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Cereal Silo-pits, Agro-pastoral Practices and Social Organisation in 19th Century Algeria

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Abstract
Quantifiable, spatially-resolved, large-scale evidence about traditional food storage facilities is extremely rare, and yet highly insightful for researchers across subjects such as human ecology, anthropology, agronomy, archaeology and economic history. This paper takes advantage of some unusually detailed French colonial era records of cereal storage and agro-pastoral practice in 19th century central Algeria that inventory the underground food stores of different sedentary and nomadic tribes at a moment of colonial confrontation in which these stores were central to ecological and political resilience. We consider how different aspects of these food stores relate to environmental, social and economic variables across the study area. The overall results suggest important north-south trends in agro-pastoral lifestyle and storage practice.

Keywords Agriculture · Food storage · *Matmora* · Toponyms · Colonialism · multi-level Regression · Algeria

Introduction

Food storage is a key factor behind the survival and prosperity of human communities. Relative success or failure in food-keeping has links to population growth or decline, urban concentration or dispersal, coevolutionary relationships among plants, animals and humans, changing gender and labour roles, and patterns of social inequality or the structure of the political economy, to name but a few domains of enquiry. It is no surprise, then, that food storage is a core research agenda across subjects such as human ecology, anthropology, agronomy, archaeology and economic history (indicatively across huge, overlapping literatures: Sigaut, 1978; McCloskey & Nash, 1984; Binford, 1990; Divale, 1999; Kunz, 2004; Delaigue et al., 2011; Douny, 2014; Bruni, 2017; Deffressigne et al., 2017; Peña-Chocarro et al. 2017; Bevan, 2018; Prats et al., 2020).

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However, the majority of ethnographic and historical studies of traditional storage practices have been small-scale and qualitative, even if often very insightful. Similarly, while there has already been plenty of quantitative treatment of historical trends in harvest sizes or food prices, formal analysis of historical storage strategies is by contrast extremely rare. This paper therefore expands upon existing approaches by taking advantage of some very detailed French colonial era records from 19th century central Algeria that do, unusually, support more complex, exploratory assessment. It considers records of traditional subterranean cereal storage that span different sedentary and nomadic Algerian communities, during a period in which these food stores were central to ecological resilience and political resilience.

We motivate and organise the study via two main research questions: (1) What is the scale and geographical distribution of cereal storage practice represented in the surviving archive? And (2) to what degree can variation in cereal silo frequencies across the study area be explained by major known social, economic and environmental variables? We also look to understand: (a) possible capacity differences in the counted silos (albeit with some enduring uncertainty over these capacities), (b) changes from one year to the next (albeit with a surviving sample of just two years) and (c) variation in the local landscape setting of silo sites (albeit from semi-quantitative toponym and descriptive

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data). Furthermore, the paper considers the central Algerian 19th century case not only on its own terms but also with a view to promoting a better understanding of the extremely widespread use of similar subterranean storage facilities elsewhere, in both the recent historical and remote archaeological past. An accompanying archive provides access to the transcribed raw data and enables the analytical results to be reproduced.

Research Context

Geography and Politics

This paper focuses on the Medea region in central Algeria, across which there is considerable variation in landscape and lifestyle from north to south (Fig. 1a; see also Urbain 1843: 398; Federman and Aucapitaine 1867a: 113–114). The North Tell includes a more mountainous, wooded extension of the Atlas, located south of the capital of Algiers (the latter with about 49,000 inhabitants in 1853, of which 30,000 Pellissier de Reynaud, 1854: 391–392) and the fertile Mitidja plain where early French colonisation was heaviest.

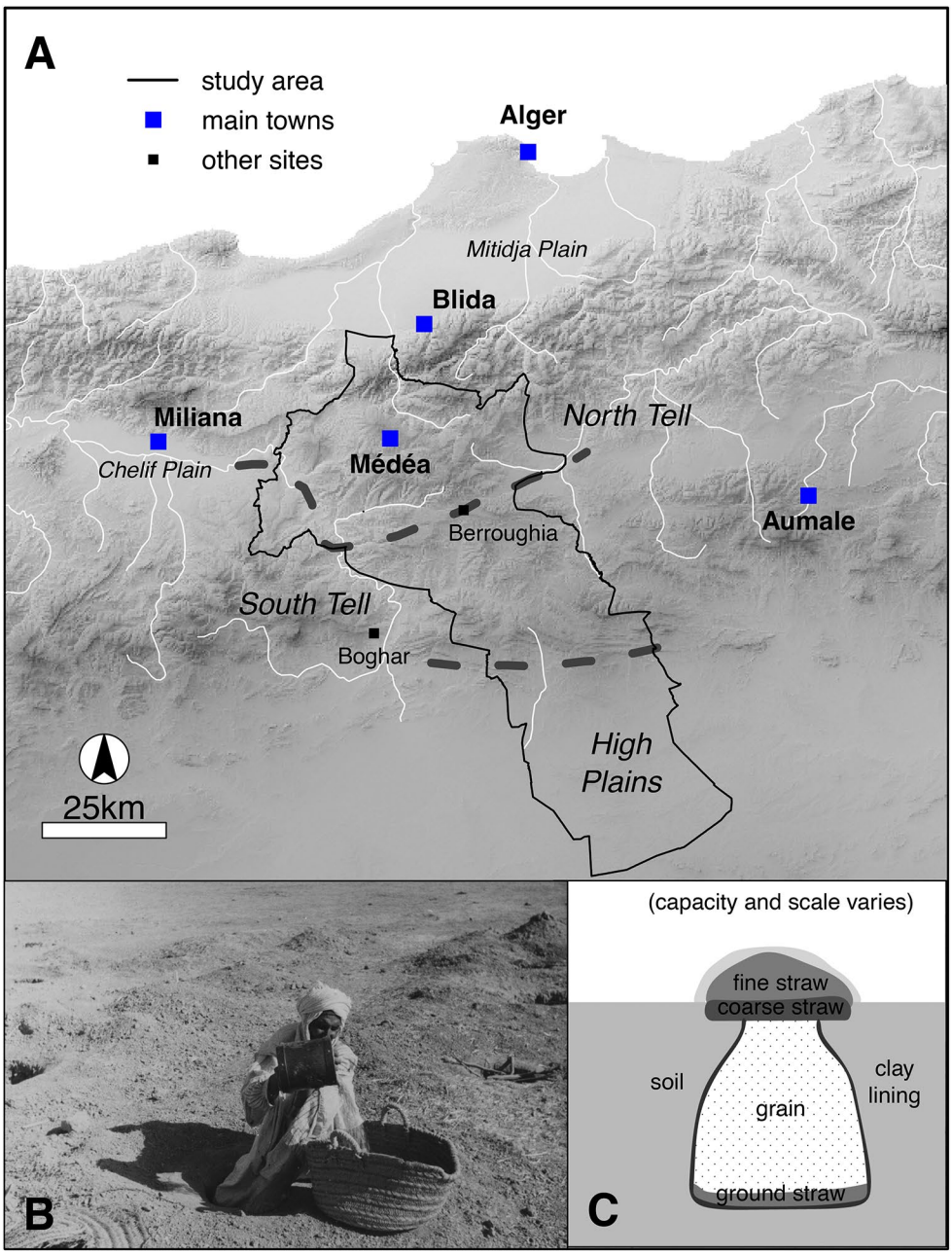

Fig. 1 (a) Study area (elevation range is 0-2000 mASL light to dark). (b) A silo-pit being emptied in the Aurès in 1936. Note the use of a standardised grain measure and a grain-carrying basket, the presence of another open pit, to the right covered by sticks, and further small mounds covering other pits. The depicted environment is some 250 km south-east of the study area and generally more arid (Fonds Thérèse Rivière PP0157001, copyright Musée du Quai Branly - Jacques Chirac), (c) a narrow-necked storage pit (from Chlef 150 km west of study area, redrawn from Holz, 1978)

The Northern Tell itself however had only a few incipient colonial communities around the town of Medea (6,750 inhabitants of which 1,200 European) and was inhabited by people who were often Berber and Tamazight-speaking rather than of Arab background and language. In the 1850s, these Berber communities and their Arab neighbours built loose clusters of small adobe or stone huts and either dwelt there year-round or switched to tents in the summer to move around for different agricultural tasks. Individual tribal fractions typically comprised a few hundred people exploiting fixed territories a few kilometers across, and these groups typically focused on a mixed economy of wheat and barley agriculture, gardens, orchards, small herds of cattle, sheep and goat, and sometimes small-scale industries such as oil, soap or iron (for a similar pattern further west, Yacono, 1953: 45–47).

