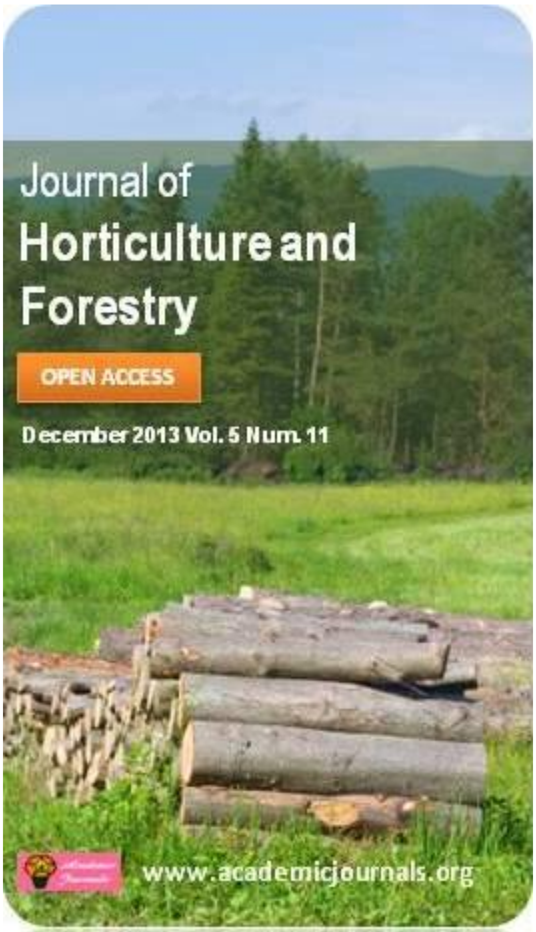

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Full Length Research Paper

Assessment and sustainable management of non-timber forest products used as food and medicine among urban dwellers in Oyo State, Nigeria

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This study assessed the Non Timber Forest Products (NTFPs) used as food and medicine by the urban dwellers of Oyo State, Nigeria. It identified the NTFPs, sources and perception about the effectiveness of utilization as medicine. Data were sourced on the basis of senatorial districts. The three senatorial districts are Oyo South, Oyo Central and Oyo North with a population size of 1,764,217, 1,906,814 and 1,909,863 respectively. Both random and proportionate sampling techniques were adopted with 217 questionnaires processed. Descriptive analysis such as frequency, percentage and histograms with Chi square were used to describe the socioeconomic variations and to assess the various utilizations of NTFPs. The Chi-square analysis showed that occupation (p = 0.001), educational status (p=0.002), income (p=0.013) and age (p=0.011) were statistically significant in determining how the respondents feel about the effectiveness of the use of NTFPs as medicine, but variables like gender (p=0.071) and religion (p=0.121) were not significant. Efforts should therefore be made by government and relevant research institutes to train the people on the domestication of these NTFPs to achieve sustainability, pharmaceutical involvement to make more refine and more awareness about NTFPs. Some of the reasons given by the respondents for using the NTFPs include cheapness, availability and accessibility and some of the sources where they obtain the NTFPs were given as market, hawkers, forest and friends.

Key words: Non-timber forest products, utilization, availability, accessibility, domestication.

INTRODUCTION

Over the years, forestry and its products have contributed immensely to the economic development of Nigeria; the importance of the products cannot be over-emphasized (Fonta et al., 2010). Forests products can be classified into two: Timber, which constitutes the bulk of forests based materials used for economic purposes, and the Non-Timber Forest Products (NTFPs). During the 1960s and 1970s, forest products earned large amounts of foreign exchange and the sector was ranked highest in employment generation. The forest sector earned annual foreign exchange of between 308 million to 412 million naira or about 4.2% of GDP (World Bank, 1988). The situation, however, turned around between 1970 and 1985, due to the discovery of oil. NTFPs have been studied by researchers from many different academic fields and each field used a slightly different definition of NTFPs. They are any product or service other than timber that is produced in a forest (CIFOR, 2004). They

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include fruits, nuts, vegetables, fish medicinal plants, resins, essences, a range of barks and fibers, bamboo, rattans, honey, insects, animals, fodder, fertilizers, medicinal extracts, construction materials, cosmetic and cultural products, natural dyes, tannin, gums, latex and other exudates, essential oils, spices, edible oils, decorative articles, horns, tusks, bones, pelts, plumes, hides and skins, non-wood ligno-cellulosic products, phytochemicals and aroma chemicals. NTFPs are indispensable part of the livelihood strategy of communities living in and near forests and constitute an important source of livelihood for millions of people across the globe.

