What lies behind a fruit crop variety name? A case study of the barnī date palm from al-‘Ulā oasis, Saudi Arabia

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Societal Impact Statement
The oasis of al-‘Ulā is subject to a vast development operation by the central government of the Saudi monarchy. Agriculture is not strictly speaking the first objective of this initiative, the emphasis being on tourism and thus on the vast historical heritage and landscape qualities of the region. Nevertheless, agriculture and, in particular, phoeniciculture remain the main resource for the inhabitants. Characterizing the local date palm agrobiodiversity is key to the sustainable development of oases. In al-‘Ulā, documenting indigenous knowledge about the locally predominant barnī variety and characterizing its genetic integrity and mode of propagation represents the essential leverage needed by farm development project planners to develop local production.

Summary
• Understanding how farmers name and categorize their crops in relation to the way they are propagated is critical for a proper assessment of agrobiodiversity. Yet, indigenous knowledge is often overlooked in genetic studies, which may result in an underestimation of crop diversity, thereby preventing its conservation and mobilization for developing sustainable agroecosystems.

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Here, we focus on the barnī date palm variety, a local elite variety of al-‘Ulā oasis, Saudi Arabia. We conducted an ethnobotanical survey on local phoeniculture practices and generated whole-genome data to determine whether or not barnī palms are exclusively clonally (vegetatively) propagated. Further, we contrasted the genomes of barnī and two other palms from al-‘Ulā with 112 Phoenix spp. to provide an initial insight into date palm diversity in this oasis.

The survey reveals that the dates of the barnī palm bear distinct names, depending on their quality. Results show that barnī is a true-to-type cultivar, indicating clonal propagation by offshoots with name maintenance, even between distinct cultivation situations in al-‘Ulā and a nearby oasis. Nonetheless, it is distinct from the prominent barnī cultivated in Oman. Its ancestry is comparable to other West Asian date palms, but another palm from this oasis shows influence from North Africa.

What lies behind the cultivar name barnī in al-‘Ulā and further afield in the Arabian Peninsula has been deciphered through the key disciplinary combination of social anthropology and genetics. Future studies will provide additional insights into the original genetic make-up of this millennia-old oasis.

**KEYWORDS**
agrobiodiversity, al-‘Ulā oasis (Saudi Arabia), date palm (Phoenix dactylifera L.), ethnobotany, indigenous knowledge, intra-varietal genetic variation, local categorization, population genetics

### 1 | INTRODUCTION

Agrobiodiversity is a proven lever for the resilience and adaptation of our food production systems (Jarvis et al., 2016). It is the spectacular product of farmers’ work over millennia, and as such, it encompasses not only the genetic diversity of crops and their wild relatives but also the local knowledge and practices associated to their cultivation (Bahuchet, 2017). Yet, the biological and social dimensions of this diversity are rarely examined jointly, even though it would promote a better understanding and evaluation of it, in turn fostering its conservation and mobilization to mitigate the adverse effects of global change (Caillon & Degeorges, 2007; Gros-Balthazard et al., 2020; Leclerc & Coppens d’Eeckenbrugge, 2011).

In predominantly vegetatively (clonally) propagated crops, farmers promote the maintenance of valuable phenotypes and adaptive potential of a lineage through the use of mixed sexual/clonal reproduction systems (McKey et al., 2010). On one hand, farmers propagate interesting genotypes vegetatively, in which case a name (of a variety or cultivar) is assumed to refer to a single genotype. On the other hand, sexual reproduction creates new combinations of genes, and the resulting seedlings may be incorporated by farmers to the cultivated pool. Farmers may voluntarily select a new seedling with attractive characteristics to become a new variety, under a new name (e.g., in cassava, Elias et al., 2000 or in yam, Scarcelli et al., 2006). By contrast, farmers may incorporate seedlings under an existing variety name, if they consider that the seedling has the same phenotypic traits, thus prompting intra-varietal diversity (e.g., in oca, Bonnave et al., 2014, or in date palm, Gros-Balthazard et al., 2020). This latter practice may lead to underestimation of agrobiodiversity because variety names may not correspond to single genotypes.

So far, very few studies have explored what lies behind a crop variety name and its connection to cultivation practices. In date palm, our aforementioned study, focusing on the oasis of Siwa in Egypt, remains unique in its integration of social and biological sciences (Battesti, 2013; Battesti et al., 2018; Gros-Balthazard et al., 2020). It appears crucial to develop this pluri-disciplinary approach in other oases to establish a comprehensive evaluation of date palm agrobiodiversity, in terms of both variety names and genetic diversity.

The date palm (Phoenix dactylifera L.) is the main crop of desert oasis agrosystems of North Africa and West Asia, first cultivated for its fruits: the dates. All parts of the plant, however, can be used—for food, architecture, handicrafts, and so forth—and the plant itself is the oasis system engineer (Battesti, 2005). Its importance can be seen in its denominations: In Arabic in particular, its generic name is always the same (ناخلة, našla), but the names of the varieties—each of which has its own use, conservation, taste, harvest period, pedoclimatic needs, and so forth—are prolific. Some are well known and refer to elite commercial varieties, such as medjool (or mejhoul [majhul], see Zaid & Oihabi, 2022) or khals [xolās], while many names are rather found locally. Inventories of varieties have been carried out locally (e.g., in Tunisia; Rhouma, 1994, 2005), but their overall number remains difficult to evaluate and could exceed 3000 worldwide (Zaid & Arias-Jiménez, 1999).
It is usually assumed that date palm varieties are vegetatively propagated by farmers (as in Krueger, 2011, and discussed in Battesti, 2013). Indeed, although this dioecious species can reproduce sexually, its multiplication is mainly carried out vegetatively by farmers, who cut and replant the offshoots growing at its base. This technique of vegetative propagation maintains the selected features, particularly that of the fruit. By contrast, palms grown from seeds have the drawback for farmers of being half males, which do not produce dates, and if females, they produce dates solely after 6–7 years, and those are typically different from that of the mother plant. Therefore, seedlings found in palm groves “merely grew by accident” (Poponen & Bennett, 1913) and are almost always regarded by farmers as of lower quality than those of the mother plant, thus resulting in their uprooting (but see Johnson et al., 2013; Newton et al., 2013).