By contrast to the North Tell, the South Tell offered a more open, less rugged landscape that encouraged a combination of small holdings, agricultural estates and larger-scale livestock-keeping such as horse-breeding. This area was mainly exploited by Arab speakers who lived in a mixture of tents and small huts and practiced short range summer-winter migrations within what were still largely fixed fraction-level territories. It was also an area with significant involvement in inter-regional exchange, and as a result, it was home to tribes given added administrative duties as cavalry, police and tax collectors (the Douaïr and Abid tribes as *makhzen*, see Emerit, 1966).

A final sub-area of the Medea region is the High Plains further still to the south, where the landscape is far more arid and flat, historically offering only limited opportunities for agriculture where wadis channelled available moisture. The local communities here in the 19th century were primarily nomadic pastoralists, focusing on sheep and camel-herding, with less clear-cut territories and much larger seasonal ranges.

These three portions of the Medea region have long interacted with one another in important ways and, more broadly, the whole area lies on one of the most important routes of long-range African exchange, linking from north to south, the Mediterranean coast, the above-described graded landscapes of the North Tell, South Tell and High Plains, the deeper Sahara with its mixture of desert tribes and oasis communities, and finally beyond that, complex trading partners in sub-Saharan west Africa (Holsinger, 1980). In particular, Saharan groups (that wintered much further south beyond the study area) migrated northwards every summer to the Tell and stayed from perhaps July to September or October so that they might exchange dates, sheep, leather and woollen goods for large quantities of recently-harvested cereals (Bernard & Lacroix, 1906: 82–96; Yacono, 1953: 41–45). Both the Tell and Saharan communities then often traded these items onward, further north or south.

Politically, the Medea region coincides roughly with the earlier Ottoman province of Titteri. After the French conquest of Algiers in 1830, this became a contested region up until the end of the Abd al-Qadir insurgency in 1842, after which it became a French provincial sub-division under overall control from Algiers (McDougall, 2017: 9–48). This paper focuses on a period in the mid-1850s when considerable military action was taking place further south in the Sahara, but during which the Medea region was comparatively quiet (Pellissier de Reynaud, 1854: 311–530). Significantly, the documents considered below provide a snapshot of traditional Algerian storage practice before it was transformed by the major upheavals of the 1860-1880 s, prior to substantial legal changes in settlement organisation and tribal property rights (e.g. *cantonnement* or the 1863 *senatus consulte*: Yacono, 1953: 149–170; Sainte-Marie, 2019: 9–92), before the main upswing in foreign grain exports and disastrous famines of 1866–1868 (Sari, 1982: 182–183) and prior to any meaningful efforts to supress the traditional silo strategies in favour of above-ground alternatives (Nouschi 2013: 499–509). Stepping back, grain stores were themselves highly political features, both practically underpinning and highly symbolic of tribal independence, power and resilience. It is unsurprising, then, that they became an obsession of French colonial imperialism (e.g. De Tocqueville, 1962 [1841]: 226), whether as indigenous places to pillage or as resources to document in minute bureaucratic detail.

Agriculture and Storage

Cereal storage was part of a wider agricultural regime that can be described with reference both to general evidence from the Maghreb, and to surviving insights directly from central Algeria (for what follows, see Fillias 1865: 80–82; Boyer-Banse, 1902: 93–117; Yacono, 1953: 53–60; Chellig, 1959; Bourdieu & Sayad, 1964; Despois, 1964; Camps-Fabrer 1997; Budin, 2017: 54). The two dominant traditional crops in much of the Maghreb were durum wheat (*Triticum durum*) and barley (*Hordeum vulgare*, often six-row hulled), although other species were also farmed and there were many different local land races (Miège, 1950; Erroux, 1991; Garrigues-Cresswell, 1998; Rahal-Bouziane, 2015). Durum wheat was a higher value staple for producing couscous and flat breads, while barley was better-adapted to drier conditions and was eaten both by people and livestock. Bread wheat (*Triticum aestivum*) was by contrast closely associated with the agriculture of recently-immigrant French colonists, in fertile zones along the coasts, as well as with the consumption of European-style leavened breads. Bread

wheat and durum wheat usually fetched similar prices, and were 2–3 times more expensive than barley by volume (e.g. ANOM GGA F80 472,473).

The cereal cultivation and mixed agro-pastoral strategies favoured by colonial-era North Africans have often been contrasted with the more technologically elaborate techniques favoured by incoming French colonists, with respect to crop rotation, harvesting tools, foddering regimes, plough types and storage methods, to name but a few (e.g. Rivière and Lecq 1900). However, such contemporary claims for French agricultural superiority should be considered critically, as they were often used to justify the project of colonial domination itself. In fact, in many ways, traditional Algerian farming and livestock management was well-adapted to local circumstances, where risks were high and significant capital for agricultural investments was hard to come by. Under traditional dry-farming regimes (focusing on the subset of Maghreb practices most relevant in the study area), fields were typically cleared of brush, often by burning, and then broadcast with seed in October or November after the first rains, after which both seed and soil were then lightly turned over with a simple wooden plough, over a period of about a month or two. A farmer might use the same plot for several years before rotating it into fallow. In more arid areas (such as the High Plains in the study area), wadis were often prioritised as these channelled available moisture and could be further enhanced with small cross-channel terraces/dams. The resulting crop was typically harvested with a toothed iron sickle and fistfuls of cereal ears were then tied together and taken by donkey or mule to a nearby threshing floor. Barley was harvested earlier than wheat in the Medea region (usually a June harvest and July threshing, versus usual a July harvest and August threshing for wheat: ANOM GGA F80 472,473). Threshing was conducted via animal treading (with cattle, mules or horses) and the results were then lightly winnowed by repeated shovelling into the air. It is this processed, but not fully ground, cereal product that was then stored.

Livestock were rarely if ever stabled over the winter, so arrangements for grazing and foddering were also different from European practice. For example, in contrast to a contemporary French preference for harvesting low on the stalk, each cereal plant was usually harvested between one third and half-way down from the ear in the Maghreb, leaving behind long cereal stems that could be grazed by livestock in the field. The use of scythes to harvest cereals and/or hay lower to the ground was something French colonial administrators tried to introduce from the late 1850s onwards to produce more of the kinds of substantial low-cut straw fodder and hay-bails common in contemporary Europe, but with limited success until much later (ANOM GGA 50II 267). Instead, a combination of three traditional foddering strategies were common: giving animals the smaller quantities of chopped-up straw produced by traditional threshing, grazing them on the left-behind cereal stalks in the field, and/or diverting stored barley grain as animal rather than human feed. Once the grain was processed, it was dried in the sun and put into storage by September or October, either very short-term before early sale, medium-term either as food for the year or next season's seed, or as longer-term 'carry-over' for multiple years as insurance against inevitable crop failures. Further post-storage processing of the crop was almost always necessary before it could be made into food (e.g. grinding cereals with a small rotary quern and/or the production of couscous). Human labour was mostly organised within the family and then pooled among those from the same tribal fraction at sowing and harvest time, with an important distinction existing between freeholders (one or more collaborating families with prevailing rights on arable land of varying extent) and sharecroppers, who were poorer and/or young adults that worked the land of freeholders in exchange for seed, tools, accommodation, sometimes food, and about a fifth of the resulting harvest (*fellah* and *khammès* respectively: Rectenwald, 1912; Yacono, 1953; Chellig, 1959).