The role and contribution of NTFPs have been crucial in subsistence as livelihood support, in rural economics and biodiversity conservation since times immemorial due to their richness of variety. About 80% of the population of the developing world depends on NTFP for their primary health and nutritional needs (FAO, 1995). Osemeobo (1991) noted that rural women were found to be making between N115 and N500 in fruit gathering and sale. It is therefore paradoxical that in spite of their real and potential value, most NTFPs remain grouped as minor products of forests. However, in the recent time, there has been increasing recognition of the fact that this approach to forest management is neither conducive to sustainable management of the forests, particularly of the tropical moist forest nor is it in the best economic interest of the predominantly rural societies in the tropics. Due to the relative scarcity of most of the NTFPs now as a result of deforestation, as noted by Nwoboshi (1986) and the present awareness of their importance, more value is being added which has made them highly marketable. Research at a global scale has identified that rural households draw from a diversity of income sources, adopt a range of livelihood strategies in order to achieve and maintain a sustainable livelihood. These include the use of NTFPs both for household consumption and for sale. The contribution of forest to poor people's livelihoods goes largely unrecorded in national statistics. This is due mainly to the role of forest products in subsistence economies and the informal sector, from which reliable and quantifiable data are inherently difficult to obtain.

Various uses of NTFPs have been revealed and described in literature; prominent among them are the uses as food and medicine. However, the utilization varies from region to region. In other words, some used as medicine in a particular region may serve as food in other region and the species used for a particular purpose may differ with regions. It is the realization of these that this study assessed the utilization of NTFPs used as food and medicine in Oyo State. The empirical study was on the assessment of NTFPs among the urban dwellers, who are the so called elites. There is, however, great variation in the extent to which forest products are used from area to area and even between households within a community. Indeed, this variation reflects the extent to which NTFPs are an integral part of rural livelihoods.

Forest foods

NTFPs species are used as food in the form of wild fruits, vegetables, and nuts, edible roots, as bush meat, snails, edible insects and honey. Others are used as food additives in form of spices, flavorings, and food colorants and as fermentation agents, various animal foods such as folder for livestock, straw, baits to catch animals and bee plants. Similar reports on the use of NTFPs as food and food condiments have been made by Andel (2006). Jimoh and Haruna (2007); Tee and Amonum (2008). Other edible food materials found in the forest include insects, rodents, wild game and fish. These have been found to have superior nutritional quality, when compared with domesticated varieties. Besides, processed and stored forest food products help to insure a year round food supply (Jimoh and Adebisi, 2005). Furthermore Jimoh and Adebisi (2005) maintained that NTFPs include a vast number of edible and now edible products gathered from the forest. Some of the products are eaten raw while others are processed in various forms through boiling, drying and other methods.

Medicinal plants

Various NTFPs species have medicinal value for the treatment of various ailments including the treatment of stomach aches, cut/wounds, diarrhea, ulcer, infertility, Malaria, fever, blood purification and others. The roots, seeds, bark, resin, leaves are used for these purposes. Others are used for fishing and to control insects. Abere and Lameed (2008) reported that the African giant land snails (*Achatina achatina* and *Archachatina marginata*) are used to cure whooping cough, anaemia, ulcer, asthma, aphrodisiac and hypertension. Abere and Lameed (2008) further maintained that the fluid of the snails is used to treat headache, treatment of dysentery, eye problems, and small pox. The meat cures bone fracture, infertislity in women while the shell is used to prepare talismans for protection and used culturally to appease the gods as well as to ward off evil spirits. Snails have also been successfully used to curtail aggression, malformation of bone structure and promotion of easy child birth, nourishment of lactating women, suppression of convulsion, healing of amputated fingers and circumcision of male children (Abere and Lameed, 2008). Medicinal and Aromatic Plants (MAPs) include plants used to produce pharmaceuticals, dietary supplement products and natural health products, beauty aids, cosmetics, and personal care products, as well as some products marketed in the culinary/food sector. MAPs have been an important resource for human healthcare from prehistoric times to the present day. According to the World Health Organization, the majority of the world's human population, especially in developing countries, depends on traditional medicine based on MAPs (WHO, 2002). About 50,000 and 70,000 plant species are known to be used in traditional and modern medicinal systems throughout the world (Schippmann et al., 2006). The importance of NTFPs was raised for the past few decades as a result of many factors such as the dependence of rural communities of NTFPs, new market preferences for natural products, increasing concerns about forests and biodiversity conservation, and occurrence of many NTFPs among the biological richness and ecological complexities of natural forests (Grimes et al., 1994).

