, and it is able to grow with as little as 40mm of water.

3.1 Desktop and field research

The analysis of time series imagery (GoogleEarth™) combined with rainfall data for the last twenty years has highlighted that 70mm of rain in July/August are enough to enable the cultivation of pearl millet over extremely large expanses of land (up to c. 120ha per field system, fig. 2).

Ethnographic interviews with local farmers revealed that the cultivated areas are divided into plots (fig. 3) owned by different families from neighbouring villages. After the late spring/early summer rains, the fields are prepared by clearing wild grasses (hoeing) while the soil is still wet. Farmers then walk the fields along parallel lines, making holes for seeds roughly every meter. The sown fields are then left unattended until the harvest in September when farmers use iron sickles to cut the plants just above the crown. Grains are then threshed in the fields and the by-products are left for the domestic stock to graze. No data are currently available for productivity of this type of rainfed agriculture in arid or hyper-arid lands and a first preliminary evaluation of the productivity of the Al Khiday fields (based on plant density and average single-plant seed production) gives a value of c. 0.1t of millet per hectare. These figures are clearly much lower than production from the world's dry sub-humid and semi-arid regions, where rainfed agriculture yields varies between 0.5 and 2t/ha (Rockström & Falkenmark 2015). In spite of the low yield, local farmers are able to produce twice the quantity of millet necessary for the families' annual needs, leaving part of the crop to be sold at local markets after having set aside enough grain for the next planting season.



What is surprising for the rainfed fields observed in Sudan is that, in wetter years (rainfall c. 100mm) a double cropping of millet and a cash crop such as hibiscus (*Hibiscus* sp.) is obtained.

3.2 Phytolith analysis: preliminary results of a pilot project

In 2015, we carried out a pilot project at Al Khiday (Sudan) to check for the presence and preservation of phytoliths in modern deposits supporting rainfed cultivation; and confirm the morphological ratios of phytoliths in respect to water availability as highlighted by previous studies (Jenkins et al., 2016). Two different field systems were sampled: (i) two small ephemeral fields (RFA15_02 and RFA15_04, Figure 2) that had been cultivated the previous year; and (ii) an abandoned field (RFA15_01, Figure 2b), which had been cultivated for over 10 years and then abandoned during the last 2-3 years. According to local informants, this field was mechanically ploughed but relied only on rain for water. Comparative samples were collected from inside and outside the furrows and holes used for planting (table 1). Phytoliths were extracted and analysed according to standard laboratory protocols in use at the Laboratory for Environmental Archaeology of the Universitat Pompeu Fabra (Lancelotti *et al.* 2017).

Phytoliths are present in all samples analysed (table 1), and the preservation is good (i.e., little or no evidence of chemical or mechanical damage, preservation of different morphotypes including the more fragile, high number of full bilobates, etc.). Concentration is generally low and seems dependent on intensity of use, as it is generally higher in RFA15_01 than in RFA15_02/04. However, the number of morphotypes identified is virtually the same in both case studies thus indicating good representativeness (Madella & Lancelotti 2012). Another interesting aspect is the relation between two of the main types recovered: bulliforms and trichomes. RFA15_02/04 has more bulliforms (average = 68) and less trichomes (average = 42) than RFA15_01 (fig. 4). These two morphotypes are considered indicative of environmental conditions in C4 grasses (Olsen *et al.* 2013). Specifically, plants grown in mesic (more humid conditions) tend to have more bulliforms and less trichomes than plant grown in xeric (drier) conditions. Our results suggest that the plants from the less intensely cultivated area and further from water sources (RFA15_02/04) grew in more mesic conditions (more water) than the ploughed field. This can be a result of the techniques used for working the soil in preparation for sowing. The intensive mechanical ploughing of RFA15_01 depleted the soil of moisture whereas the



soil of RFA15_02/04 preserved more humidity. These preliminary results encourage the pursuit of this line of research and confirm the viability of the methodology.

4. Exploring the past: a methodological proposal

The results of the pilot project reported in section 3.2 showed the potential of phytoliths as a proxy to study crop water management practices in drylands. However, the methodology needs to be further tested and improved in order to obtain significant results. Following is a proposal on how to further the research on this topic.