The Maghreb presents a mix of very fertile and very challenging environments in which to produce and keep food, and it is unsurprising that storage facilities have long fascinated those studying both its deep and more recent history. The Moroccan *agadir* is by far the most famous of these storage structures, both in academic and popular imagination: an upland community's hilltop fortress protecting large numbers of family-scale cells for keeping grain and other goods (e.g. Montagne, 1930; Jacques-Meunié, 1951; Delaigue et al., 2011). Loosely analogous examples of fortified, nucleated, cellular above-ground stores also come from the Algerian Aurès and southern Tunisia (Faublée-Urbain, 1951; Louis 1979), while further diversity in storage facilities can be seen in interesting traditions such as the small raised post-granaries of the Morrocan Rif, or widespread use of semi-sunken structures, dedicated rooms in houses, large alfa-grass baskets, or mud-covered in-house containers (Camps & Vignet-Zunz, 1998; Peyron & Vignet-Zunz, 1999; Couranjou 2002).

Even so, the most common lowland storage tradition across all of pre-modern Tunisia, Algeria and Morocco was undoubtedly the subterranean silo-pit (Fig. 1b-c, Arabic sing. *maṭmûra*, Tamazight sing. *tsraft* or *muḍmar*: Valensi, 1977: 191–192; Louis 1979; Lefébure, 1985; Rosenburg 1985; Bartali, 1987). Similar underground grain storage pits have been found in a huge variety of agricultural contexts worldwide and provided sealed, anaerobic environments in which an initial reaction with the residual air prompts an outer layer of the grain to ferment into an external crust that

then protects the remainder of the cache from further temperature change, bacteria and insects (Sigaut, 1978, 1988). Such pits were less expensive to make and maintain than the alternative of building a large above-ground, heavily-ventilated store, and they also offered additional protection against fires (that were common in above-ground grain stores) and theft and indeed tax collectors (as they could be wholly hidden). They also have very deep pre-Arab history in the region, mentioned at least as far back as the 1st century BCE by Roman writers (Fantar, 2007), but likely part of a patchily-understood, prehistoric tradition of agriculture in the region.

The size range for rural, tribal subterranean silo-pits across much of 19th-early 20th Maghreb was typically 400-3500 L (with a still larger upper threshold for those documented in the later 20th century; see Villot, 1888: 335; Rovart, 1902; Holtz 1978; Vignet Zunz, 1979; Lefébure, 1985; Bartali, 1987). These were therefore human-scale features, often 50 cm at their narrowest and 1-2 m deep, that one person could often fit inside and dig, sometimes with one helper nearby. Well-made rural silo-pits of this kind could keep a single stock of grain for at least several years, and sometimes decades, without obvious increased spoilage. They were also highly reusable, and with proper maintenance (fumigation by burning, then relining) might last up to several generations. In the Medea region, rejuvenation and repair of such pits was a task scheduled alongside the early part of the harvest (June-July), so that all grain could be in silo by late September or October before the new rains (ANOM GGA F80 472). The base and sides of such silo-pits were typically covered in straw and fine clay, while the narrow necks were stoppered with layers of coarser straw and clay. Silo-pits might be found singly or in smaller numbers within or next to houses (particularly for sedentary peoples), or in larger groups, close to fields, garden plots, threshing floors, villages, large estates, winter-camps or assembly-places. Such geographically-concentrated groups of silo-pits were known as *retba* in Arabic in Algeria (*mars* in Morocco) or *aswir* in Tamzight and might prompt the creation of a whole series of indicative placenames (e.g. El Matmora). Year-round guards were often given responsibility for particular silo-pit groups, for remembering or labelling who owned the contents, and for constructing new pits at these locations when needed (Sainte-Marie, 1985; although itinerant pit-making specialists were also known: Lefébure, 1985: 217). Beyond the main 400-3500 L size range, even smaller provisional pits were occasionally used, while at the other end of the scale, there were also much larger subterranean silos both in the Maghreb and other parts of the Mediterranean (Triantafyllidou-Baladie, 1979; Valls et al., 2015), typically associated with major port sites and inland towns used by major merchants and/or by the government for stockpiling cereals (e.g. examples ~ 60,000 L in capacity were noted by European travellers in 18th century Touati, 2019).

Data and Methods

In what follows, and as noted above, we have two main aims in terms of exploratory data analysis: (a) to characterise the scale and geographical distribution of storage practice represented in the archive, and (b) to assess the extent to which variation in major known social, economic and environmental variables explains variation in silo counts across the study area. Further analytical goals include understanding (c) possible capacity differences in the counted silos, (d) changes from one year to the next (albeit with a surviving sample of just two years) and (e) variation in the geographic character of silo site locations from north to south (via the formulaic descriptions that French administrators used to identify such sites on the ground).

Basic Terminology

While terms such as 'tribe' and 'fraction' are in common ethnographic and historical use worldwide, they are nonetheless worth clarifying. According to the French colonial records, an indigenous Algerian was expected in almost all cases to belong both to a single tribe (French *tribu*, Arabic *qabila*, Tamazight *taqbilt*) and a single tribal sub-unit known as a fraction (French *fraction*, Arabic *fakhd*, Tamazight various terms including *ettebel*, *beṭṭu gar teqbilin*, *beṭṭu gar leɛrac*). In many cases, Algerian tribe and fraction names existed long before the French conquest and were identities that local communities used self-consciously. Most such groupings were justified via oral traditions about shared geographical origins or genealogies, while a few were simply acknowledged to be historically recent and fairly convenient amalgamations. A range of privileges and obligations were officially imposed by the Ottoman and French administrations at the level of the whole tribe, such as particular taxes or military contributions. In contrast, the fraction was often seen as the more important decision-making unit, for example with regard to seasonal agro-pastoral strategies and migrations. Despite the deeper tradition however, most of the details we have today about tribal names, origin stories and territories come from the writings of French administrators, so it is difficult to be certain about where the latter might have deliberately or inadvertently shaped them, even in the early years after conquest and prior to more obvious attempts at reorganisation. Cutting across such tribal groupings were also other affiliations of language, ethnicity, religion, geography, caste and class, and within such large groupings were also important structures such as the

family household or tentful. However, 'tribe' and 'fraction' were made especially hard-edged labels by French emphasis on censuses and property definitions. They were thereafter also a clear part of the apparatus of tribal *cantonnement* and should therefore be used cautiously. A related problem exists with terms such as 'Arab', 'Berber' or 'indigenous' that were also categories used quite aggressively and with hard edges by the colonial bureaucracy. For example, the label 'indigène' was often meant in a derogatory way, and in any case is potentially confusing, because not all Algerian peoples considered themselves native to Algeria, with the Tamazight-speaking groups typically making a stronger case than Arabic speakers based on suggested arrival times in the region. So, all five terms — tribe, fraction, Arab, Berber and indigenous — are used sparingly in the discussion that follows, and typically only where the narrow colonial administrative semantics seem appropriate. Looser terms such as 'community', 'people', etc. are favoured for more general reference.

Main Sources

The main historical documents used below were the product of a 19th and early 20th century 'statistical fever', associated with European imperial conquest and resource appropriation worldwide (Etemad 2007: 99–118), and should be approached with an eye for particular biases and agendas. The specific records used here date to the mid 1850s, a couple of decades after the French conquest, and reflect the work of the local *Bureau Arabe* of Medea. The evidence used in this paper comes exclusively from the archive taken to Aix-en-Provence in 1960 at independence (part of the Archives Nationales d'Outre-Mer, hereafter ANOM), and it remains possible that further evidence might exist in the Algiers or Medea wilaya archives in Algeria itself (although documents from the mid-19th century are rarer in such archives, see Kudo et al., 2004). Census-taking was a key function of the *Bureaux Arabes*, with a view both to demographic profiling of local communities and inventorying of their economic resources, in many cases with the explicit goal of enabling further colonisation and unchallenged control (Yacono, 1953). These sources are further described below:

Silo Registers for 1853-54

A first key physical document (ANOM GGA 50II 240) preserves two registers of tribal grain silos for consecutive years, organised by local toponym, by tribal fraction and by overall tribe. The two lists were finalised after the harvest, on 30 September 1853 and 31 October 1854 respectively, and hand-written copies were sent to the Division headquarters at Algiers. Each one offers a near-complete coverage of some 22,000 silos each year in the Medea region, belonging to about 25 tribes and their 100 or so tribal fractions.[1] As noted above, the 1850s were years of comparative quiet in this particular part of Algeria, despite significant military expeditions further south, and the years 1851–1856 saw an uninterrupted series of relatively productive cereal harvests.