Sustainable management of NTFPs

Sustainability issues

The increasing demand for natural products in the sectors of food and medicinal ingredients poses major ecological and social challenges. High pressures on wild resources are threatening the survival of populations and species, while also endangering local ecosystems. Overharvesting of selected plants for commercialization, premature collection along with habitat destruction, open grazing, forest fire and soil erosion are major threats to the sustainability of NTFP conservation. Sustainable management of NTFPs is important because of their value as a perennial source of subsistence income and to conserve biodiversity. For the past few decades, these resources have been highly exploited for trade. Harvesting usually takes place before the plants mature. Moreover, bark is harvested by cutting plants of all size classes within the available area. These practices not only hamper the regeneration of the concerned species, but also pose threats to their long-term survival (Edwards, 1996; Olsen and Larsen, 2003). Most high-valued NTFPs are collected from the wild without paying attention to the quantity and quality of harvested material. Being the least benefitting groups, collectors often tend to harvest more than the harvestable quantity to get more money. Similarly, competition among collectors compels them to collect NTFPs prematurely, resulting in their gradual disappearance from the wild. Soil erosion and forest fires are issues that occur mostly by anthropogenic causes.

Specific objectives

1. To identify non timber forest products (NTFPs) in the study area,
2. To identify the sources of NTFPs to urban dwellers,
3. To determine the relationship between the socioeconomic variables of the respondents and their perception about the effectiveness of the utilization of NTFPs as medicine,
4. To identify the constraints faced by the respondents (urban dwellers) in getting the NTFPs.

METHODOLOGY

The research was carried out in Oyo State, which is an inland state in south-western Nigeria, with a population of about 5,580,894 (NPC, 2006) and its capital at Ibadan. It is bounded in the south by Ogun State and in the north by Kwara State, Nigeria. In the west it is bounded partly by Ogun State and partly by the Republic of Benin while in the east it is bounded by Osun State. The State is located on Latitude 8° and Longitude 4° east and covers a total of 27,249 km^2 of landmass. The vegetation pattern of the state is that of rainforest in the South and guinea savannah to the North. Thick forest in the South gives way to grassland interspersed with trees in the North.

Oyo state is divided into three senatorial districts: Oyo South, Oyo North and Oyo Central, Oyo North has 13 Local Governments viz: Saki West, Saki East, Atisbo, Irepo, Olorunsogo, Kajola, Iwajowa, Itesiwaju, Ogbomoso North, Ogbomoso South, Orire, Oorelope and Iseyin. Oyo Central comprises 11 Local Governments of Afijio, Akinyele, Egbeda, Ogo-Oluwa, Surulere, Lagelu, Oluyole, Ona-Ara, Oyo East, Oyo west and Atiba. While Oyo South consists of 9 Local Governments. They are Ibadan North, Ibadan North East, Ibadan North-west, Ibadan South-East, Ibadan South-West, Ibarapa Central, Ibarapa North, Ibarapa East and Ido.

Method of data collection

Data were collected on the basis of Senatorial District and the three senatorial districts are Oyo South, Oyo Central and Oyo North. Both random and proportionate sampling techniques were adopted. Random sampling technique was adopted in selecting the Local Government Areas from each Senatorial District. The proportionate sampling technique was used to determine the exact number of questionnaire that was administered to respective communities in the chosen Local Governments in relation to the population of the Senatorial District they belong. A total of two hundred and thirty (230) copies of questionnaire were administered at household level out of which two hundred and seventeen (217) copies were found analyzable.

Method of data analysis

Descriptive statistics such as frequency, histogram and percentage were used to describe the socioeconomic characteristics of the respondents. Chi-.square was used to test the relationship between socioeconomic variables of respondents and their utilization of non timber forest products as medicine.

Chi Square (X^2) = $\sum (O-E/E)^2$

Where O = Observed Frequency of users of NTFPs who feel they are more effective than orthodox medicine.

Hypothesis

The null hypothesis (Ho) states that there is no significant relationship between the selected socioeconomic variables (occupation, educational status, income, age, gender and religion)

Table 1. Socioeconomic characteristics of respondents.

Variable	Frequency	Percentage
Sex		
Male	130	62.8
Female	77	37.2
Total	207	100.0
Age (years)		
≤ 30	25	12.1
31-40	63	30.4
41-50	71	34.3
Above 50	48	23.2
Total	207	100.0
Marital status		
Single	28	13.5
Married	174	84.1
Divorced/Widow/Separated	5	2.4
Total	207	100.0
Religion		
Christianity	109	52.7
Islam	98	47.3
Total	207	100.0
Occupation		
Civil Servant	37	17.9
Trading	93	44.9
Artisanship	48	23.2
Farming	13	6.3
Others	16	7.7
Total	207	100.0

Source: Field Survey, 2012.

Table 2. Socioeconomic characteristic continued.

