Genet Resour Crop Evol (2009) 56:609–614
DOI 10.1007/s10722-009-9442-2

SHORT COMMUNICATION

Ecology and morphological traits of an ancient *Musa acuminata* cultivar from a mountain oasis of Oman

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Received: 5 February 2009 / Accepted: 11 May 2009 / Published online: 9 June 2009

Abstract Recent reports have shown a surprising diversity of agricultural crops in Omani oases which was attributed to the country's traditional role at the crossroads of cultures and trade between the Middle East and Asia. Recent surveys have indicated a relatively small diversity of banana (*Musa* spp.) germplasm which was thought to reflect the prevailing hyperarid conditions of Oman where this drought-sensitive species can only be cultivated in well-watered oases in the North or in Dhofar, the monsoon-dominated south eastern tip of the Sultanate. Surveys near Umq Bi'r, a half-abandoned oasis in the hardly accessible spring area of Wadi Tiwi, famous with Arabic sailors for its abundant fresh water resources, led to the discovery of a so far undescribed triploid *Musa acuminata* cultivar surviving in a limestone rock niche. Its morphological traits are different from any of the currently grown banana cultivars. Since *acuminata* bananas are quite sensitive to drought spells, characteristic for the Arabian Peninsula, the occurrence of this specimen provides further evidence for Oman's role as a refuge of relict crops imported from a more humid region such as coastal East Africa and nearby islands, or Indonesia.

Keywords AAA · Archaeobotany · Agrobiodiversity · Banana · Cultural exchange · Genetic erosion · *Musa acuminata*

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Introduction

Given its long isolation and harsh environmental conditions it was only during the last 5 years that Oman's rich history as a seafaring trade nation was shown to be reflected in ancient germplasm of major crops of which wheat (*Triticum* spp.) has received particular attention (Al-Maskri et al. 2003; Hammer et al. 2004; Al Khanjari et al. 2005; Al Khanjari et al. 2007a, b, 2008). Paleobotanical findings of wheat and other cereals (Potts 1993; Willcox and Tengberg 1995) coupled with archaeological evidence (Häser et al. 2009) suggests that the rise of early agriculture on the Oman Peninsula has been heavily dependent on climatic change and the development of agriculture at about 5,500 years before present (BP), probably as a consequence of early trade relationships with Mesopotamia and subsequently SE Asia. For wheat, morphological (Al Khanjari et al. 2008) and molecular analyses (Zhang et al. 2006) suggest that at least some of the 10 so far undescribed botanical varieties of wheat discovered in farmers' landraces cultivated in oases throughout Oman are closely related to Asian and Ethiopian material, constituting thus botanical relicts of germplasm which most likely has gone extinct elsewhere in the region.

With a few exceptions the rapid transformation of most Omani oases into modern settlements where agriculture is either abandoned or reduced to back-yard decoration farming has lead to genetic erosion whereby traditional germplasm of crops with a long cultivation history in Oman such as barley (*Hordeum vulgare* L. s.l.), date palm (*Phoenix dactylifera* L.), field bean (*Vicia faba* L.), mango (*Mangifera indica* L.), mulberry (*Morus* spp.), citrus (*Citrus* spp.), cucumber (*Cucumis* spp.), fig (*Ficus* spp.), olive tree (*Olea europaea* L.), sweet basil (*Ocimum basilicum* L.) and water melon (*Citrullus* spp.) has at least been partly replaced by modern cultivars. The same was reported for banana (*Musa* spp.) for which INIBAP conducted an intensive survey in 2002 (De Langhe 2006). However, this survey focused on oases in the country's interior regions of Sharqia and Dakhilia and on Dhofar with its Indian summer monsoon climate. It left out remote mountain oases which were believed to be of only minor interest as banana environments given their notorious risk of water scarcity in the ancient aflaj irrigation systems.

Given earlier work on nutrient fluxes and agrobiodiversity in the northern Hajar mountain range (Buerkert et al. 2005) and on the agroecology and paleoclimatic conditions of oasis agriculture in the Jabal Bani Jabir (Siebert et al. 2005; Fuchs and Buerkert 2008; Urban and Buerkert 2009), we hypothesized that the high water storage capacity of the calcareous rocks in these mountain ranges may have allowed the survival of ancient germplasm of banana, a drought sensitive perennial in some remote niche environments.