According to both main local and scientific narratives, a name matches a variety that matches a genotype (a true-to-type cultivar). But numerous studies have highlighted the existence of genetic variability within a name (e.g., Al-Khalifah & Askari, 2003; Al-Ruqaishi et al., 2008; Elhoumaizi et al., 2006; Sabir et al., 2014). Several hypotheses were raised to explain this variability, such as the presence of somatic mutations (Elmeer et al., 2020; Gros-Balthazard et al., 2020) or the existence of homonyms, that is, when two different lines of clones are called the same. The latter is particularly relevant given that names may refer to general features (e.g., sukari for sugary) or a common anthroponym (e.g., nabit saif, Saif’s plant). Local practices of naming and categorizing palms may also promote diversity under a name. First, seedlings sharing some characteristics or qualities according to local standards, for example, fruit color or usage, may be called by a single name. The most obvious examples of such a so-called “local category” (Battesti, 2013) are the categories of “males” or “seedlings” (the latter usually called khalt [kalf], Johnson et al., 2013). Second, a small number of clonal lines, all sharing, from farmers’ local point of view, the same phenotypic characteristics (in particular the fruit), and vegetatively propagated by farmers, may be called deliberately by a single name; we coined the result of this process as ethnovariety (Battesti et al., 2013; Battesti et al., 2018; Gros-Balthazard et al., 2020). Consequently, the number of cultivated genotypes in the field of this clonally propagated crop can be very different from the number of named types, which can lead to an underestimation of local agrobiodiversity if the system of naming and classification of palms remains undocumented (Gros-Balthazard et al., 2020).

In this study, we explore which kind of identity lies behind the named type “barnī” (بِنَرٍ), the local elite date palm of the oasis of al-‘Ula, province of Medina, in northwestern Saudi Arabia. “Barnī” is used today to designate a variety of date palm. In Saudi Arabia, it is grown in the provinces of Asir, Medina, Najran, Riyad, and Tabuk (Al-Khayri et al., 2015), but whether they belong to a single clonal line or are cases of homonymy remains to be elucidated. According to Zhang et al. (2015), for instance, the “Barnī Al Madinah” date is a medium to long date, cylindrical in shape, and of brown color. This description matches the barnī cultivated in al-‘Ula, but it is unknown however if it is genetically the very same barnī. In addition, a “barnī” variety is grown in Oman where it is one of the top 10 producing varieties (Al-Yahyai & Al-Khanjari, 2019), but Poponen and Bennett noted that the “Oman variety apparently has no relation to the classical Birnī of Arabia and North Africa” (1913, p. 227). This possible homonymy may be based on the antiquity of the term barnī coupled with its reputation or connotation. Indeed, barnī is one of the few (e.g., “ajwa”) date palm varieties mentioned in the collections of reports of the Sunnah of the Prophet Muhammad. In Sahih al-Bukhari, one of the collection of hadith, it is mentioned that Bilāl ibn Rabāḥ brought barnī to the Prophet (Muḥammad ibn Ismā‘īl al-Bukhārī, 2312, Book 40, Hadith 12). In this saying, it is quite clear that barnī stands for a date of superior quality. The etymology of the term “barnī” is confusing. Poponen and Bennett (1913, pp. 226–227) tentatively ventured this for the barnī variety grown in Oman: What is called Barnī or Bemi might derive from the name of a city named “Bum” or from the Persian “bir,” fruit/drop” and “nik, good/heavy.” Before them, the lexicographer E. W. Lane (1863, p. 196) compiled these same etymologies (an Arabicized Persian word) from classical Arabic authors, adding a meaning of “clay vessel” also mentioned by these authors. We can cautiously hypothesize that a variety of date may have taken the name of the pottery that preserved it (not long ago in al-‘Ula, for example, certain varieties of date were preserved and exported in paste form, see below, in goatskin called šānna or basketry called mijla‘).

In this study, we explore the identity of the date palm barnī in al-‘Ula and in the Arabian Peninsula. We assess whether the local identity of barnī, as given by the farmers, corresponds to a unique genetic identity (and therefore, strictly vegetatively propagated from offshoots locally) or if it refers to a multiplicity of genetic forms with an ethnobotanical survey and genetic analysis. The two approaches are essential and complementary. Indeed, an extensive ethnographical field survey will shed light on the local categorization processes and assist with designing an effective sampling strategy of the local diversity. The genetic data will permit an exploration of what lies behind the named type barnī in term of genetic variability and provide insight into how it relates to other date palms from the oasis and beyond.

2 | MATERIALS AND METHODS

2.1 | Ethnobotanic survey and sampling of the date palm named type barnī in al-‘Ula

We carried out an ethnobotanical survey in the oasis of al-‘Ula between April 2019 and November 2021, totaling more than 9 months divided into four fieldwork stays. It involved observations, non-directive and semi-structured interviews and theme-based group discussions with farmers. The purpose of the survey was to understand the local cognitive and practical relationships with plants and specifically the date palm of the named type barnī.