Human Population, Production and Livestock Censuses

Three further documents provide census data for Medea tribes including not only counts of total human population, but also of quantities for different livestock, dwelling forms, cultivated land and economic production. The first is from 1854 (ANOM GGA F80 542) and provides tribe-level information only. The other two are from 1855 to 1856 and form part of the first systematic census effort in French Algeria (ANOM GGA 50II 272, 283; see also Kateb, 2014), which in Medea region was conducted first for certain Northern Tell tribes (documenting the harvest for 1855 where grain production is mentioned) and then extended to a more southerly portion of the region the following year (documenting the harvest for 1856).

Other Relevant Documentary Sources

Additional context is offered by a later, a further fraction-level census from 1872 (ANOM GGA 01II 277) that needs to be treated cautiously given substantial socio-economic change in the interim. A smaller list of silo sites was made in 1884 for nomadic tribes at the southern end of the study area, accompanied by a rare map of the actual silo site locations and estimates of the amount of wheat and barley per site (Sainte-Marie, 1985; ANOM GGA 71i 16–17). Urbain's discussion (1843) of tribes in the region is a further important point of departure and other authors offer specific insights and statistics. We have used a combination of contemporary maps (Carette & Warnier, 1846; Dubois 1852; Sainte-Marie, 1985), recognisable toponyms in the silo registers and further archival descriptions to locate individual tribes and fractions approximately in geographic space. Tribes based in the Northern Tell were more sedentary and often some

[1] Three tribes on the northern edge of the study area that were recorded in 1853 were omitted from the 1854 list, while two tribes from the southern desert fringe were added. It appears that the first such efforts at silo registration occurred the year before, in 1852 (ANOM GGA 50II 13/1027), but no surviving record has yet been found and it seems unlikely to exist in the documents now kept at the ANOM. There is passing mention in the wider sources to other registers from the neighbouring Boghar and Laghouat administrative regions to the south (ANOM GGA 50II 15/784; GGA 1II 77/487), and a very partial later example from Boghar survives for 1884 (Sainte-Marie, 1985), but the two lists considered here are the fullest surviving evidence of this kind to our knowledge.

suggestion of the location of individual fraction territories is possible, whereas tribes in the High Plains were considerably more mobile and overlapping in their activities.

Environmental Data

In the absence of fine-grained weather and environmental data contemporary with the silo registers, we have instead used more modern datasets to offer simple maps of rainfall and calcareous soils (see Table 1 below for further details).

Multi-Level Regression

The silo registers document information about storage in three clear ascending organisational levels: the silo-site, the tribal fraction and the tribe. Our aim is to explain the silo count via a number of explanatory variables. In statistics, this is a regression problem. The most common model for a counts response variable is a Poisson regression, but initial modelling suggests that the basic Poisson model assumption is not fulfilled (that variances equal means as implied by the Poisson distribution). So we have also considered a negative binominal model instead. Furthermore, in order to model the dependence between observations that belong the same tribe, and within a tribe the dependence between observations that belong to the same fraction, we fit a multilevel-model (aka a 'mixed effect' or 'hierarchical' regression model, Gelman & Hill, 2006; Finch et al., 2014) with a random effect corresponding to tribe and another one for fraction within each tribe. Both exploratory models and the final negative binomial model are reproducible in full via the code archive (including an ordinary unscaled Poisson model, check for over-dispersion and comparison with quasi-Poisson following Ver Hoef & Boveng, 2007).

The lowest documented level describes an aggregate of individual silo-pits found geographically-clustered together at one place in the landscape (hereafter "silo-site" or "silo-group"). Overall, a silo-site was typically used by just one tribal fraction, although some sites were shared across fractions and there are limited observable instances in which families or individuals used a pit at a site in a wholly different tribe's territory (e.g. as a result of travel for sharecropping, trade, seasonal labour). The contents of each individual silo-pit usually belonged to just one person or family. Methodologically, if the exact geographical locations of each silo-site were known (or each individual silo-pit or each within it), then the data might best suit treatment as a point distribution via an inhomogeneous point process model (Baddeley et al., 2015). However, apart from some brief toponymic descriptions treated separately below, we have neither this accurate georeferencing nor any covariate information at the level of each silo-site. Nor is there systematic surviving evidence for the individual family households (housefuls or tentfuls), in terms of the number of silo-pits they used, their level of wealth, etc. So both the lowest documented level of record – the silo-site – and a further important lurking level of decision-making – the family household – remain hard to analyse directly. In contrast, the registers consistently subdivide their listings of silo-site counts by tribal fraction and we also have some information about the location of the fraction territory (in cases where this is fairly fixed), its human population size, economic resources, etc. Sometimes information about population or resources is only available at the coarser tribal level (e.g. where summaries of agricultural output are only know per tribe or where a nomadic tribe does not have obvious fixed territories at fraction level).

As noted above, the careful organisation of the registers and the messier reality behind them suggests that analysis of the evidence might be best conducted via multi-level regression. This approach improves on the estimation of basic regression model parameters in a situations where observations cannot be treated as wholly independent of one another (silo-site counts per location depend in part on nested relationships per fraction and per tribe), where certain explanatory information is only available at coarser scale (e.g. by tribe rather than by fraction) and/or where the substantive causal role of each level is of interest (e.g. the relative importance of tribes or fractions in decision-making). We also consider more briefly varying silo clustering per fraction and observable changes in the pattern from 1853 to 1854.

A potentially very wide range of political, social, economic and environmental information might be relevant as covariates for explaining variation in the observed silo data. Out of a more extensive set of possibilities that were initially explored, Table 1 summarises and justifies a final choice of both response variables and covariates.

Results

General

For the two favourable years of 1853 and 1854 where we also have detailed silo surveys, a range of sources suggest that ~65–70,000 ha of arable land was being cultivated in the study area to produce overall cereal harvests of 35–45 million litres each year, roughly half wheat and half barley. In each of these years, ~25 local tribes stored their harvest in ~22,000 individual silo-pits at ~500 distinct sites. If you made the simplifying assumption, for a moment, that all of the threshed harvest went at least temporarily into storage locally somewhere, then it implies a mean silo capacity of

Table 1 A summary of regression model set-up (for further clarity on the treatment of these variables please refer to the data and code archive where both the verbatim original text and all subsequent programmatic transformations of it are provided)