4.1 State of the art

Research on African past crops, and especially for the drier areas, is still very limited. During the early and mid-Holocene (10-5.000 BC) patchy savannah-like vegetation supported small communities of hunter-gatherers that were exploiting a range of wild millet-type grasses (Fuller 2003), including attempts at opportunistic cultivation without domestication (Mercuri et al. 2018). These populations adopted livestock rather early, and certainly by 6000–5000 BC (Marshall & Hildebrand 2002; Fuller 2005). The shift from the more humid ‘Green Sahara’ to the present-day conditions occurred by the end of the Middle Holocene (Gasse 2000), and it is generally marked by relevant socio-economic transformations (Kuper & Kröpelin 2006). After 3500 BC, when the environmental conditions became drier, some of the nomadic pastoral groups seem to have taken up cultivation in selected locations in the Sahara (Cremaschi & Zerboni 2009). Yet, the role that rainfed agriculture might have had in such a critical transition has not been explored and very few data are available on the first agricultural experiments in the Sahara. Past studies have also emphasized the adoption of more drought-tolerant livestock, such as dromedary and goats, in parallel with the progressive abandonment of cattle (Clarke *et al.* 2016).

Research on rainfed practices in the Sahara, and an understanding of their chronological depth, is urgently needed in order to address the role of cultivation in the resilience of human societies in unfavourable climatic settings. Notwithstanding the importance that rainfed agriculture could have had in the Sahara and North Africa during the Late Holocene, it has only occasionally been part of the current discourse on the strategies of human adaptation. This is likely due to the objective difficulties in detecting direct evidence of rainfed cultivation in the archaeological record. On the one hand, identification



of ancient fields is extremely difficult even using techniques such as geoarchaeology or molecular footprints (Motuzaitė-Matuzevičiūtė *et al.* 2016) and is usually inferred from the presence of related technology (e.g. the plough, terracing, etc.). On the other hand, the different levels of water management are also problematic to discern and currently there are few proxies able to clearly identify and differentiate such practices. Determining water availability directly from archaeobotanical material offers a possible solution to this issue. Previous efforts to address past water management practices explored charred macrobotanical remains (see review in Jenkins *et al.* 2016), analysis of weed assemblages and isotopic studies of $\delta^{13}\text{C}$, which all demonstrated good potential for C3 crops (i.e. trees, legumes and winter cereals) (Styring *et al.* 2016). However, approaches exclusively based on charred remains can be problematic in drylands, where they are often poorly preserved. The alternative use of plant microfossils, such as phytoliths, has consequently been explored (Madella *et al.* 2009; Jenkins *et al.* 2016). Phytoliths are silica bodies produced in plant tissues and, being inorganic, their preservation is ubiquitous and their presence much less affected by pre- and post-depositional issues (Piperno 2006). Morphology – through indices based on morphotypes proportions (Madella *et al.* 2009; Jenkins *et al.* 2016) – and isotopic analyses (McClaran & Umlauf 2000; Webb & Longstaffe 2003; Hodson 2016) have been explored to identify different water regimes from archaeobotanical samples.

4.2 RAINDROPS: an innovative approach

RAINDROPS aims at developing an innovative and reliable methodology for the identification of crop water availability and management from archaeobotanical remains. Highly controlled data on phytolith ratios, and carbon, oxygen and silicon isotopes from macro- and micro-remains from experimental fields are being validated with ethnographic evidence before being applied to selected key archaeological case studies in Africa and Asia.

Crops grown in experimental fields at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), under constantly controlled conditions, form the basis of genotypic variation in phytolith production and isotopic fractionation for sorghum, finger millet and pearl millet landraces. To further strengthen the comparison between the experimental isotopic data and archaeological samples, the effect of charring on isotopic ratios is also being assessed.

Phytoliths concentration and ratios between genetically *vs.* environmentally controlled morphotypes analysed from the plants grown experimentally are being tested to confirm



that the observed correlation with plant water availability identified in C3 plants holds true for C4 species. At the same time, oxygen and silicon isotopes are assessed for their potential as proxies for crop water availability and soil conditions. Pilot projects have anticipated the possible inroads of such an approach and have laid a strong foundation for the analysis of these two stable isotopes in phytoliths (Chapligin *et al.* 2011). These studies indicate that the degree of silica ^{18}O enrichment in leaves can be related to transpiration water loss and relative humidity (Webb & Longstaffe 2003) and that silicon isotopes are sensitive to environmental conditions and changes (Opfergelt *et al.* 2006; Ding *et al.* 2008; Leng *et al.* 2009).