Materials and methods

Description of the survey area

For our explorations (a total of three expeditions in 2003 and 2004) we chose the upper part of Wadi Tiwi in the Jabal Bani Jabir mountain range given a 14th Century description about of its lush banana gardens (Battuta 2004), its widely known reliable and abundant fresh water resources which in Oman's past had facilitated trade along the eastern coast of Arabia, and the existence of a satellite image-based map of its multitude of terraces mostly planted to date palms with an understorey of citrus and banana (Korn et al. 2004; Fig. 1a, b). In August 2003 the lower part of the wadi was explored through an old track along the water course west from Mibam, however, water falls running over large cliffs and a series of deep lakes prevented further entry. Making use of a routine helicopter medical flight of Royal Air Force of Oman for a second expedition in October 2003, we reached the half-abandoned oasis of Umq B'ir which proved to harbour the mother springs of Wadi Tiwi. Interviews revealed that the last permanent dwellers had left the oasis only a few years ago and abandoned the cultivation of irrigated annual crops such as wheat. At the end of a small path to the lower part of the oasis, a permanent spring surfaced of the bare rock about 20 m above the valley ground (Fig. 1c, d). In this about 100 m^2 niche environment characterized by ferns growing in the midst of moist limestone rocks we found two old citrus trees and in a barely reachable corner we detected a few banana plants of which two suckers were taken back by helicopter. The banana germplasm collection was complemented by four more suckers taken during a third expedition in March 2004 when we accessed Umq Bi'r from the top of Jabal Bani Jabir on foot. All suckers were grown to full plants in the Tropical Greenhouse at University of Kassel-Witzenhausen, Germany where the first specimen reached flowering/fruiting 3 years later in March 2007 (Figs. 1e, 2e). The banana section of our greenhouse has natural light conditions and an average temperature of about 22–35°C (annual average 25°C) and 80% humidity.

Except for one specimen of which a detailed description follows, the collected plants proved to belong to contemporary relatively drought-resistant AAB and ABB clones typical for the Middle-East region. Their occurrence provided evidence of the continued linkage of the niche environment in Umq Bi'r to modern day banana cultivation. The one unknown specimen was characterized at mid-flowering and at maturity using the IPGRI-INIBAP/CIRAD Descriptor List (1996). Root meristem material was