We sampled in situ, in collaboration with local farmers, 23 barnī palms while conducting this ethnobotanical study (Table 1: Figure 1; Figure S1). Twenty-two were identified as such by and with their owner or otherwise by their permanent manager. The last palm,
TABLE 1 Sampling of barnī and other palm accessions for the intra-varietal genetic study. We sampled 23 barnī from al-‘Ula oasis and surroundings along with three date palms (two barnī from Khaybar, Saudi Arabia and from al-Kamil, Oman, and one mabrouma from the United Arab Emirates)

| ID      | Name type | Place of sampling and type of palm grove where barnī palms were sampled in al-‘Ula |
|---------|-----------|----------------------------------------------------------------------------------|
| barnī_00010 | barnī     | al-‘Ula, Saudi Arabia (old palm grove)                                           |
| barnī_00011 | barnī     | al-‘Ula, Saudi Arabia (old palm grove)                                           |
| barnī_00012 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00013 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00017 | barnī     | al-‘Ula, Saudi Arabia (Bedouin palm grove)                                       |
| barnī_00018 | barnī     | al-‘Ula, Saudi Arabia (Bedouin palm grove)                                       |
| barnī_00019 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00021 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00022 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00023 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00024 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00025 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00026 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00029 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00030 | barnī     | al-‘Ula, Saudi Arabia (Bedouin palm grove)                                       |
| barnī_00031 | barnī     | al-‘Ula, Saudi Arabia (Bedouin palm grove)                                       |
| barnī_00032 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00033 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00034 | barnī     | al-‘Ula, Saudi Arabia (new 21st c. palm grove.)                                  |
| barnī_00035 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00036 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00037 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00046 | barnī     | al-‘Ula, Saudi Arabia (modern 20th c. palm grove)                                |
| barnī_00067 | barnī     | al-‘Ula, Saudi Arabia (old palm grove)                                           |

Samples of barnī and mabrouma collected outside of al-‘Ula

| ID      | Name type | Place of sampling |
|---------|-----------|-------------------|
| barnī_00268 | barnī     | Khaybar, Saudi Arabia |
| barnī_Oman | barnī     | al-Kamil, Oman     |
| mabrouma | mabrouma  | al-Shiwayb, United Arab Emirates |

Clones used to calibrate the analyses

| ID      | Name type | Place of sampling |
|---------|-----------|-------------------|
| barnī_00036A | barnī     | al-‘Ula, Saudi Arabia |
| barnī_00036r1 | barnī     | al-‘Ula, Saudi Arabia |
| barnī_00036r2 | barnī     | al-‘Ula, Saudi Arabia |
| ‘asēla_00169A | ‘asēla    | al-‘Ula, Saudi Arabia |
| ‘asēla_00169r1 | ‘asēla   | al-‘Ula, Saudi Arabia |
| ‘asēla_00169r2 | ‘asēla   | al-‘Ula, Saudi Arabia |
| ġakar_00254 | ġakar     | al-‘Ula, Saudi Arabia |
| ġakar_00254r1 | ġakar   | al-‘Ula, Saudi Arabia |
| ġakar_00254r2 | ġakar   | al-‘Ula, Saudi Arabia |

Note: Ten additional accessions (three sets of clones) were used to calibrate the analyses.

so-called “potential barnī” (barnī_00018), was sampled in a Bedouin palm grove where our Bedouin informant did not specifically point out the collected palm but stated that most of the palms there were supposed to be barnī; it was nonetheless identified as barnī by another informant who did not belong to the tribe owning the palm grove.

We voluntarily maximized both the diversity of the social criteria (sedentary and Bedouin, tribes, social groups, large and small landowners, and so forth) and the different types of palm groves (which include different farming conditions) (see Results; Figures 1 and 2) in order to verify whether some of these criteria could be explanatory.
Sampling of additional date palms and Phoenix spp.

In the first part of this study, we explored the intra-named type genetic variability of barnī through genome sequencing of 23 barnī palms sampled in al-'Ulā/C22a region, analyzed along with the genomes of 12 other date palms (Table 1; Figure 1; Dataset S1). Specifically, three accessions from other regions, having either the same name or a name that may also be used to refer to barnī, were included. The first one is a “barnī,” identified as such by the owner, sampled in the oasis of Khaybar located 200 km from al-'Ulā (Figure 1). The second one is also named “barnī” and is grown in al-Kamil, in Oman. The third is a GenBank accession (from Hazzouri et al., 2019) of a date palm cultivated in the UAE (al-Shiwayb) and called “mabrūm” by its owner, easily associated with the name given in al-'Ulā to a category of barnī dates, mabrūm (see Results).

Further, three sets of clonal accessions consisting of one quartet and two triplets were sampled to calibrate the analyses aiming at identifying whether those palms represent a single clonal line (Table 1; Figure 1; Dataset S1; Figure S2). A quartet of barnī clones was constituted by sampling one accession a first time in 2019 (barnī_00036) and re-sampling the same palm 2 years later (barnī_00036A), along with two of its offshoots (barnī_00036r1 and barnī_00036r2). The two triplets were constituted by a male palm and a female variety (ḏakar_00254 and ʿasela_00169A, respectively) sampled along with two of their offshoots (ḏakar_00254r1/ḏakar_00254r2 and ʿasela_00169r1/ʿasela_00169r2, respectively).

In the second part of the study, we assessed the diversity of date palms in al-'Ulā by analyzing three unique genomes from this region (barnī_000268, ḏakar_00254 and ʿasela_00169A) along with 112 Phoenix spp. genomes from previous studies (Dataset S1) (Flowers et al., 2019; Gros-Balthazard et al., 2017, 2021; Hazzouri et al., 2015). This includes 88 date palms from 13 countries of North Africa and West Asia, 8 Phoenix sylvestris, 18 Phoenix. theophrasti, and 1 Phoenix reclinata.
Overall, a total of 146 Phoenix spp. genomes were analyzed, of which 34 were new to this study and 112 were retrieved from GenBank SRA (Table 1; Figure 1; Dataset S1).

2.3 | DNA extraction, whole-genome sequencing, and bioinformatic processing

Genomic DNA was extracted from silica-dried leaf tissue using plant DNeasy mini kit (Qiagen, Venlo, Netherlands). Libraries (2 × 100 or 150 bp paired end) were constructed with either NEBNext Ultra II FS, Nextera DNA Flex, or Illumina trueq nano DNA library preparation kits, and sequenced on an Illumina NextSeq 550 or a NovaSeq 6000 system according to the manufacturer’s protocols.