4.2.2 Ethnographic data and Traditional Ecological Knowledge

The same set of analyses is being performed on crops grown locally with traditional methods (no chemical fertilizers and/or pesticides) in three study-areas (Sudan, Ethiopia and Pakistan) through collaborations with local farmers. At the same time, structured and unstructured interviews are conducted with a number of farmers (according to established ethnographic protocols) to specifically assess water management practices, as well as to collect Traditional Ecological Knowledge (TEK) on cultivation systems. These interviews target quantifiable data on cultivation methods (tilling, weeding, manuring, ploughing methods, etc.) as well as information on decision-making related to where and when cultivation is carried out and how these processes are affected by climate variability. The three case studies were selected because of their geographical and environmental locations, representing biophysical hotspots areas in Asia and Africa, for their significance in the long-term human adaptation to drylands, as well as for the presence of preliminary results (such as the case of Al Khiday, with the ethnoarchaeological work presented in this paper). Furthermore, each site is located in one of the three ecological areas that broadly define the concept of drylands (UNEP 1997): arid to hyper-arid (Al Khiday, Sudan), dry sub-humid (Mezber, Ethiopia) and semi-arid (Harappa, Pakistan), thereby covering the geo-climatic variability of drylands. Water management practices at these three sites have been hypothesised on the basis of geographic features, economy and degree of social organisation, but no test for these hypotheses has ever been provided. All the sites are archaeologically well studied, there is much palaeoenvironmental and palaeoclimatic information and they have a long sequence of occupation, which will allow for the study of long-term dynamics (Terwillinger *et al.* 2011; Giosan *et al.* 2012; D'Andrea *et al.* 2015; Williams *et al.* 2015; Iacumin *et al.* 2016). Lastly, all sites are located in areas where



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traditional agriculture is still practiced, and where a rich source of TEK still exists, which RAINDROPS is both recording and utilising as part of its data analysis.

5. Concluding remarks

Desertification has been internationally recognised as one of the main challenges of sustainable development, and in 1994 the United Nation Convention to Combat Desertification (UNCCD) was created. One of the aims of UNCCD is to put science, technology and traditional knowledge at the forefront in dealing with desertification. In this perspective, environmental archaeology and ethnoarchaeology can play a fundamental role in understanding the dynamics of long-term strategies of adaptation and resilience in drylands. Archaeologically, considerable research has been devoted to the study of the origin of agriculture, focusing especially on the Near East, the cradle of domestication- and crops such as wheat and barley that provide the foundation for modern agricultural systems in the Old World. However, it is clear that past human groups also experimented with a diverse assemblage of crops, some of which are well adapted to areas with water constraints (e.g. millets). Such crops constitute today one of the most important sources for future biodiverse and sustainable agriculture in many parts of the world. Furthermore, drylands agriculture is becoming utterly relevant in development studies due to the impact of desertification on food security for a great part of the human population. The current work in Sudan is highlighting the importance of rainfed cultivation in drylands and our approach will provide the research community with an innovative and reliable methodology to understand past water management practices for C4 crops. This will extend the chronology of TEK in key low-precipitation areas, contributing long-term data to explore resilience and to ameliorate model building for future policies.

Ethic statement

Fieldwork in Al Khiday has been conducted in the area licensed to Donatella Usai of the Center for Sudanese and Sub-Saharan Studies. The licence includes permits for exporting sediments for analysis for which clearance have been obtained also by the National Corporation for Antiquities and Museums in Khartoum. Oral consent has been obtained from the people interviewed during ethnoarchaeological surveys. No personal or sensitive



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data have been collected during, or stored after, these interviews. Universitat Pompeu Fabra health and safety measures have been followed during both field and laboratory work.