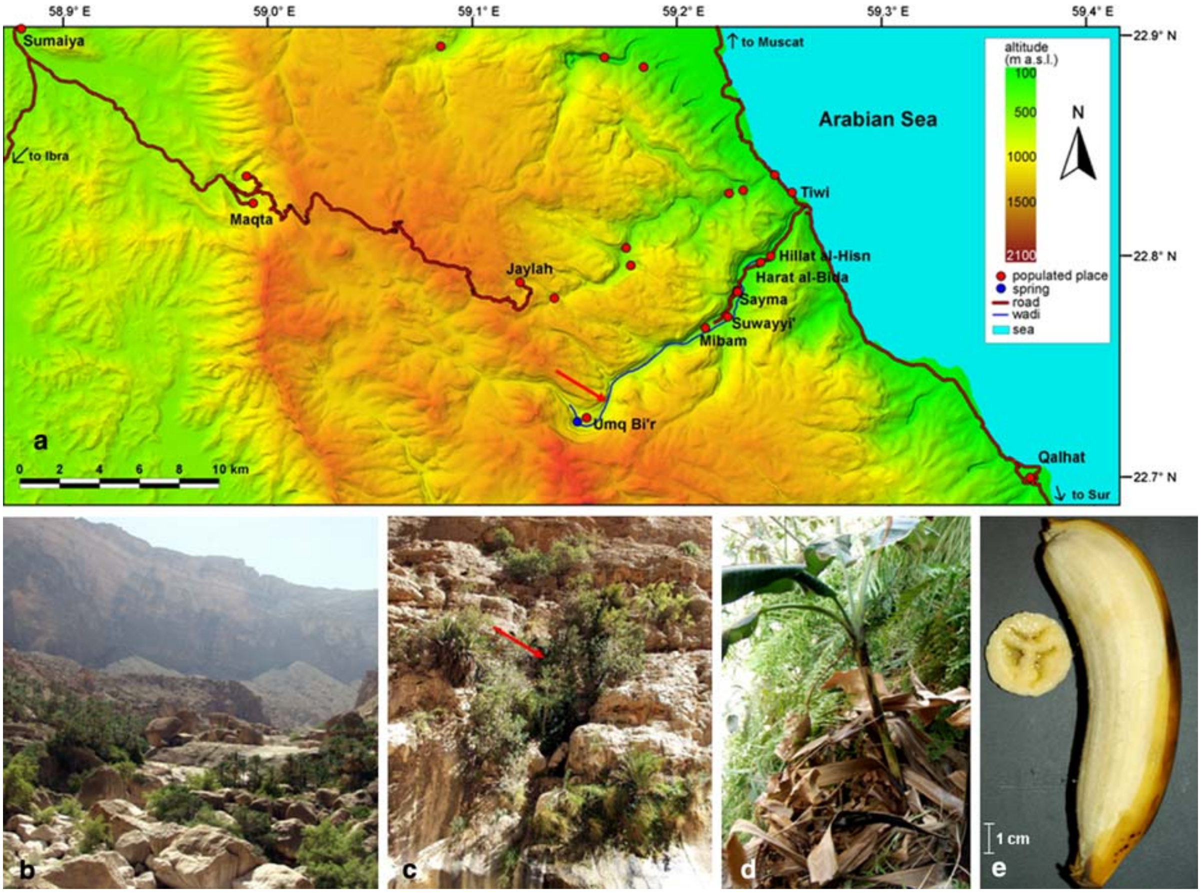

Fig. 1 **a** GIS-based 3D map of the Jabal Bani Jabir mountains, Wadi Tiwi and the oasis of Umq Bi'r in northern Oman, **b** View of Umq Bi'r, **c** Lateral spring area with the habitat of the *Musa* (*AAA*) 'Umq Bir' clone, **d** Young *Musa* (*AAA*) 'Umq Bir' clone *in situ* and **e** Edible fruit of the clone in the greenhouse. The *arrows* show the natural location of the banana clone near the mountain oasis of Umq Bi'r

used to verify the ploidy-level by flow cytometry in the laboratory of J. Doležel at the Institute of Experimental Botany, Sokolovská, 77200 Olomouc, Czech Republic (Doležel et al. 1998).

Results

The morphological description of the first flowering plant, called "Omani 1", unequivocally comprises nearly all the typical characteristics of an edible *M. acuminata* (Annex 1; Fig. 2). The fruit flesh has a pleasant taste reminding that of the commercial AAA Cavendish bananas. The grooves on the bract surface are unusual but also occur on *Musa acuminata* subspecies *truncata*.

Of particular interest is the evolution of the male bud shape, from plump and rounded with extremely imbricate bracts at young fruiting stages to slender and lanceolate with somewhat less imbricate bracts towards the maturity of the fruits (Fig. 2c). This feature to the best of our knowledge has not been previously described. A second collected plant, called 'Omani 5', showed exactly the same characteristics as 'Omani 1' in the same glasshouse and also had the curious male bud form at early fruiting stages. This would indicate that the feature is typical for the clone, rather than being the result of stress conditions, and would point to a vestigial state of the specimen. The results of the flow cytometry allowed to further classify the clone as a triploid (AAA). Despite consultation of the relevant literature (Stover and

Fig. 2 Vegetative parts (**a**) and infrutescence (**b**–**e**) of the *Musa* (*AAA*) 'Umq Bir' clone ($2n = 3x = 33$) from Umq Bir, upper Wadi Tiwi, Oman

Simmonds 1987), as well as of several specialists in *Musa* taxonomy, the specimen could not be identified more exactly, although a vague similarity with some cultivars growing in the Comores can not be excluded (Bioversity International 2006; Horry, CIRAD France, personal communication). We therefore named this clone *Musa* (AAA) 'Umq Bir'. Research on molecular markers for precise classification of *Musa* cultivars is only recently progressing so that no molecular references can yet be used.

Discussion

Following earlier work of Guarino (1990), recent studies of the agro-biodiversity of Omani mountain oases have led to a checklist of cultivated plants (Hammer et al. 2004, 2009; Gebauer et al. 2007) comprising 194 species of 133 genera and 52 families. Of these 21% most likely originated from South and Southeast Asia and another 21% from the Near East and East Mediterranean, whereas, only a few species such as *Boswellia sacra* Flueck. and *Prunus arabica* (Oliv.) Meikle are considered autochtonous.

The fact that all banana cultivars investigated in Oman during the survey of De Langhe (2006) were AABs or ABBs, lacking evidence of Oman being a secondary center of origin of banana and the fact that *M. acuminata* cannot survive under frankly dry conditions, all strongly suggest that our new *Musa* bears further testimony of Oman's ancient position at the crossroads of cultivated plants (Hammer et al. 2009). As all AAA cultivars originated in SE Asia, our cultivar most likely has been brought from there via East Africa (maybe through Zanzibar, Madagascar or the Comores where many AA or AAA banana got established early on) during the past centuries when Oman's sea trade—often through the port of Tiwi—was flourishing.