The detailed protocol for read processing, genome alignment, variant calling and filtering may be found in Methods S1. Briefly, we filtered reads based on quality and length before aligning them to the Barhee BC4 reference genome assembly (Hazzouri et al., 2019). We carried out low depth sequencing and performed population genetic analyses to identify the intra-varietal genetic variability by computing the genotype likelihoods from short read alignments. For the second part of our study, we called variants from higher coverage data using GATK v4.2.0.0 (McKenna et al., 2010) and filtered sites and genotypes based on several criteria detailed in Methods S1.

2.4 | Data analysis of intra-named type variability in the date palm barnī

Relatedness of the samples was quantified with the King-robust kinship estimator, given its robustness to SNP ascertainment bias and applicability to low-depth sequencing data (Waples et al., 2019), and calculated using NGSrelate v2 (Hanghøj et al., 2019). A principal component analysis was performed using PCAngsd v1.01 (Meisner & Albrechtsen, 2018). In both cases, genotype likelihoods were computed with ANGSD v0.933 (Korneliussen et al., 2014) using the GATK method (option -GL 2). Of note: only repeat masked annotated regions from the 18 linkage groups (Hazzouri et al., 2019) were used. Additionally, reads that did not map uniquely were discarded, and only those reads where the mate could be mapped were kept. We filtered out sites based on the following criteria: non-biallelic sites, minimum mapping quality and minimum base quality of 20, minimum number of individuals 12 (34%), minimum global depth 250 and max depth 415, minimum individual depth 5×, and SNPs with a p value < 1.10^{-6}.

Further, genetic distances among those samples were computed using ngsDist v1.0.10 (Vieira et al., 2016). ANGSD was used to compute genotype posterior probabilities with the same filtering options as above and downsampling the sites to obtain ~10,000 sites. Bootstrap replicates (n = 100) using blocks of 20 sites were generated, and fastME v2.1.5 (Guindon & Gascuel, 2003) was employed to compute the trees with default parameters. The consensus function from ape R package (Paradis & Schliep, 2019) was run to obtain a consensus tree where nodes found in 90% of the 100 bootstrap trees were represented. Finally, TreeDyn v198.3 (Chevenet et al., 2006) was used for plotting with mid-point rooting via the phylogeny.fr web interface (Dereeper et al., 2008).

FIGURE 2 Photographs of four different types of palm groves: (a) old palm grove, here a bustān, a garden nearby the old city of al-‘Ulá oasis, April 15, 2019; (b) Bedouin palm grove in the bed of wādī Werd, about 100 km west of al-‘Ulá oasis, November 8, 2019; (c) modern 20th century palm grove, here a farm with only lined up barnī date palms, in al-Khurayba sector, north of the old palm grove of al-‘Ulá, September 23, 2021; (d) new 21st century palm grove, with a view of the agricultural farm mazra‘a planted in al-‘Oḏeb district, north of al-‘Ulé, November 1, 2021. Pictures: Vincent Battesti
2.5 | Data analysis of the genetic make-up of al-‘Ula date palms

Three unique genotypes from al-‘Ula (barnī, ʿaselā, and ḍakār) were compared with 112 Phoenix spp. genomes in order to have a first glimpse into the genetic diversity present within al-‘Ula oasis. First, the structure of the genetic diversity was analyzed by estimating individual ancestries using ADMIXTURE (Alexander et al., 2009) v1.3.0 with a cross-validation of 100, and a principal component analysis (PCA) was run with the pcmdap (Luu et al., 2017) R package v4.3.3 filtering out SNPs with minor allele frequencies below 5%. A maximum likelihood tree was generated using RAXML-NG (Kozlov et al., 2019) v0.9.0. To do so, 20 maximum likelihood tree searches were performed using 10 random and 10 parsimony-based starting trees. The best scoring topology was picked and checked for robustness by performing 100 bootstrap replicates.

The fraction of heterozygote sites for each date palm accession was calculated using pixy (Korunes & Samuk, 2021). Finally, admixture tests were performed using the admixr R package v0.9.1 (Petr et al., 2019) (Methods S2).

To gain insight into the maternal origins of the date palms from al-‘Ula, a bootstrapped chloroplast DNA tree was constructed using the Neighbor-joining method with the phangorn v2.8.1 package in R (Methods S1). The tree was rooted with Phoenix reclinata (PREC1).

Statistical analyses and plotting were conducted with the R Statistical Programing Language (R Core Team, 2022).

3 | RESULTS AND DISCUSSION

Our study focused on the date palm locally named barnī, the local elite date palm of al-‘Ula oasis, Saudi Arabia. We first performed an ethnobotanic survey to better understand folk categorization in conjunction with local date palm agrobiodiversity and set up an in situ sampling methodology with the essential cooperation of the local farmers. We then performed whole-genome sequencing of barnī date palms from al-‘Ula region in order to assess whether this name refers to a unique clone, an ethnovariety or a local category with multiple genetic identities. By adding two barnī date palms from outside of al-‘Ula (i.e., Khaybar, Saudi Arabia and al-Kamil, Oman) and one “mabrouma” (mabrum is the name given in al-‘Ula to a quality of barnī dates; see below) from the UAE, we further explored the genetic variability of barnī at the scale of the Arabian Peninsula. Finally, we studied three date palms from al-‘Ula, including a barnī, along with 112 Phoenix spp. to obtain a first glimpse into the genetic makeup of this millennia-old oasis.