Variable	Frequency	Percentage
Educational background		
No formal	30	14.5
Primary	60	29.0
Secondary	68	32.9
Tertiary	49	23.6
Total	207	100.0
Household size		
1-5	54	26.1
6-10	85	41.1
Above 10	68	32.8
Total	207	100.0
Household monthly income		
<N10,000	26	12.6
N10,000-N30,000	128	61.8
N31,000-N50,000	34	16.4
>N50,000	19	9.2
Total	207	100.0

Source: Field Survey, 2012.

of the respondents and their perception about the effectiveness of the utilization of NTFPs as medicine while the alternative hypothesis (H_1) states that there is a significant relationship between the socioeconomic variables and respondents perception about the effectiveness of the utilization of the NTFPs as medicine and food.

RESULTS AND DISCUSSION

The socioeconomic characteristics of the respondents are summarized in Tables 1 and 2. From the table, it is shown that majority (62.8%) of the respondents or users of NTFPs found in the urban centers were males and 37.2% were females. This may not be unconnected to the fact that the male folk are mainly the household head and the major controller of household resources, as attested to by Edeh and Mbam (2010) in their research on constraints limiting efficient utilization of improved cassava technologies in Ebonyi State. It was discovered from the field that males uses NTFPs as medicine more as they move in their daily activities. For instance the hawkers of the traditional medicine are seen more on the street, in front of offices and Motor Park in the urban area. About sixty five percent (64.7%) of the respondents were between age range of 31 to 50 years; an indication that the respondents were within the active workforce, with majority (84.1%) married. The respondents that were Christians accounted for 52.7% while 47.3% were Muslims. This implies that both Christians and Muslims use Non timber Forest Products (NTFPs) both as food and medicine in the study area. Larger proportion (about 45%) of the respondents was traders 22% were artisan 37% were civil servant and remaining were farmers. From Table 2, about 62% of them either had primary or secondary school education the remaining had post secondary education. This is an indication that education does not really constitute a barrier in using NTFPs. The World Health Organisation (WHO, 2002) confirmed that 80% of the world's population presently uses herbal medicine and tend towards organic value for some aspects of primary care. It has become indispensable practice. Adekunle and Samwobo (2004) documented 103 plants species of different life forms traditionally used to treat different sickness and diseases. About 74% of the respondents had household size of six or more people, with monthly income of N30, 000 and below accounting for about 74% of the respondents. This implies that majority of the respondents are within the low income class.

Table 3 depicts the various species of NTFPs used as medicine by the respondents. Different reasons were given by the respondents for their use of these species

Table 3. NTFPs used as medicine.

Local name	Scientific name	Part used	Uses
Bamboo	*Bambusa vulgaris*	Leaves	Syphilis/gonorrhea
Honey	*Apis mellifera*	Fluid	wound dressing/cough
Bitter kola	*Garcinia cola*	Fruit	Healthy liver/gall bladder
Kola nut	*Cola nitida*	Nut	Asthma/stimulant
Walnut	*Juglans nigra*	Nut	Detoxification
Snail	*A. achatina*	Whole part/fluid	Ulcer/Hypertension
Alligator pepper	*Aframomum melegueta*	Leaves	Malaria fever
Shea butter	*Vitellaria paradoxa*	Fruit/seed	Cosmetics
Locust bean	*Parkia biglobosa*	Roots	Infertility/poison
Cashew	*Anacardium*	Leaves/bark	Diabetes/hypertension
Irvingia	*Irvingia gabonensis*	Leaf/fruit/bark	Diarrhoea
Lemon grass	*Cymbopogon Spp.*	Leaves	Perfume
Neem	*Azadirachta indica*	Leaf,/root/ bark	Malaria/gonorhoea
Pawpaw	*Carica papaya*	Fruit, leaves	Poison/nausea/typhoid
Ugwu	*Telfairea occidentalis*	Leaves	Anaemia
Cassia	*Cassia alata*	Leaves	Skin infections
African pear	*Dacryodes edulis*	Stem bark	Cough/body ache
Scent leaf	*Occimum gratissimum*	Leaves, tender stem	Diarrhoea/typhoid
Mango	*Mangifera indica*	Leaves/bark/fruit	Fever/hypertension
Garden egg	*Solanum melongena*	Fruit	Heart disease/glaucoma
Pineapple	*Ananas comosus*	Fruit	Healthy bone
Tea Leaf	*Camellia sinensis*	Leaves	Heart disease/cancer
Bitter leaf	*V. amygdalina*	Leaves/root	Diarrhoea
Guava	*Psidium guajava*	Leaves	Diarrhoea
Baobab	*Adansonia digitata*	Bark/Seed	Low sperm count
Jatropha	*Jatropha curcas*	Leaves	Stomach ache

Source: Field Survey, 2012.

as medicine. These include cheapness, addiction, availability, accessibility and others. This corroborates the works of Amusa et al. (2010) and Jimoh et al. (2012) in which factors accounting for the dependency of communities on traditional medicine were given as culture, efficacy, cost, availability, accessibility and poverty. However, when asked if they observed any side effects from the use of NTFPs as medicine, less than 10% of the respondents claimed they had observed one form of side effect or the other. Some of the side effects include excessive sleeping, dizziness, running stool, weakness of the body, vomiting, and stomach ache. This may not be unconnected to lack of specification on the required dosage or quantity of the medicinal plants to take as many of them claimed they took as much as they can while others claimed they took 2 to 3 cups (with no specific unit of measurement) twice or thrice a day. This also confirms the earlier work by Famuyide et al. (2011) in which the negative effects from the medicinal use of NTFPs were stated as vomiting, nausea, stomach ache and body itching.