The apparent absence of black sikatoga (caused by *Mycosphaerella fijiensis*) and panama disease (caused by *Fusarium oxysporum* f.sp. *cubense* [Foc]) in banana in the whole of Wadi Tiwi makes this an all the more interesting area of further research on banana diversity with a potential to discover germplasm with tolerance traits against both widely devastating diseases.

Conclusions

During the past years numerous reports have provided evidence for the role of Oman's oases as *in situ* conservation centers for ancient germplasm. The challenge will remain of how to best protect this treasure of humanity given the rapid genetic erosion observed with the modernization of these oases. In such protection efforts the continued, economically profitable existence of oases as integrated livelihood systems and not just as museum-type assemblages of physical structures seems of particular importance.

Acknowledgments We are thankful to Royal Air Force of Oman and the College of Agriculture and Marine Sciences, Sultan Qaboos University, Muscat (Oman) for technical support, to Khamis Rashid Al Muqaimi of Umq Bi'r for climbing with the first author barefoot to the spring where the Musa cultivar was maintained, to Jaroslav Doležel for conducting the flow cytometry of the banana germplasm, to Karl Hammer for his advice, to the gardeners of the Tropical Greenhouse at University of Kassel-Witzenhausen for bringing the banana to flowering and to the Deutsche Forschungsgemeinschaft (DFG) for funding this study within the Omani-German research project 'Transformation Processes in Oasis Settlements of Oman' (BU1308).

ANNEX 1. Description of the *Musa* (AAA) 'Umq Bir' clone from Oman

Vegetative parts (Fig. 2a)

Plant freely suckering with first (oldest) sucker about half the length of the pseudostem at fruiting stage. Suckers vertical and close to pseudostem.

Pseudostem green, shiny, of normal stature, 2.5–3 m high. Sap watery. Underlying color (at base, when outern leaf removed) watery green with faint purple pigmentation.

Leaves rather erect. Cigar leaf (the youngest emerging leaf) green without any pigmentation. Leaf sheaths faintly to slightly waxy, moderately covered with brown–black transversal streaks.

Leaf blade length around 150 cm. Proportion width/length = 0.32. Smooth (non-corrugated) surface. Midrib green at both sides. Green, shiny upperside; medium green, shiny lowerside without notable wax. Insertion on the petiole asymmetric with one pointed, one rounded side.

Petiole length around 45 cm. Green with open canal. Narrow (<1 cm) outward-spreading green margins with pinkish edge. The margins dry up at the petiole base.

Infrutescence

Peduncle dark green, velvety, about 30 cm long and 6 cm wide, with one empty node.

Bunch slightly angled to slightly pendulous; lax, with few (3–4) hands of 8–10, long fruits, developed from female flowers in the common biseriate arrangement (Fig. 2b).

Rachis (male axis) strictly pendulous, bare, with very prominent bract scars.

Male bud (<20 cm long) at early fruiting stages rounded and very broad, with extremely deeply imbricate bracts, leaving the emerging youngest bract tips discolored (Fig. 2c).

Male bud at late fruiting stage slender and nearly lanceolate but with pronounced shoulder; still deeply imbricate (Fig. 2d).

Bracts lanceolate, highly shouldered with slightly pointed apex (Fig. 2e). External bract face uniformly red–purple with a slight bluish tinge, moderately waxy and with rather pronounced longitudinal grooves; internal face pale-purple brown, fading on basal part. Bracts lifting one or two at a time are revolute.

Male flowers are white and drop with the bract. Compound tepal white without pigmentation, with developed yellow lobes. Free tepal oval, corrugate, and translucent white, with hardly visible triangular apex. Anthers are inserted, on creamy filament and with creamy dorsal face; pollen sac pale pink to pink–purple, without any pollen. Style white with slight pink to purple pigmentation; stigma bright yellow. Ovary slightly arched, white without pigmentation.

Fruits strictly seedless, 12–15 cm long, curved upwards and straight in the distal part, with persistent style. Slightly ridged when immature but rounded at maturity. Persistent at ripening stage. Apex slightly bottle-necked. Pedicels slightly hairy, short (<10 mm) and narrow (<5 mm), without any trace of fusion-trend. Fruit peel ca. 3.2 mm thick, smooth, green to dark-green when immature, bright yellow at ripening and peels easily off. Pulp with firm texture, white. Remains white when ripe, with sweet taste (like Cavendish).

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