3.1 | The cultivation of date palm in the oasis of al-‘Ula

Our anthropological survey (a 10-month field survey in 2019–2022) of al-‘Ula oasis and the region highlighted different types of palm groves, each with its own social and spatial organization, space, and cultural practices, depending on their location, their history and the social group that exploit and own them (Notes S1; Figure 2). To summarize, two of them reflected historical growing situations, namely, the date palms grown in the subsistence-type gardens (basāṭīn) of the palm grove near the old city of the oasis and those found in the Bedouin palm groves scattered in desert wadis outside the oasis (Figure 2a,b). The two other grove types were more recent and commercial: the modern palm groves established during the 20th century outside of the historical core area, but in its immediate vicinity and the more recent gardens established during the 21st century beyond the perimeter of the old and modern palm groves (Figure 2c,d).

Our fieldwork was performed among all local social categories with several hundred farmers being interviewed in Arabic following the ethnographic methodology. This ethnobotanical survey suggests a very rich agrobiodiversity for date palm alone, drawing up a complex picture of variety names (n = 99, at this stage of our survey). Farmers classify the two million palms in the region into categories and assign names to them by consensus based on local criteria and shared features. We found that they typically propagate their palms by offshoots, as is usual in palm groves in the Sahara and Arabia (Munier, 1973), but we lack assurance that the clonal propagation has been applied consistently and systematically throughout al-‘Ula region for all varieties. As a matter of fact, we witnessed reproduction by seed and analyzed emic discourses of palm biology that enable such practices, but we do not yet know the extent to which this technique is used (in practice and over time): it may have emerged in recent decades due to a less extensive knowledge of date palms by newcomers to phoeniculture (sedentarized Bedouins in particular, as declared by both the social group of oasis sedentaries and the Bedouins themselves).

3.2 | The barnī, a socialized date palm in al-‘Ula

3.2.1 | A local elite variety, but a recently increased supremacy over the local date agrobiodiversity

The ethnobotanical survey conducted on date agrobiodiversity in al-‘Ula clearly revealed the special and shared status, today, of the named type barnī. Indeed, in al-‘Ula, there is “the barnī” and “the rest,” al-bāqi (الأص 살ن), or “the [other] varieties,” al-asnaf (الاسناف). It is by far the most cultivated variety and is found in all four agricultural contexts described above (Figure 2). It also is the most exported date variety of this oasis. It is considered by all farmers hardy and local and, as such, enjoys an elevated status among the inhabitants and is perceived to be a superior fruit and crop and to grow better. The alternate local elite variety, presently second in rank for all farmers, is the variety named ḫelwa (and when it is necessary to specify, the ḫelwa ḥamraʿ to distinguish it from another local variety, the ḫelwa beyṭaʿ). Together, barnī and ḫelwa constitute the main varieties in the oasis and are usually the only two reported to be grown in Bedouin palm groves in the region.

The orientalists Jaussen and Savignac (1914, p. 40) noted in the early 20th century the elite status of the barnī and ḫelwa: “Dans
3.2.2 | Naming a palm and naming its dates according to their quality

The elite status of the barnī is also reflected by the fact that the palm, the barnī, produces dates that are not named/sold under this name. According to our study, in al-‘Ulā, three names are used to sort its dates depending on date quality (jawda) for marketing (Figure 3): #1 mabrūm: the best quality; #2 mašrūk: almost good, but of lower quality (smaller, and has a qešra “skin,” i.e., a more wrinkled epidermis); #3 ‘ādī: good only for livestock, damaged with too much “skin” (a cracked epidermis; the term ‘ādī here refers to the notion of “ordinary,” “worthless”). The second quality or the merged second and third qualities are sometimes also referred to as the name abū qešra (because of that whitish skin, qešra, epidermis). In addition to the shape, the tastes differ with the qualities, according to most farmers. The mabrūm are said to taste better, be more presentable, and sell for much more (Notes S2). These different commercial
qualities of dates are present in the same bunch of the same date palm. It is said that the older the barnī palm, the greater the proportion of mabrūm in its yield. Besides, farmers say that this proportion varies across years, and since this variety now dominates the date economy (Notes S2), it is a sign of a bad or good phoenicicultural harvest.

That barnī fruits go by different names seems to have already been noticed by Doughty a century ago (1921, p. 153), who stated that “there are many kinds.” This is best explained later by Nasif (1988, p. 174), who highlighted that “this date is sometimes divided into two kinds, when the better quality of this type is selected because it is without a skin; this class of the barnī is known as mabrūm.”

The case of naming a palm and its dates differently is unusual but not unique: One example is in Siwa (Egypt, a Berber-speaking oasis) of a variety, also elite, the tasutet palm whose dates are named sacidi (Battesti, 2013). Further, naming dates of the same variety according to their quality is also uncommon, although the case is not entirely unique either. For instance, in Siwa, the second elite cultivar (after the above-mentioned sacidi) is the true-to-type alkak date palm whose local name depends on fruit quality which varies according to growth conditions and age. The higher alkak date palms are called “alkak namles,” meaning bearing smooth or wrinkle-free alkak dates, while the lower alkak date palms bearing smaller dates, and three times cheaper, are called “alkak nifugen” (Gros-Balthazard et al., 2020). The case is not entirely analogous to al-‘Ula though: in Siwa, the palms bear either of these two names, and so does their production, while for the barnī, it is the dates from the same palm that are given different names.

3.3 What lies behind the name barnī?

To study the genetic variability within the barnī, we sequenced the genomes of 35 date palms, including 23 barnī from al-‘Ula collected in the four agricultural contexts (Figures 1 and 2), and obtained between 18 and 122 million of paired reads of size >76 bp (Table 1; Dataset S2). Sequencing reads from these runs and those retrieved from GenBank SRA were mapped to the Barhee BC4 genome assembly (Hazzouri et al., 2019), resulting mostly in low coverage alignments, ranging from 2.9× to 20.5× (9.3× on average; Dataset S2).