Table 4 shows the species that are used as food by the respondents. Some of these species are eaten raw as snacks while others are cooked or transformed into edible form. Some of the species that are eaten raw as snacks include *Carica papaya* (pawpaw), *Psidium guajava (*Guava)*, Anacardium occidentale* (Cashew), *Irvingia gabonensis* (Bush mango), *Musa accuminata (*Bannana), while those cooked or transformed into edible form include *Thryonomys swinderianus* (Grasscutter), *Agaricus bosporium (*Mushroom), *Juglans nigra* (Walnut), *Parkia biglobosa* (Locust bean). Several reasons were given by the respondents for using non timber forest products as food, as shown in Figure 1. Some (26.2%) of the respondents said that they eat NTFPs because of the taste and flavor while about 27% claimed they eat the NTFPs because of their nutritional value, as evident in Figure 1. This corroborates the study by Awe et al. (2009a) in which majority (76%) of the respondents claimed they consumed grasscutter meat (a non timber forest product) because of its taste and quality. Figure 2 shows the different sources where the respondents obtained their NTFPs. About 43% of them claimed they got theirs from the market, while those that got theirs directly from the forest accounted for about 33%. Different reasons were given by the respondents as

Table 4. NTFPs used as food.

Local name	Scientific name	Part used	Uses
Pawpaw	*Carica papaya*	Fruit	Snacks
Guava	*Psidium guajava*	Fruit	Snacks
Mango	*Mangifera indica*	Fruit	Snacks
Grasscutter	*Thryonomys swinderianus*	Whole part	Meat
Cashew	*Anacardium occidentale*	Fruit	Snacks
Mushroom	*Agaricus bosporium*	Strip/pileus	Condiment
Honey	*Apis mellifera*	Fluid	Sweetener
Walnut	*Juglans nigra*	Fruit	Snacks
Snail	*Archachatina marginata*	Whole part	Cuisine
Locust Bean	*Parkia biglobosa*	Fruit pump, seeds	Condiment
Bush mango	*Irvingia gabonensis*	Fruit	Snacks
Orange	*Citrus sinensis*	Fruit	Snacks
Banana	*Musa accuminata*	Fruit	Snacks
Ugwu	*Telfairea occidentalis*	Leaves	Cuisine
Garden Egg	*Solanum melongena*	Fruit	Snacks/condiment
Pineapple	*Ananas comosus*	Fruit	Snacks
Coconut	*Cocos nucifera*	Fruit/nut	Snacks
Baobab	*Adansonia digitata*	Fruit	Snacks
Bitter leaf	*Vernonia amygdalina*	Leaves	Cuisine
Sheabutter	*Vitellaria paradoxa*	Fruit/seed	Cooking oil

Source: Field Survey, 2012.