	Justification	Source
Response variable		
SiloCount	The frequency of silos in a given year at a given location in the landscape. This includes positive integers only, but it was not deemed necessary to model zero-truncation explicitly.	ANOM GGA 50II 240
Covariates (all are rescaled [0,1] prior to modelling)		
TotalPop	Estimated total population per fraction in 1853/1854. This slightly adjusts the fraction totals given in the 1855-56 census by the total count for each tribe in 1854. Where 1855-56 census date is unavailable populations have been estimated from various sources. This variable has been log-transformed before rescaling between 0 and 1.	ANOM GGA 50II 272, 283;various
Makhzen	A binary variable indicating if the tribe was considered to be makhzen or not. Makhzen tribes that were given privileges in exchange for performing tax collection and mounted military duties during the Ottoman and early French colonial period (Emerit, 1966), and who hence might have a different approach to storage.	Urbain, 1844; Tableaux 1845; Emerit, 1966
Marabout	A binary variable indicating if the fraction was considered to have links to local holy men and hence religious roles in the wider tribe. Religious associations sometimes possessed silos that provided charitable reserves for the whole tribe (Richardot, 1935: 39–43).	Urbain, 1844; Tableaux 1845
Berber	A binary variable indicating if the tribe was considered to be culturally and linguistically Berber (rather than Arab). Further east in the Kabylie at least, Berber tribes placed more emphasis on above-ground and in-house storage rather than silo-pits (Varlet, 1900: 58).	Urbain, 1844; Tableaux 1845
HaCultPP	A measure of the amount of cultivated, arable land per person in the fraction. The amount of arable land is assumed to be closely associated with the amount of stored cereal. Records declared to be under crop for tax purposes in *zouidja* (the amount of land that two-animal plough team could work over the course of the autumn sowing season) have been converted at ~10ha/*zouidja* in line with contemporary administrators' rule of thumb. This variable has been log-transformed before rescaling between 0 and 1.	ANOM GGA 50II 272, 283; GGA 50II 14/578;GGA 50II 270/32
WealthPP	A composite measure of the amount of wealth per person in the fraction. Varying wealth may impact on storage strategies, especially with regard to degree of investment in carryover or market speculation. For each fraction, approximate average prices have been used to weight the sum of agricultural land (assuming a yearly revenue 50 francs/ha), livestock (camel 150, horse/mule/donkey 100, cattle 30, sheep/goat 5) and other products (olive oil 1 franc/L, tobacco 0.5 francs/kg, fruit trees 5 francs each). Revenue from salt collection, charcoal production, stone masonry, rope-making, beekeeping etc. were also of modest importance but not easily calculated so omitted. The 1855-56 censuses are used wherever available and otherwise the 1872 census. This variable has been log-transformed before rescaling between 0 and 1.	ANOM GGA 50II 272, 283; Nouschi 2013
LivestockPP	A measure of overall livestock investment per capita in the fraction. This is created by summing large-bodied livestock and then adding smaller-bodied livestock at 0.2 (following Nouschi 2013: 316). The 1855-56 censuses are used wherever available and otherwise the 1872 census. Investment in camels and sheep rather than other livestock is a good proxy for tribes practicing fuller nomadic pastoralism who may adopt different foddering and food storage practices. Animal body size weighting and source treatment as for WealthPP. This variable has been log-transformed before rescaling between 0 and 1.	ANOM GGA 50II 272, 283
TentProp	The proportion of tents to more substantial built dwellings in the fraction. This can be used as a proxy for the impermanence of dwelling construction, as expressed via the proportion of tents out of all dwelling types (see also Yacono, 1953: 48). Source treatment as above.	ANOM GGA 50II 272, 283
SaharaMarkets	An index of accessibility to known encampments in the Tell where migrating Saharan tribes bought grain and paid the associated *heussa* tax each year. Modelled as an average exponential decay from all markets, with a halving distance of ~4.5 km (chosen to maximise univariate correlation with SiloCount). This variable has been log-transformed before rescaling between 0 and 1.	ANOM GGA 50II 13, 16; Federman and Aucapitaine 1865, 1867b; Bernard & Lacroix, 1906: 91
WeeklyMarkets	Accessibility to known locations in the main towns, where there were routine, weekly transactions in a variety of goods including grain. This variable has been log-transformed before rescaling between 0 and 1.	Urbain 1843; ANOM GGA 50II 267, 270
AnnPrec	Mean annual rainfall from 30 arc-second interpolation of 1970–2000 weather station data (values for each fraction are the same within tribes).	Fick & Hijmans, 2017
CalcThick	Calcareous soils often allow for better quality, larger silo-pits (Lefébure, 1985: 217). This variable is calculated as the proportion of land that has calcareous soils per tribal territory (values for each fraction are the same within tribes).	Durand, 1954
Grouping Levels		
Fraction	Lower level. Naming variation between documents has been harmonised via a FractionID. Fractions belong within only one larger tribe.	ANOM GGA 50II 240, 272, 283

Table 1 (continued)

	Justification	Source
Tribe	Higher level. Naming variation between documents has been harmonised via a TribeID.	ANOM GGA 50II 240, 272, 283

1600-1800 L which is in the middle of the known size range in the Maghreb.[2] Given a tribal population of 33,500 people, this level of cereal production was 4–5 times a nutritional minimum per person per year (~250 L per person per year according to Clark and Haswell 1970: 1–59), but of course there were plenty of reasons to produce far more than that theoretical subsistence threshold. As much as 10% of the grain harvest was used to pay tax, increasingly after being converted into cash via market sales, but historically with some stored in large complexes at three major provincial centres (Medea, Berrougia and Boghar: Urbain 1843: 410; Federman and Aucapitaine 1867b: 216–218). Central stores were then used to support government bureaucracy, military policing or expeditions and loans to favoured parties. Perhaps a further 20% of the original harvest had to be kept back as seed corn for the next year. Additional quantities were routinely 'carried over' in storage for multiple years as a buffer, with a commonplace assumption being the need for enough carry-over to buffer the expectation of four bad harvests for every good one (Chellig, 1959: 11). Furthermore, not all tribes or families were self-sufficient in cereals or equally wealthy, and all of them bought necessities at local markets, where several million litres of grain circulated each year in exchange for livestock, clothing, wool, leather, butter and oil (ANOM GGA 50II 266/118; Varlet, 1900: 62). Monthly average grain prices for 1853 and 1854 (see also Nouschi 2013: 237–238 for comparable assessment further west) show lower seasonal volatility for barley compared to durum wheat, and a higher, more stable price for both in Medea versus regions further south (in francs, Medea wheat 18.0 ± 1.93, barley 7.13 ± 1.43, Boghar wheat 13.1 ± 3.0, barley 4.52 ± 1.37, mean and standard deviation from 24 months of data in 1853–1854 recorded in ANOM GGA F80/472, 473). Larger local towns such as Medea (about 6,750 inhabitants in 1853, and for the figures that follow: Pellissier de Reynaud, 1854: 391–392), Blida (8,300), Boghar (1000) and, to the east and west, Miliana (4,300) and Aumale (4000) all provided further modest cereal-consuming centres (Fig. 1). Far more importantly, however, it can be estimated that perhaps 5–10 million litres of grain from the local region's harvest were annually exchanged with Saharan nomadic tribes who travelled long distances to camp in the southern Tell, expressly for the purpose of acquiring cereals that they could not produce themselves, and who then sometimes traded grain onwards to others hundreds of kilometres further south (Urbain 1843: 434; Federman and Aucapitaine 1867b: 211–212; Holsinger, 1980). Finally, further exports went north to Algiers (about

[2] The computational details for these overall calculations are provided in the article's data archive. Information about arable extent and total annual production comes both from assessments of the *achour* grain tax (ANOM GGA 50II 270/32; GGA F80 472) and from separate summaries of the annual autumn harvests (ANOM GGA 50II 266, 267, 270). These two kinds of source are distinct but mutually informative. The *achour* tax assessment is more challenging because its base unit – the *zouidja* in Arabic or *charrue* in French -- is not a measure of area but rather of how much land a farmer and two animals could plough over the course of the autumn sowing season (about a month). This unit was convenient to assess in the absence of fine-scale cadastral mapping. The actual tax was then calculated via a final multiplier based on the quality of the harvest (very good, good, moderate, poor, negligible: ANOM ANOM GGA 1II 75/145), and was increasingly paid in money over the course of French rule (Van Vollenhoven, 1903: 123–126). Across the Maghreb, the *zouidja* and equivalent terms can refer to arable areas of 5-20 ha depending on both terrain and whether fallow land was included or excluded (Despois, 1964: 155; Budin, 2017), but the Medea documents suggest administrators were using a rule-of-thumb average of 10 ha to each *zouidja* in the 1850s. For the amount of grain sales at local markets, a detailed summary in 1858 of five of the seven main weekly markets in the study area summarises annual transactions involving 1 million L of wheat and 0.87 million L of barley (ANOM GGA 50II 267/179), but we should expect considerable additional sales at the two largest markets of Medea and Berrougia excluded from that list. Estimating the outflow of grain south is difficult, but useful earlier context is provided by mention for the period 1813–1830 of caravans as large as 10–15,000 camels (each potentially carrying 150-200 kg of grain for a longer journey, although some carrying people and other belongings) and revenues of 50–100,000 francs deriving from a grain-purchasing tax (*heussa*) that was annually fixed at levels ranging from 1.8 to 5.4 fr/camel-load (Urbain 1843: 434–442; Marey 1846: 54–58; Carbuccia, 1853; Federman and Aucapitaine 1867a: 293–311, 1867b: 211–212). More direct and contemporary evidence for 1850–1855 suggests the three main tribal confederacies involved in grain purchases were the Ouled Naïl, Larbaa and Beni Mzab, and that they were each paying 25,000–45,000 francs in *heussa* tax annually (rates unknown, but conceivably within the above-stated earlier range of 1.8–5.4 fr/camel-load; ANOM GGA 1II 76/1853.209, 1855.207; GGA 50II 16/663–667). The total human population from a tribal-scale census of 1854 (ANOM GGA F80 542) and from partial fraction-scale census from 1855 to 1856 (~60% coverage, ANOM GGA 50II 272, 283). The figure for the typical number of 22,000 silos is based on a full 1853 count and a reconstructed (interpolating for three missing 1854 tribes based on the percentage change from 1853 in the rest of the dataset): ANOM GGA 50II 240). Although small amounts of grain were also sometimes stored in other ways for immediate use, the vast majority of the tribes employed underground storage pits, and the silo survey makers state explicitly those rare examples where bulk in-house storage was practiced by highly sedentary tribes instead (given the Tamazight-speaking connections of the particular tribes, perhaps mud-covered baskets, in-house cupboards of leather containers were used as visible in the Kabylie further east: ANOM GGA 50II 271/271–272; Varlet, 1900: 58; Couranjou 2002).