We assessed whether 26 barnī and mabrouma date palms from Saudi Arabia, Oman and the UAE are genetically identical using the King-robust kinship estimator (Waples et al., 2019) (Figure 4a; Dataset S3), a principal component analysis (Figure 4b), and a tree based on genetic distances (Figure 4c; Figure S3). In all three cases, 305,610,249 sites across the 18 linkage groups of the date palm genome were analyzed by ANGSD. After filtering, 1,508,939 sites

![Figure 4](image-url) Intra-named type variability of the barnī date palms. (a) Heatmap of the king-robust kinship estimator calculated across 1,508,939 sites in 35 date palms; (b) principal component analysis of 35 date palms (1,508,939 sites). Variance explained by each principal component (PC) is provided within parentheses; (c) tree of genetic distance calculated across 10,742 sites in 35 date palms. The consensus tree obtained from 100 bootstrap replicates may be found in Figure S3.
were retained for both the relatedness analysis and PCA analysis, and we further downsampled these sites to get 10,742 sites for computing genetic distances while limiting the effects of linkage.

Low coverage sequencing may yield kinship estimates that differ from the expectation of 0.5 for members of a single clone particularly for heterozygous samples such as date palms. We therefore sequenced three clones multiple times to assess the deviation from 0.5 that can be expected using our approach to kinship estimation (Figure S2). The barnī we sampled and sequenced twice revealed a King-robust kinship of 0.482, while kinship estimates for the mother palm and two offshoots ranged between 0.481 and 0.499 (Figure 4a; Dataset S3). Sequences of two clone triplets (jākar and ‘aselā) that each consisted of a palm tree and two of its offshoots each yielded a kinship estimate of 0.499. Since these samples are known to be clonal, we attribute any differences in kinship estimates from the expectation of 0.5 to be attributable to our low coverage approach. In the PCA, the accessions from each triplet/quartet of clones overlap (Figure 4b), while they group together in separate clades in the genetic distance tree (Figure 4c; Figure S3), as expected given their genetic identity.

3.3.1 | Barnī is a true-to-type cultivar in al-‘Ulā region

We found that the 23 barnī from al-‘Ulā are genetically identical, except barnī_00010. Indeed, those 22 accessions cluster together in both the PCA (Figure 4b) and the tree (Figure 4c; Figure S3). Further, the King-robust kinship among them ranges from 0.424 to 0.491, nearing the theoretical 0.5 expectation and the 0.481–0.499 range observed among the known clones (Figure 4a; Dataset S3). On a technical note, we hypothesized that lower kinship estimates among the 22 barnī, compared with the known clones, may be due to a lower coverage in the former (Dataset S3). We tested the relationship between the fraction of sites with information for two individuals (used to calculate pairwise kinship) and the King-robust kinship estimate, and indeed found that they are highly positively correlated (Notes S3; Figure S4).

To understand why barnī_00010 is genetically different, we returned to the field and found that it had been misidentified by the farm manager (a foreign worker) at the time of collection. The error is attributable to his lack of knowledge of the planting history of the sample as well as the youthfulness of the palm which made it difficult to identify using botanical characteristics. This demonstrates the need for meticulous sampling pre-informed by ethnobotanical and anthropological study.

The samples of the named type barnī were voluntarily collected from the different categories of palm groves of al-‘Ulā and these palm groves represent a great diversity of management, farming practices and social origins (Figure 2; Notes S1). Nevertheless, these differences did not lead to the selection of an ethnovariety. Indeed, all barnī whether from old, modern (20th c.) or new (21st c.) palm groves are identical. More intriguing, the four barnī from Bedouin palm grove (including the so-called “potential barnī” barnī_00018) also are identical to those found in the oasis palm groves. Those Bedouin palm groves found in the Balawi tribal territory about 100 km west of al-‘Ulā are of the picking palm grove type, i.e. characterized by very little labor investment, a monoculture of a few barely pollinated palms, in the bottom of the wadi, thus without necessary irrigation and without permanent habitation. This suggests a circulation, difficult over great distances, of palm offshoots between the apparently antagonistic Bedouin and sedentary worlds. The local saying that refers the Bedouin to “‘ibel w gānem” (dromedary and sheep) and the sedentary to naxla (the date palm) does suggest very different ways of life and mode of production, and consequently distinct domains of knowledge: Bedouins are less knowledgeable about date palms than oasian people, but apparently enough to maintain a clonal lineage in their picking palm groves (Notes S1).

This result—barnī is a true-to-type cultivar—was, in a sense, expected, since the mode of reproduction is supposedly vegetative in al-‘Ulā (according to our field survey, in spite of some discordant evidence of cases of seed propagation). Besides, barnī is a local elite variety and we have previously hypothesized that local elite date palms are likely to be true-to-type cultivars, despite their prevalence and therefore the mechanical probability of becoming an ethnovariety (Gros-Balthazard et al., 2020). The system of ethnovariety and local category would allow farmers to organize the diversity of palms with lower commercial value (but potentially high local value) while not multiplying the denominations for the same characteristics (i.e., not creating named types for palms that are locally considered the same); it offers a fairly flexible management of agrobiodiversity (Gros-Balthazard et al., 2020).

On a practical note, processing and distributing (including identification and traceability) a heterogeneous or a homogeneous commercial product obviously differs. Our clarification of the status of this local elite variety in al-‘Ulā, covering thousands of hectares, is thus of great importance regarding the agronomic and economic development of the phoenicultural sector in this region. The barnī of al-‘Ulā is not only precisely identified by the farmers and multiplied strictly by offshoots, even by Bedouins, but can now also be easily identified through genetic fingerprints.

On a separate note, we found that the male accession used to calibrate the genetic identity analyses (jākar_00254) is closely related to barnī, with a King-robust kinship estimate ranging from 0.194 to 0.284 (Figure 4; Dataset S3). Since barnī is by far the most cultivated named type in al-‘Ulā and that males mostly arise from accidental seedlings, this male is probably an offspring of barnī.