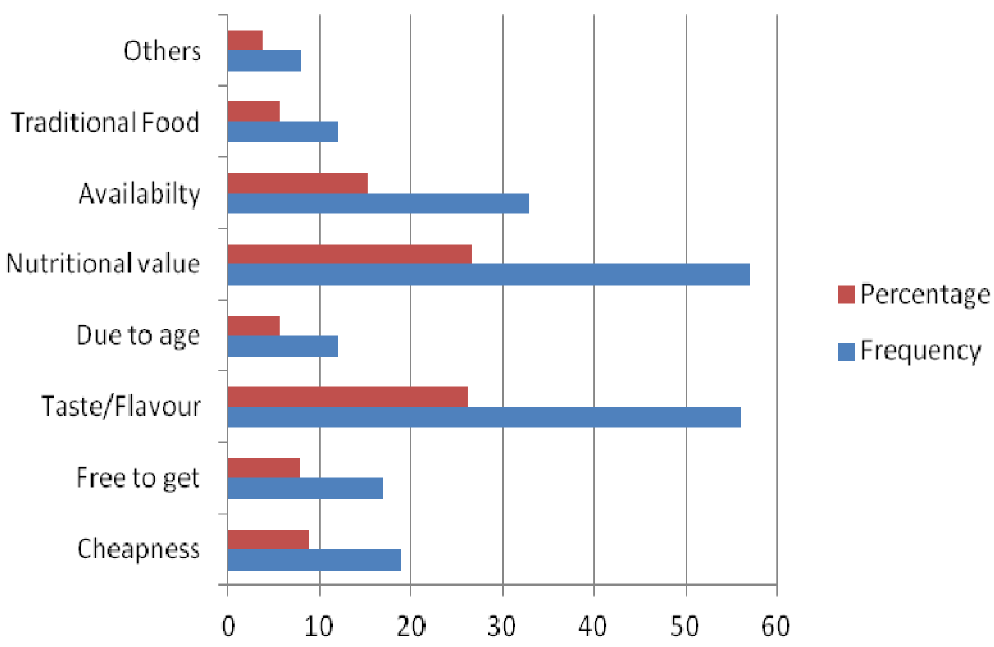

Figure 1. Reasons for using NTFPs as food.

problems being encountered in getting the NTFPs when they needed them. These include seasonality (63.1%), perishability (22.9%), transport cost (8.9%), with others such as proximity, affordability, e.tc, accounting for 5.1%.

Table 5 shows Chi-square analysis testing the relationship between socioeconomic variables of respondents and their perception about the effectiveness of the utilization of NTFPs as medicine. In other words, the test was to ascertain whether there was any significant relationship between the selected

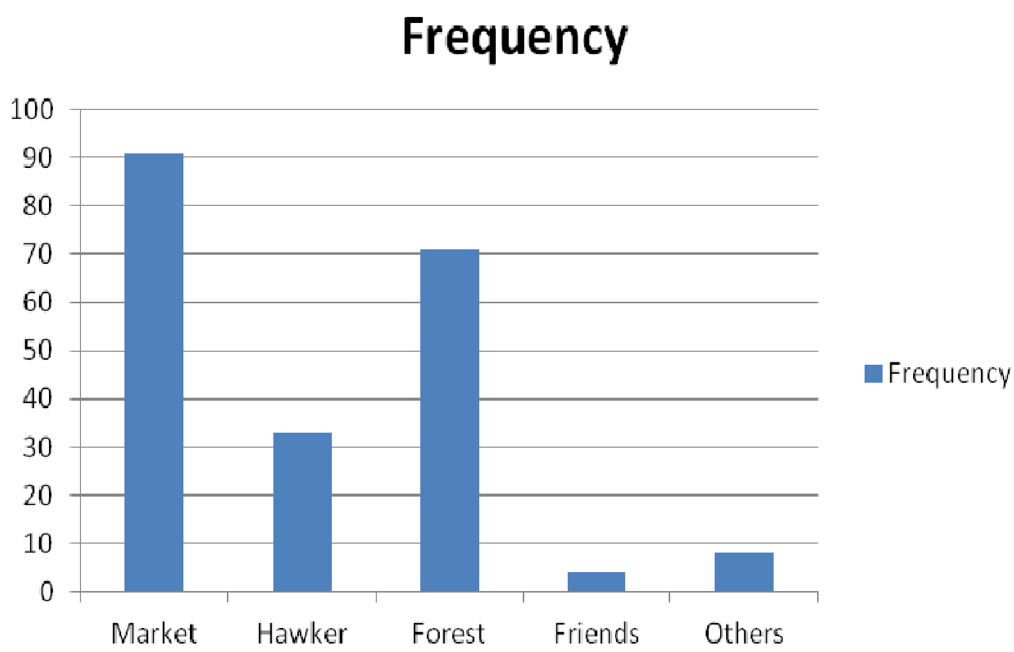

Figure 2. Sources of NTFPs in the area.

Table 5. Chi-square result of relationship between socioeconomic variables of respondents and their perception about the effectiveness of the utilization of NTFPS as medicine.

Variable	X^2	DF	P-value	Decision
Occupation	12.217	4	0.001	Significant
Educational status	16.014	3	0.002	Significant
Income	18.337	3	0.013	Significant
Age	19.194	3	0.011	Significant
Gender	3.102	1	0.071	Not significant
Religion	3.006	1	0.121	Not significant

Source: Chi-square analysis.

socioeconomic variables of the respondents and what they felt about the effectiveness of the medicinal use of NTFPs. It was found that occupation, educational status, income and age were statistically significant while religion and gender were not significant. This implies that religion and gender have nothing to do with what the respondents feel about the effectiveness of medicinal use of non timber forest products in the study area. This conforms with the work of Odebode et al. (2011) in which religion was found not to be significant in determining the perception of consumers about the consumption of grasscutter meat within Ibadan Metropolis.Hence the null hypothesis that there is no significant relationship between the socioeconomic variables of the respondents and their perception about the effectiveness of the utilization of NTFPs as medicine was rejected for occupation, educational status, income and age, while it was upheld for religion and gender.