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Figures and tables

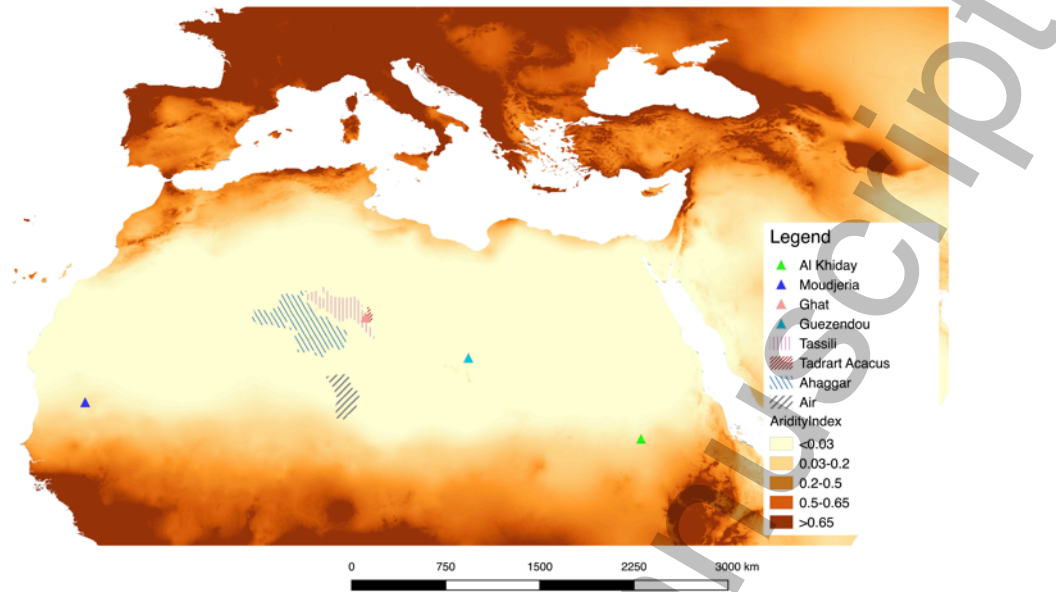


Fig. 1: CGIAR-CSI Aridity index and the localities mentioned in the text. The Aridity Index takes into account the values of precipitation, temperature, and/or potential evapotranspiration. The cases of rainfed agriculture in the Sahara so far mentioned fall within the ‘hyper-arid’ (Ghat, Guezendou, Tassili, Tadrart Acacus), or ‘arid’ (Al Khiday, Moudjeria, and Air) class, well beyond the threshold for the supposed suitability of rainfed agriculture.

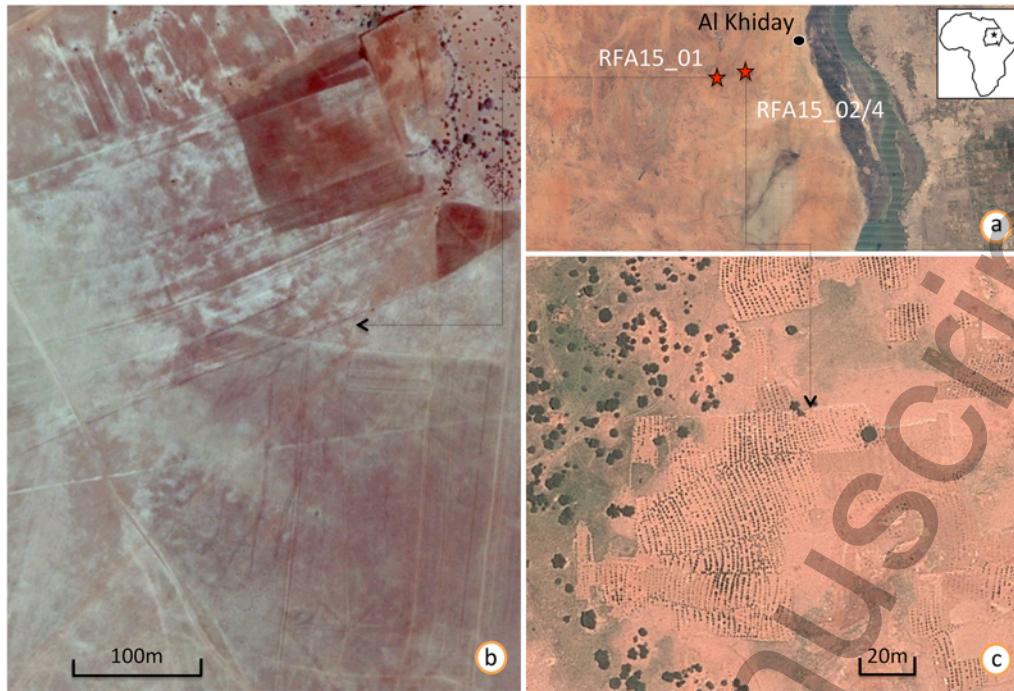


Fig. 2: GoogleEarth view of RFA15_01 and RFA15_02/04. (a) the study area; (b) RFA15_01, imagery taken in November 2014, plough marks are clearly visible; (c) RFA15_02/04, imagery taken in September 2012 plots of cultivated lands; crops growing form a pattern of coarsely-parallel, vertical lines, clearly bounded by uncultivated land (one of the fields boundaries is indicated by the arrow).