3.3.2 | The date palm barnī across the Arabian Peninsula

We compared the barnī of al-‘Ulā with two barnī date palms from outside this oasis (Khaybar, Saudi Arabia and Nizwa, Oman) and with a palm identified as mabrouma (name given in al-‘Ulā to the best date category of barnī, see above; Figure 3) in a private collection from the UAE.
We found that the barnī from Khaybar, a sedentary oasis palm grove 200 km away, is genetically identical to the barnī from al-‘Ula, indicating that the named type barnī refers to the same entity not only at the scale of al-‘Ula oasis, but possibly at the scale of the region. The mabruma from a palm grove in the UAE is also identical to the barnī of al-‘Ula. It originates from a collector’s farm (the exotic character is often valued by collectors). Perhaps originating from al-‘Ula, this palm was supplied to the owner under the name “mabruma,” possibly in reference to the mabrum quality of its dates.

On the other hand, the barnī from Oman turns out to be different from that of al-‘Ula (Figure 4). This alternate barnī appears to be present in Oman, mainly in the Northern and Southern al-Sharqia regions and is the tenth most cultivated variety in the country (Al-Yahyai & Khan, 2015). Although Popenum and Bennett (1913, pp. 226–227) recognized the probable difference between these barnī, our genetic study confirmed this example of homonymy.

### 3.4 A first glimpse into the date palm agrobiodiversity in al-‘Ula

In Northwestern Saudi Arabia, date palms have dominated the oasis agricultural system since at least the fourth century BCE (Bouchaud, 2013), and al-‘Ula region is known to be home to the two-millennia-old Nabataean site of Hegra (Mada'in Saleh). In this area, dates have been consumed since at least the end of the 2nd millennia BCE (Rohmer et al., in press) and they have a particular symbolic importance in the Nabatean period as attested by the date necklace excavated in a tomb of this period (Bouchaud et al., 2015). The region is positioned in a strategic location, on a critical trade route, namely, the incense road, connecting the South of the Arabian Peninsula with the Levantine region roughly during the 7th century BCE and the 2nd century CE. It is also at the crossroads of date palm diversity, between the distinct North African and West Asian gene pools (Flowers et al., 2019; Hazzouri et al., 2015).

So far, no studies have focused on the origin and extent of the diversity of Northwestern Saudi Arabia date palms, including al-‘Ula oasis. A few studies focused on the genetic diversity of date palms varieties in Saudi Arabia (Aleid et al., 2015; Al-Khalifah & Askari, 2003; Al-Qurainy et al., 2011) but how those varieties, some potentially cultivated in al-‘Ula, relate to cultivars from other regions remain to be elucidated.

Here, we analyzed the genome of the barnī of al-‘Ula and of two other accessions from this oasis, one of the ‘asela variety (‘asela_000169A) and a male (jašak_00254), along with that of 112 Phoenix spp. (Dataset S1). Given the genetic identity of all barnī palms from al-‘Ula, we picked the accession with the highest coverage, namely barnī_000068, for downstream analyses. Aligning reads to the Barhee BC4 genome led to an average coverage of 17.3x across accessions (Dataset S2) and we identified 1,007,281 SNPs after quality filtering, which we used in subsequent analyses (Methods S1).

#### 3.4.1 Genetic relationships between date palms from al-‘Ula and from North Africa and West Asia

The relationships and the genetic structure of the 3 date palms of al-‘Ula and 88 date palms from North Africa and West Asia were determined by performing model-based genetic clustering (Figure 5a; Figures S5 and S6), reconstructing a phylogenetic tree (Figure 5b) and applying a PCA (Figure 5c; Dataset S4) using the SNP data. All three analyses (Figure 5) corroborated previous results on date palms, that is, that they can be split in two main clusters (North Africa and West Asia) with Egyptian accessions being a mix between the two (reviewed by Gros-Balthazard & Flowers, 2021).

Regarding the diversity in al-‘Ula, our results revealed that it may represent a unique mixing among West Asian date palms (Figure 5): The three al-‘Ula palms indeed cluster with West Asian date palms, but the male jašak shows influence from North African diversity. It is found on the edge of the West Asian group in the PCA, close to North African date palms (Figure 5c) and shows mixed ancestry from the West Asian and the North African clusters in the clustering analysis (Figure 5a).

#### 3.4.2 Genetic diversity of al-‘Ula date palms

To determine the genetic diversity of al-‘Ula date palms, the proportion of heterozygous sites in each date palm accession was calculated using pixy (Korunes & Samuk, 2021), which confirmed results from previous reports (Flowers et al., 2019; Gros-Balthazard et al., 2017, 2021; Hazzouri et al., 2015): i.e., North African date palms display a higher diversity (mean heterozygosity 0.094 ± 0.016%) than cultivated West Asian date palms (mean heterozygosity 0.062 ± 0.0069%): one-sided Wilcoxon rank sum test, \( W = 1243, P = 1.11 \times 10^{-11} \). Regarding the three al-‘Ula date palms analyzed in this study, their diversity (mean heterozygosity 0.065 ± 0.0064%) was on average comparable to that of cultivated West Asian date palms (Wilcoxon rank sum test, \( W = 99, P = 0.41 \)), and lower than that found in African date palms (one-sided Wilcoxon rank sum test, \( W = 3, P = 0.0021 \)).