CONCLUSION AND POLICY RECOMMENDATION

This study assessed the Non Timber Forest Products (NTFPs) used as food and medicine by urban dwellers of Oyo State, Nigeria. The study revealed that majority (62.8%) of the respondents was male while 37.2% were female. It was also discovered that the utilization of NTFPs has no religious barrier as both Christians (52.7%) and Muslims (47.3%) used them. Some reasons given by the respondents for using the NTFPs include cheapness, availability and accessibility and some of the sources where they obtain the NTFPs were given as market, hawkers, forest and friends. Some of the constraints encountered by the respondents in obtaining the NTFPs included seasonality (63.1%), perish ability (22.9%), transportation (8.9%), with others such as proximity, affordability, e.tc, accounting for 5.1%. In view of this, efforts should therefore be made by governments at all levels and relevant research institutes to train the people on the domestication of these NTFPs so as to achieve sustainability. Pharmaceutical companies should work on processing of NTFPs medicinal plants to make it more available in a refined form, less chemical and still natural. More awareness should be made about utilization of some NTFPs as food for their nutritional value and medicinal value especially when organic food is advocated for globally.

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Review

Banana domestication on the Arabian Peninsula: A review of their domestication history

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Bananas are one of domesticated crops prehistoric in Arabian region. However, domestication history of this crop in this region did not receive attention by researchers. The strategic location of the Arabian Peninsula at the intersection of several main Old World trade routes has made it an incubator for bananas coming from different continents of the world. Tracing the history of bananas in this region and understanding the drivers of their diversity under inhospitable conditions may help maintain and further develop banana cultivation in similar areas of the world, especially where this issue has not been extensively studied. Domesticated banana cultivars presently found in the Arabian Peninsula are not indigenous to the region. The Islands of Southeast Asia and Southern China are the strongest candidate to be the primary sites of banana domestication, the subsequent phases of cultivation and translocation to other parts of the world during the prehistoric era. The Gulf ports, in particular Omani coastal ports and Indian Ocean trade effectively contributed to the exchange of plant genetic resources including bananas between the Arabian Peninsula areas and the Indian subcontinent, Africa and China. There is a relationship between ancient coastal ports and the presence of a variety of banana subgroups in some areas of the Arabian Peninsula such as Oman.

Key words: Maritime routes, ancient ports, linguistic, archaeological, translocation, banana history.

INTRODUCTION

Bananas have a long history of domestication and the role of mankind in their diffusion throughout the tropical and subtropical regions of the world has made them one of the most important fruit crops. Over the centuries, bananas have contributed to the stability of rural communities where they have provided work for farmers and reduced farmer migration to cities in search of alternate livelihoods (De Langhe et al., 2009). Eighty-seven percent of bananas produced globally are consumed locally (Biodiversity International, 2012). Even in many countries of the Arabian Peninsula, bananas play an important role as a food crop, although this arid region has an ecologically unfavourable climate for banana cultivation. Banana production in Arabian countries accounts for 2% of the total world banana production and 1.5% of total area harvested (FAOSTAT, 2010).

Over the past millennia, the banana domestication process has undergone different stages involving exploitation, hybridizations, somatic mutations and cultivation inside the natural habitat (De Langhe et al., 2009).

Subsequent steps involved the dispersal of domesticated varieties outside their natural habitats, to different geographical regions of the world. This led to often unpredicted genetic changes in banana varieties (Buerkert et al., 2009; De Langhe et al., 2009). Given the serious challenges in particular biotic and abiotic stresses facing sustainable banana production, in addition to local