49,000 inhabitants in 1853) and then to Europe, a trend that goes back to the 18th century, but sees a renewed uptick with the demands of the 1853–1856 Crimean War, the 1870-71 Franco-Prussian War and increasingly for Algerian barley from European brewers (Villot, 1888: 386; Sari, 1982: 182–183; Merouche, 2007).

Silo Counts

Turning to the silo counts in more detail, Fig. 2a-b map this information for 1853, first with each silo site shown separately and then as a per capita measure for each tribal fraction. The pattern at a glance seems to be that silo-pits, whilst still the dominant strategy, existed in lower overall densities per capita and fewer pits per site in the North Tell (mean 0.2 silos per capita, mean 18.6 and maximum 95 silos at any given site), while they clustered in larger numbers in the South Tell (mean 1.0 silos per capita, mean 62.6 and maximum 320 silos at any given site) and part of the High Plains (maximum 580 silos at one site, but with smaller silo sites in some examples further south beyond the area mapped here). A similar pattern is present for 1854 (see supplementary materials).

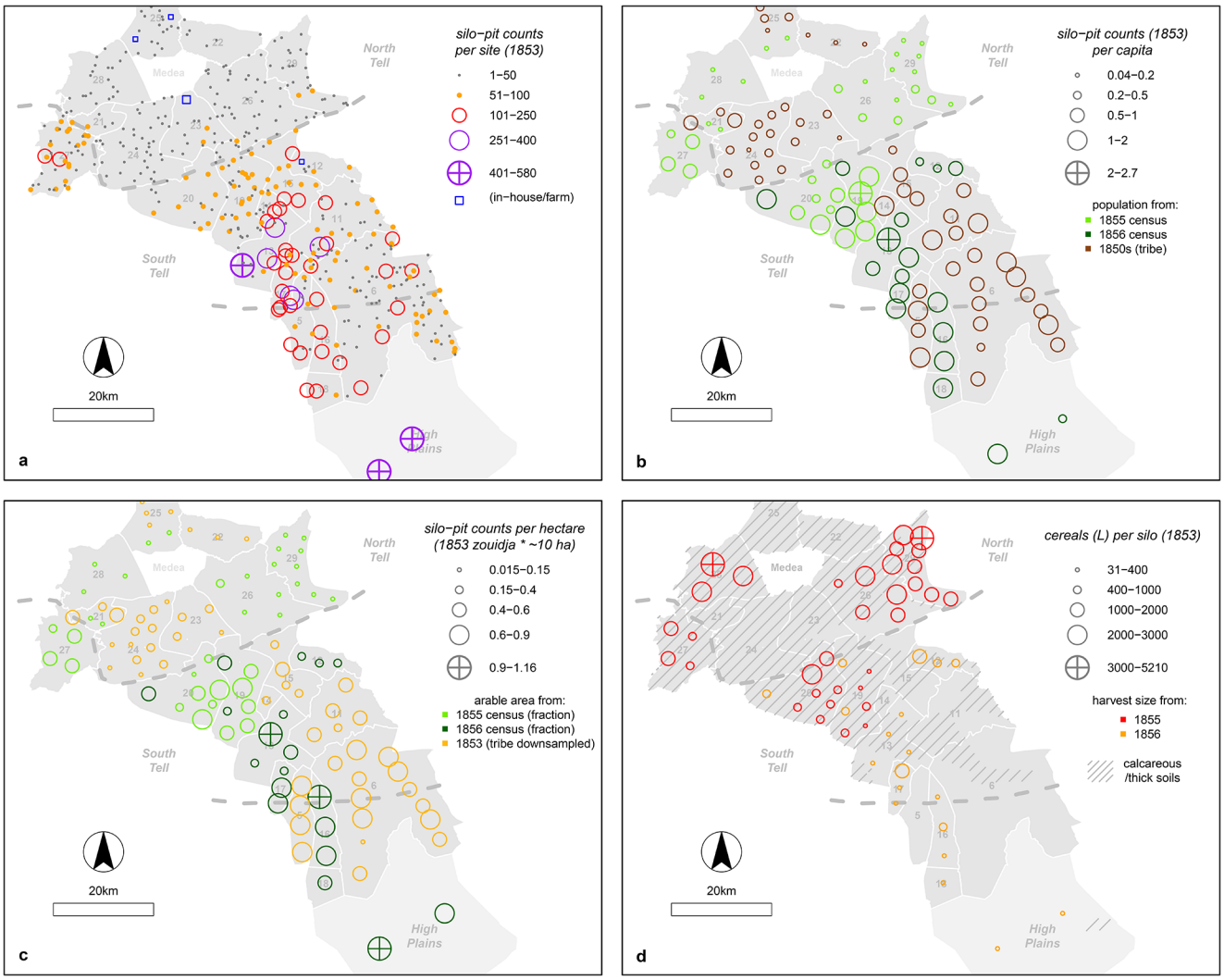

Fig. 2 The spatial distribution of silo-pits in 1853 and comparisons with contemporary cereal production in the study area: (a) silo-pit counts per silo-site (symbols for each silo-site have been placed at random within the fraction or tribal territory), (b) the number of silo-pits per capita in each tribal fraction, (c) the number of silo-pits per hectare of officially-declared agricultural land pre-harvest (original units are converted from *zouidja*), and (d) the amount of officially-declared cereal harvest per silo-pit (N.B. combining different agricultural years). Approximate 1850s tribal territories shown in white outline with grey IDs as follows: *East Chelif*: 27 Gherib; *North Tell*: 21 Hannacha, 22 Ouzera, 23 Haouara, 24 Righa, 25 Mouzaïa, 26 Hassen Ben Ali,, 28 Ouamri, 29 Beni Bou Yacoub; *South Tell*: 5 Titteri, 6 Ouled Allan, 11 Rebaïa, 12 Ouled Sidi Ahmed ben Youssef, 13 Douaïr, 14 Ouled Hedim, 15 Ouled Deïd, 16 Souari, 17 Ouled Maaref, 18 Deimat, 19 Abid, 20 Beni Hassen; *High Plains*: 7 Ouled Mokhtar, 8 Mouïdat (9 Sahari Ouled Brahim and 10 Ouled Sidi Aïssa el Adab are present in the 1854 silo register, but off map to the south, and without sufficient covariate information to make them analytically useful)

Table 2 Summarises the covariate relationships and it is worth noting that a few of them are fairly highly correlated, due to a shared north-south structure behind the precipitation, soils and markets variables and related interactions with livestock types and overall wealth. These correlations are interesting general socio-economic patterns in their own right, but excluding them as variables does not lead to different conclusions, so all variables have been retained for the preferred regression model presented here in the main text. Similarly, while the supplementary material offers wider exploration of alternative families of regression, in Table 3 we prioritise the results of a multi-level negative binomial regression applied to the total silo count per fraction for 1853 and using the covariates listed in Table 1. The AnnPrec, LivestockPP, WealthPP and TentProp variables all suggest a significant prevailing role for a well-known north-south climate and culture gradient, (higher silo counts per capita correlate with lower precipitation, greater emphasis on livestock wealth and higher residential mobility. Other variables seem less relevant. If we consider the slightly smaller sample from 1854 then the results are similar (Supplementary Materials, note in passing a count of 825 silos for one location in 1854 that is the largest count in either census, and thus is either an unusual event or conceivably a typographical error)