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Fig. 3: View of recently harvested fields in the Al Khiday area in December 2016. The upper picture shows a general view, where the margins of the fields are clearly marked in straight lines by the wild grass cover. The lower picture shows a recently harvested plot where the tufts of millets are still visible in regular rows.

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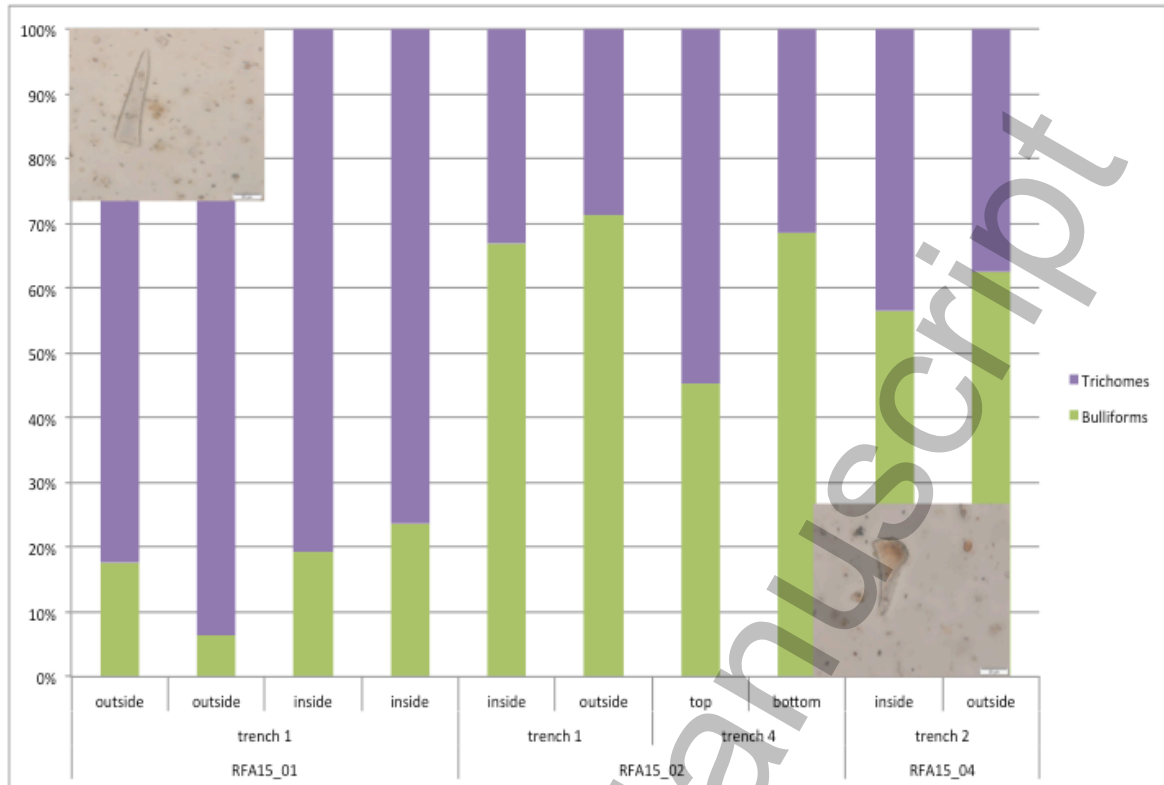


Fig. 4: Phytolith analysis. Proportions of bulliforms (lower left photograph) and trichomes (upper right photograph) identified at the three sampling locations.

Table 1. Phytolith data. Summary results of the phytolith analysis performed at the three sampling locations.



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Field	Trench	Sample	Concentration g(AIF)	Morphotypes (n)	Bulliforms	Trichomes	Ratio bull:tric
RFA	trench 1	outside	32,427	13	20	93	0.22
15_0 1		outside	79,389	14	5	74	0.07
		inside	177,932	12	14	59	0.24
		inside	150,907	19	18	58	0.31
RFA	trench 1	inside	593	19	109	54	2.02
15_0 2		outside	459	18	84	34	2.47
	trench 4	top	507	12	44	53	0.83
		bottom	1,399	12	39	18	2.17
RFA	trench 2	inside	253	12	78	60	1.30
15_0 4		outside	1,576	17	55	33	1.67