#### 3.4.3 Evidence of gene flow between al-‘Ula date palms and the wild relative P. theophrasti

Interspecific introgression has shaped the diversity of North African and Levantine date palms since at least 2000 years (Flowers et al., 2019; Gros-Balthazard et al., 2021; Pérez-Escobar et al., 2021). The date palm was presumably domesticated in the Persian Gulf region during the fifth millennium BCE and its cultivation then spread across Arabia and further across North Africa. Modern North African date palms and ancient Levantine date palms show higher genetic diversity than that found in West Asia, which may at least partially be explained by gene flow from a wild relative species, that is, Phoenix theophrasti, whose present-day distribution includes Crete and the coast of...
Turkey, or a theophrasti-like species (Flowers et al., 2019; Gros-Balthazard & Flowers, 2021). The oasis of al-'Ula has long been connected to the Levantine region and its ports on the Mediterranean Sea. Whether the genetic make-up of its date palms also displays ancestry from *P. theophrasti*, reflecting this possible bond, remains to be determined.

To evaluate whether the date palms from al-'Ula showed evidence of introgression, both $D$- and $f_4$-statistics were computed (Figure 6; Methods S2; Datasets S5-S6). This revealed that both barnī and 'aselā do not show any evidence of introgression (Figure 6). On the other hand, North African date palms, and the ancient Judean date palms, that were previously shown to be admixed, displayed significant positive $D$- and $f_4$-statistics (Figure 6; Flowers et al., 2019; Gros-Balthazard et al., 2021). Interestingly, this is also the case for the male *ḏakar_00254* from al-'Ula (Figure 6).

We further estimated the fraction of *theophrasti* ancestry in the date palms showing evidence of admixture according to $D$- and $f_4$-statistics (Figure 6; Dataset S7), including the male *ḏakar_00254*. We found that the latter displays about 1.1% of its genome from *Phoenix theophrasti*. This is in the lower range of what is observed in North African and Judean date palms (average 11.23%, ranging from 0.59 to 21.58%; Dataset S7).
The evidence of gene flow from *P. theophrasti* found in date palms of the Levant has been hypothesized to be related to the growing control of the Roman Empire in the region 2000 years ago, favoring exchange of goods, including dates, with North Africa (Gros-Balthazard et al., 2021). Indeed, a changeover from absence or low *P. theophrasti* ancestry to ~10% of *P. theophrasti* ancestry coincided with a shift in imperial control of the region in favor of the Romans. The region of al-‘Ula, with the famous site of Hegra, was part of the Nabatean kingdom, and a stop on the trading routes connecting southern and eastern Arabia to Petra and the Mediterranean Sea. The site is also located, since 106 CE, on the border of the newly created Roman province of Arabia on the ruins of this kingdom. To observe evidence of ancestry that is rather characteristic of North Africa and the Levant is therefore not unlikely. Whether this reflects ancient (i.e., from the Nabateo-Roman period) or other gene flow remains to be elucidated.

3.4.4 | Maternal origin of al-‘Ula date palms

In date palm, two deeply diverged chlorotypes (so-called western and eastern) have been reported (Pintaud et al., 2013). The eastern (or oriental) chlorotype is found in most West Asian date palms, while in North Africa, the so-called occidental is prominent. Previous analysis of date palm chlorotypes showed a gradient in frequency of the oriental chlorotype from low in Northwestern Africa to ~50% in Egypt, which suggest strong gene flow from West Asia (Gros-Balthazard et al., 2017; Zehdi-Azouzi et al., 2015). Our analysis of chloroplast sequences from three al-‘Ula date palms revealed that all bear the oriental chlorotypes indicating a maternal origin from West Asia (Figure S7).

4 | CONCLUSION AND PROSPECTS

What lies behind variety names in clonally propagated crops has been insufficiently explored, although it is a key element for assessing agrobiodiversity (e.g., in oca, Bonnave et al., 2014 or in date palm, Gros-Balthazard et al., 2020). Many studies have highlighted variation within variety names; in date palms (Al-Khalifah & Askari, 2003; Al-Ruqaishi et al., 2008; Elhoumaizi et al., 2006; Sabir et al., 2014), and in other clonally propagated fruit crops as well (e.g., in grapevine, Meneghetti et al., 2012 or in olive, Lazović et al., 2018), although most do not reference deliberate cultivation practices as a source of this variation (but see Battesti et al., 2018; Gros-Balthazard et al., 2020).

By engaging with local farmers, we have established that barni cultivated in al-‘Ula and its surroundings, is a true-to-type cultivar, that is, its local identity given by the farmers corresponds to a unique genetic identity. It implies that, locally, barni date palms have always been...
strictly vegetatively propagated, even by Bedouins in remote desert areas and in different palm grove farming systems. But geographic scale matters: barni from al-‘Ula oasis is distinct from that of Oman, and we therefore confirmed the homonymy foreseen by Popenoe and Bennett (1913).

In al-‘Ula alone, to date, we estimate that about 99 varieties are cultivated, some of which have been given names close to barni: for example, barniyat al-‘aį, barniyat banat sa’ad, and barniyat bader. The two latter are probably old local rare named types, while barniyat al-‘aį (the “barni from al-‘Aį”) clearly designates a variety said from the oasis of al-‘Aį (KSA), which is referred to in al-‘Aį as barni. This stresses the importance of understanding the categorization and naming systems used by farmers in relation to the way they propagate palms for a proper understanding and assessment of crop biodiversity.

In addition, our joint analyses of three date palms from al-‘Ula and other Phoenix specimens, have revealed an intriguing diversity patterns, where, although clustering with West Asian date palms, one of them shows influence from North Africa. Further analyses, comprising all date palm diversity from al-‘Ula area, will provide further insights into the diversity and history of the keystone species of this antique oasis.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS
MGB and VB conceived and designed the analysis. VB led the ethno-botanical survey accompanied by MGB, MGB, VB, SF, JMF, MDP, RW and NM contributed to data. MGB, VB, MB, SI, JFT, JMF, MDP, YB contributed to the analyses. MGB and VB wrote the paper.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available in the supporting information of this article. Sources for all downloaded genomic data are stated in Dataset S1. Sequencing reads for the newly sequenced accessions can be found in the public sequence database GenBank under the BioProject ID PRJNA817028 and BioSample IDs can be found in Dataset S1.

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