Silo Sizes

One extremely important kind of direct information that is missing from the 1853 and 1854 silo censuses is any mention of the actual quantity of cereal stored per silo-pit, and by 1855 the Algiers divisional military command was asking for this as an additional column in the administrative registers (ANOM GGA 50II 16/667), even if relevant later examples with this data unfortunately do not survive in the ANOM archive in Aix-en-Provence to our knowledge (apart from one partial example from 1884, see below). Without such information, raw silo counts remain hard to interpret. As noted above, the general size range for rural, tribal silo-pits across the Maghreb was typically 400-3500 L, although much larger silos were also built to house the taxes and export grain held at major ports and large towns. More locally in the study area, a series of 1852–1860 judicial records about cereal thefts are helpful and, where it is clear that a single pit was involved, the stated capacities range from 500 to 1600 L (ANOM GGA 54II 4/2158; GGA 50II 271/244–246, 269–271,273,275; GGA 54II 6/1856.72,122; ANOM GGA 54II 1/366).[3]

[3] The original measures are in *sâa* and, for conversion, this has been assumed to be the metric-aligned version equivalent to 200 L that was instituted at Medea for taxes purposes since 1849. However,

Table 2 Pearson correlations among the regression covariates (r > |0.5| is shown in bold)

		1	2	3	4	5	6	7	8	9	10	11	12
1	TotalPop												
2	Makhzen	0.051											
3	Marabout	0.079	-0.016										
4	Berber	-0.273	-0.234	-0.124									
5	HaCultPP	-0.205	0.273	-0.181	0.074								
6	WealthPP	0.075	0.177	-0.088	-0.109	0.159							
7	LivestockPP	-0.203	0.209	-0.098	0.086	0.182	**0.513**						
8	Camel SheepProp	0.135	0.109	0.024	**-0.516**	-0.084	**0.626**	0.132					
9	TentProp	0.231	0.15	0.147	**-0.565**	-0.228	0.496	0.163	**0.703**				
10	Sahara Markets	-0.02	0.382	0.094	-0.476	0.006	0.434	-0.027	**0.733**	**0.707**			
11	Weekly Markets	0.102	0.138	-0.128	0.223	0.349	-0.212	-0.013	-0.498	**-0.564**	-0.386		
12	AnnPrec	-0.048	-0.15	-0.137	**0.567**	0.24	-0.411	0.058	**-0.757**	**-0.84**	**-0.808**	**0.653**	
13	CalcThick	-0.124	0.151	-0.104	0.39	0.27	-0.252	0.136	**-0.776**	**-0.618**	**-0.623**	**0.616**	**0.748**

Table 3 Results from a negative binomial, multi-level regression on 1853 silo count response variable (see Table 1 for further set-up, 491 observations [silo locations], 113 fraction levels, 23 tribe levels)

	Estimate	Std.Error	*p*
(Intercept)	5.001	0.603	0
TotalPop	0.069	0.287	0.81
Makhzen	0.171	0.37	0.643
Marabout	0.114	0.118	0.333
Berber	0.153	0.196	0.435
HaCultPP	-0.415	0.439	0.345
WealthPP	1.203	0.44	0.006
LivestockPP	-1.433	0.532	0.007
CamelSheepProp	-0.549	0.434	0.206
TentProp	1.126	0.565	0.046
SaharaMarkets	0.257	0.426	0.546
WeeklyMarkets	0.071	0.347	0.837
AnnPrec	-2.123	0.813	0.009
CalcThick	0.189	0.473	0.69

It is possible to consider this issue further by looking at agricultural intensity. Figure 2c compares silo-pit counts to officially-declared arable land under crop per tribe in 1853, *for tax assessment before the harvest*, and suggests many more silo-pits in the south compared to land under crop. Figure 2d complements this picture by comparing the amount of cereals declared, *for tax adjustment after the harvest*. The latter data is more problematic because it mixes silo-pit counts from 1853 and harvest sizes from 1855 to 56 (the only data available), but again it suggests considerable north-south variation. One possible explanation in both cases is that (a) silo-pits were larger on average in the north, so fewer of them were needed per household. For example, the values of 2000-3000 L per silo-pit for many fractions in the north in Fig. 2d match well the upper end of the typical 19th century Maghreb rural range of 400-3500 L (see above). Local soil conditions may play a part here as the calcareous soils in the north could support construction of larger silo-pits, whereas the soils further south were adequate for pit-making but not as ideal. Furthermore, we have one very partial silo census for three nomadic High Plains tribes in 1884 (ANOM GGA 71I 1–20; Sainte-Marie, 1985) that does add the amounts of stored cereals next to its register of silo counts, and here the mean capacities indicate typical small-sized silos at these southern sites of 722-962 L.

So we are left without exact estimates, but with the imprecise impression that Medea tribal silo-pit sizes fit comfortably within the 400-3500 L range typical elsewhere, but that there is a likely size gradient form larger in the north to smaller in the south. However, in contrast to the north, in the south the small amount of locally-produced cereals in Fig. 2c-d in no way justifies the large number of local silos whatever their size. So two further possible explanations are that (b) southern tribes purchased additional cereals on the market for their own needs, and/or additionally (c) they were buying and stockpiling extra grain locally in order to trade further south with nomadic groups. We come back to these three explanations in the discussion below.

Silo Clustering and Annual Change

Silo-sites to the south of the study area are clearly more nucleated (aka concentrated), with many pits at fewer sites, a pattern also known amongst communities much further south still, in the Sahara. Some of this greater concentration may be offset by possible smaller sizes of silo-pits further south. In other words, to some degree concentrations of grain were achieved by bigger pits in the north and by more numerous pits in the south, but above and beyond that, the concentrations in the south remain striking. Concentrating storage brought certain benefits in terms of protection, organisation and access, but also brought certain risks (e.g. sites that were potentially easier to find and more catastrophic if successfully pillaged) and logistical costs (potentially the need to bring processed cereals further from field to store). Turning to the evidence provided by comparing the 1853 and 1854 silo registers, we see a very similar modelled set of relationships. While there is not that much overall change in total pit counts across the study area from 1853 to 1854 (-4.8%), there is considerable local variation not only across different tribal fractions (an average 61.6% absolute change per fraction, up or down) but also at those individual silo-sites that can be reliably matched up in both registers. There is one uniquely-extreme case of a location with 825 silos in the South Tell in 1854 that either matches a location with only 115 in 1853 or is entirely new (as noted above, it is possible but not certain that this site is a recording error). By contrast, there were also seven more clearly labelled new silo-sites in 1854 ("nouvel emplacement") which each has only small numbers of pits (7–15). Indeed, we might expect such variability in how intensively a given silo-site was used from year to year, based on the success or failure of family or fractional cropping choices, differing amounts of carryover of old grain, shifting locations to match fallow field rotations and changing choices about economic speculation. No major spatial pattern is visible in the changes from 1853 to 1854, apart from slight spatial autocorrelation in the increase/decrease of silo-pits (among those more northerly tribes where we can assess this reliably because of their clearer fixed territories, Moran's I, $p = 0.04$, see Supplementary Material) that may relate to micro-climatic impacts on harvests. Even so, without any opportunity for

considerable local variation in this measure, from 128 to 200 L, continued to exist at local markets (Federman and Aucapitaine 1867a: 118 n.2).

more longitudinal temporal comparison over multiple years it is hard to interpret this evidence further.

Silo Locations

One further source of information in the silo registers comes from the association of each group of silos with a local placename and from the addition of a very short description of each locality. Previous studies have demonstrated that Algerian toponyms are a considerable historical resource, but have so far been largely interested in country-wide toponym distributions or the historical layering of Berber, Arabic and French colonial influences (e.g. Pellegrin, 1952; Atoui, 1996; Margouma, 2004; Benramdane, 2005; Yermèche, 2018), rather than a functionally-specific micro-study such as this one. It would be potentially very insightful to identify (on the ground) and georeference every placename in the silo surveys, but without substantial consultation and fieldwork, it is hard to know how feasible such a goal might even be. Instead, here, we simply focus on what the placenames and description keywords can offer. For example, the *Bureau Arabe* administrators responsible for conducting and compiling the 1853 silo register also provided short descriptions of the immediate environs around each silo group, often by looking systematically north, south, east and west. The goal seems to have been to allow reidentification of each site on the ground if necessary, in the absence of precise mapping.

Table 4 follows up by offering a thematic comparison of the relative prevalence of different landmarks and further elucidate some strong differences, in terms of both natural landscapes and built structures, between the North and South Tell (with yet further differences also existing in the High Plains further south but not tabulated given the small sample size). The North Tell was dominated by silo-sites located close to adobe/stone huts, agricultural installations (e.g. sufficiently-elaborated threshing floors to be worth naming explicitly) and fruit trees. In contrast, the silo-sites South Tell (and High Plains) are more regularly given descriptions that refer to nearby pathways and wells, as well as natural features such as mountains and rocky outcrops. In many ways, these patterns simply mirror wider differences in landscape and lifestyle in different parts of the study area. However, this demonstrable structuring of nearby landmarks remains interesting, and a useful further insight is that cereal stores of the South Tell and High Plains often lay close to routes of communication and/or on features such as escarpments that afforded them a degree of protection.

Discussion

The decades that immediately followed the period of study here were dramatic. First, there were substantial legal changes to settlement organisation and tribal rights in the late 1850 and 1860 s in favour of fixed concentrated settlement and more clearly alienable private property (see above; Yacono, 1953: 149–170; Sainte-Marie, 2019: 9–92). Second, a ramping-up of cereal exports and erosion of

Table 4 A contingency table of keywords from the 1853 silo register's description of the immediate environs around each site (along with the site toponym itself where informative). the sorting is by pearson residuals, so that the top-most rows are more associated with the north tell and the bottom-most rows with the south tell

Group	Keywords	North Tell	South Tell	Total	% North	Resid
Inhabited Places: Houses and Gourbis	*gourbi, gourbis, maison, dechera, bit, bordj*	129	20	149	86.6	6.31
Orchards and Vines	*amandier, figuier, lemonnier, grenadier, terebinthe, caroubier, olivier, vigne*	34	2	36	94.4	3.77
Other Trees	*chêne, peuplier, tremble, orme*	38	9	47	80.9	2.99
Hay and Threshing	*noueder, paille, grange*	17	1	18	94.4	2.67
Hagionyms/ Holy Places	*marabout, sidi, kadi, mosquée, cimetière*	46	20	66	69.7	2.26
Markets and Assembly Places	*marché, djema*	8	5	13	61.5	0.59
Political and Honorific Titles	*Agha, Caïd, Cheikh, Chaouch*	6	4	10	60	0.45
Inhabited Places: Estates and Larger Farms	*haouch, ferme, beylik*	13	17	30	43.3	-0.52
Other Features	*ruines, cave, terres, matmora, kherba, bordj*	2	9	11	18.2	-1.49
Wells, Fountains, Cisterns, Small Dams	*puits, citerne, fontaine, bir, sed*	4	15	19	21.1	-1.78
Plains and Prairies	*plaine, prairie, plateau, debdeb, daiyra, merdja*	4	16	20	20	-1.9
Natural Hydrology	*rivière, ruisseau, ravine, source, aïn, nahr, chabet, oued, kheneg, fawar, fiadh, hania*	104	148	252	41.3	-1.96
Routeways	*chemin, route, faïdja, firdjen, regba, teniet*	21	44	65	32.3	-2.02
Small Hills and Outcrops	*mamelon, rocher, coudiet*	61	100	161	37.9	-2.17
Inhabited Places: Winter Village	*mechta*	9	30	39	23.1	-2.38
Escarpments, Mountains, Plateaux	*escarpement, montagne, plateau, kef, dera/draa, kala*	16	72	88	18.2	-4.22
Total		**512**	**512**	**1024**		

traditional tribal resilience were factors, alongside severe drought, locusts and ongoing insurgency, in the disastrous famines of 1866–1868, which led to a loss of up 25% of the local tribal population in some areas of Algeria (Yacono, 1953: 289; Sari, 1982; Taithe, 2010). In the aftermath of the famine, there were also increasing efforts to build and control larger silos, often constructed with cement and above ground (e.g. via the *Sociétés Indigènes de Prévoyance* from 1893 onwards: Yacono, 1953: 106–107; Nouschi 2013 [1963]: 499–509), and this marks the beginnings of the disappearance of traditional underground silo forms, even if they did survive in certain areas until much later. By the early 20th century, huge above-ground 'dock-silos', indirectly perhaps modelled on well-known US grain elevators, had become important, often photographed, examples of colonial agricultural infrastructure in Algeria (Musset, 1924). There were also increasing attempts to control and concentrate the seasonal northward migrations of Saharan tribes (Bernard & Lacroix, 1906). So, as noted in the introduction, the evidence considered in this paper come from an unusual moment for which there is both sufficient documentation of tribal storage practices to facilitate quantitative analysis, and sufficient survival of traditional practices before they were wholly transformed. We would also argue that this is also an unusual situation worldwide which gives the current study broader relevance.

Returning to the research questions and additional objectives outlined at the start, the analytical results above suggest that in the south of our study area, semi-sedentary and full nomadic groups kept grain in large, nucleated sites of often hundreds of smaller-sized pits each, located on escarpments and near routeways. In contrast, those in the north dug fewer larger-sized pits in calcareous soils, closer to houses, processing installations and orchards. The lack of direct recording of pit capacities is a frustrating feature of the surviving evidence (hopefully one day be supplemented by new archival discoveries). Geographic differences in silo size could, in theory, have been nil or relatively modest, but there are hints that the upper end of the anticipated size spectrum (e.g. ~3500 L) might be more common in the north while we have later evidence that the southernmost silo-pits in the High Plains were ~800 L on average. The concentrations in the south also are strikingly close to areas where Saharan nomads came to pay tax and trade for grain each year. In other words, a combination of factors, including varying precipitation, community mobility and economic orientation may have played a role in the storage decisions being made by local people in this region.

These factors are to some extent correlated as north-south trends in the regression model above and do not offer the simplicity of a single explanation, but they nevertheless provide useful, transferable insights that remain highly relevant to other historical and archaeological cases where storage pit locations, concentrations and sizes are empirically observable but wider social, political and economic practices need to be inferred. For example, it is here worth noting the fact that a global count of silos across the study area multiplied by a rough average size of silos in the Maghreb (e.g. 22,000 × 1750 L = 38.5 million L) is a good predictor of the estimate of total annual production that we might arrive at wholly independently from the grain tax records (35–45 million L). Despite the fact that silo sizes clearly can vary regionally (so ~1750 L is certainly not an appropriate single value to use cross-culturally, or even when comparing sub-regions, as noted above), the above global regularities are still a useful outcome to note for historians or archaeologists missing one or other of these information sets and wishing to infer it. By contrast, if we try to estimate the size of the human population within the study area based only on this silo count data and an assumption about basic nutritional needs per person per year (Clark and Haswell 1970: 1–59), the resulting calculation would dramatically over-predict population (in reality, ~33,500 inhabitants, but predicted in this way as 22,000 × 1750 L / 250Lpp = 154,000 inhabitants), rather than also taking into account, as we should, the need for seed corn for the next year, the likely storage of additional food for trade, and the routine 'carryover' of food stores across multiple years to spread the risk of crop failure.

We also hope that this work will encourage wider checks in local archives for other colonial era silo registers of similar type. Already there are opportunities for comparison-and-contrast with other areas of the Maghreb where a rich mix of physical and documentary evidence does exist (Delaigue et al., 2011), albeit in not quite the same detail. In Europe, there are further opportunities to apply similar methods to geographically-referenced observations of food storage practices that have been carried out at village level as part of early 20th century folk atlases (Nandor, 1966; Barabás et al., 1987). We also would suggest that this case study can be theory-building with regard, for example, to archaeological situations where the changing density, size and/or spatial clustering of cereal silos seem to correlate with latitudinal or altitudinal trends in environment, with interactions between coastal access and inland trade, or with earlier episodes of colonialism (e.g. Iron Age Gaul and north-eastern Iberia: Garcia & Isoardi, 2010; Deffressigne et al., 2017; Prats et al., 2020). In any case, we gain much from thinking through the organisation and consequences of food storage concentration or dispersal in a range of different historical and cultural settings.

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Declarations

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