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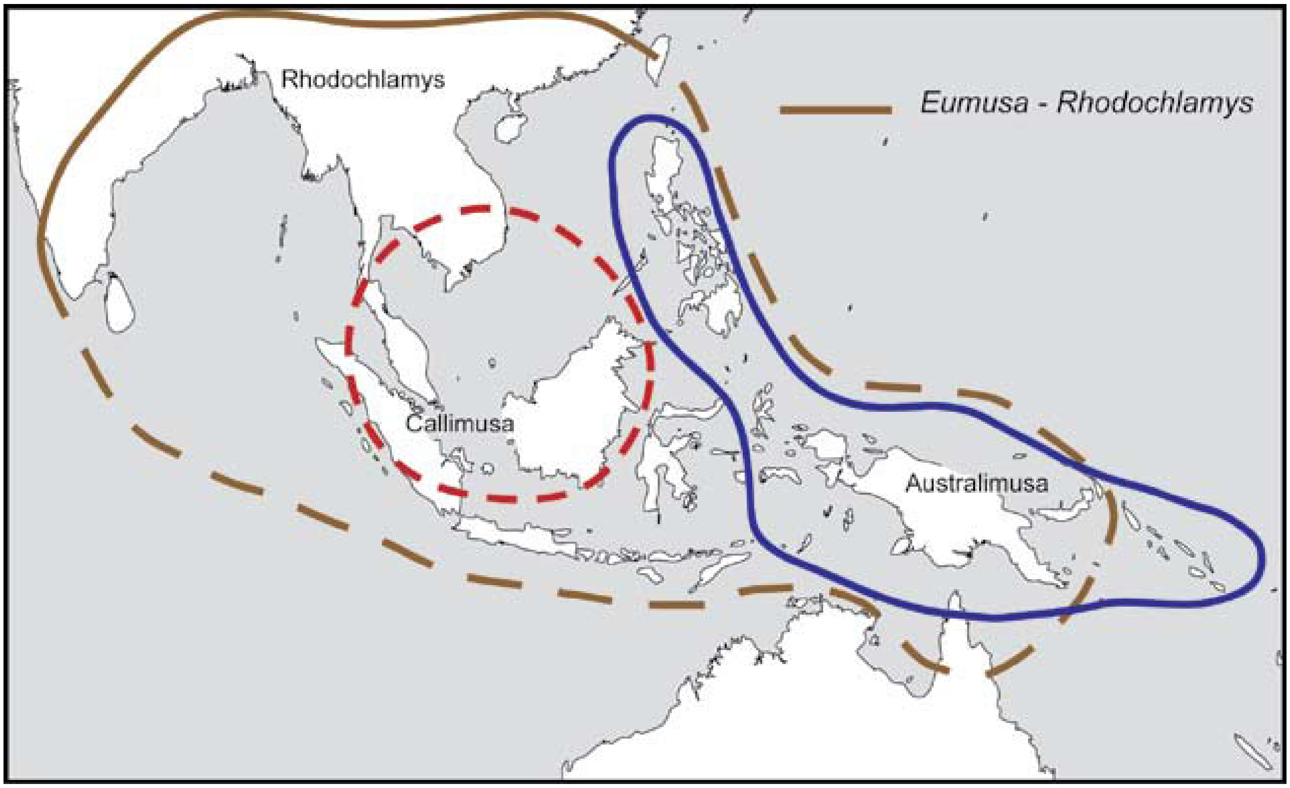

Figure 1. Distribution of *Musa* genus in East Asia (Simmonds, 1962, altered from De Langhe, 2009).

problems such as oasis modernization (Buerkert et al., 2009; Al-Saady et al., 2010), understanding and tracing banana diversity in the Arabian Peninsula is important. The diverse cultivars found in this region of the world include specially adapted varieties, not found anywhere else in the world. This study highlights the history of banana domestication in the Arabian Peninsula areas, particularly introduction and cultivation by reviewing papers that discuss linguistic, genetic and archaeological evidence as well as maritime routes that were perhaps used to introduce bananas to the Arabian Peninsula.

BANANA DOMESTICATION IN THE WORLD

Classification and distribution of banana species

The exact date of banana domestication is still subject to speculation, but recent multidisciplinary evidence indicates that the first domestication stage took place about 4500 years before present (BP) (De Langhe and de Maret, 1999; De Langhe et al., 2009). However, based on the archaeological evidence from New Guinea (Perrier et al., 2011), cultivation of domesticated banana varieties started about 6500 years BP. Human contact and migration played a crucial role in the domestication of banana varieties outside their natural habitat (Mindzie et al., 2001; Vrydaghs et al., 2009; Perrier et al., 2011).

Banana belongs to the family Musaceae which includes three genera; Asian and African *Ensete*, Asian *Musella* and East Asian *Musa* (De Langhe et al., 2009; Perrier et al., 2011). All edible bananas belonged to the genus *Musa* (Perrier et al., 2011). Simmonds (1962) divided the genus of *Musa* into 4 sections (Figure 1): Eumusa which covers all of East Asia, except Eastern Melanesia, Rhodochlamys which is spread along the monsoonal mainland of Southeast Asia, Australimusa which is distributed from south-eastern Indonesia and the southern Philippines to Melanesia, and Callimusa which is presented in Southern Vietnam, Malaysia, Borneo and Sumatra. According to Simmonds and Shepherd (1955), most of the edible diploid and triploid bananas are formed by inter- and intra-specific crosses of *Musa acuminate* (A) and *Musa balbisianana* (B) and are classified into the groups representing both their ploidy and species composition, that is AA, AAA, AAB and ABB. Fuller and Boivin (2009) mentioned that most plantains belonged to the AAB group and most desert bananas to AAA.

Secondary and tertiary distribution followed (Figure 2) and produced seven recognizable geographical areas each with a high density of specific cultivars (De Langhe, 2009):

(1) AA and AAA cultivars in the triangle between Indonesia, the Philippines and Melanesia (red line), with an exceptional density of AA cultivars in and around New

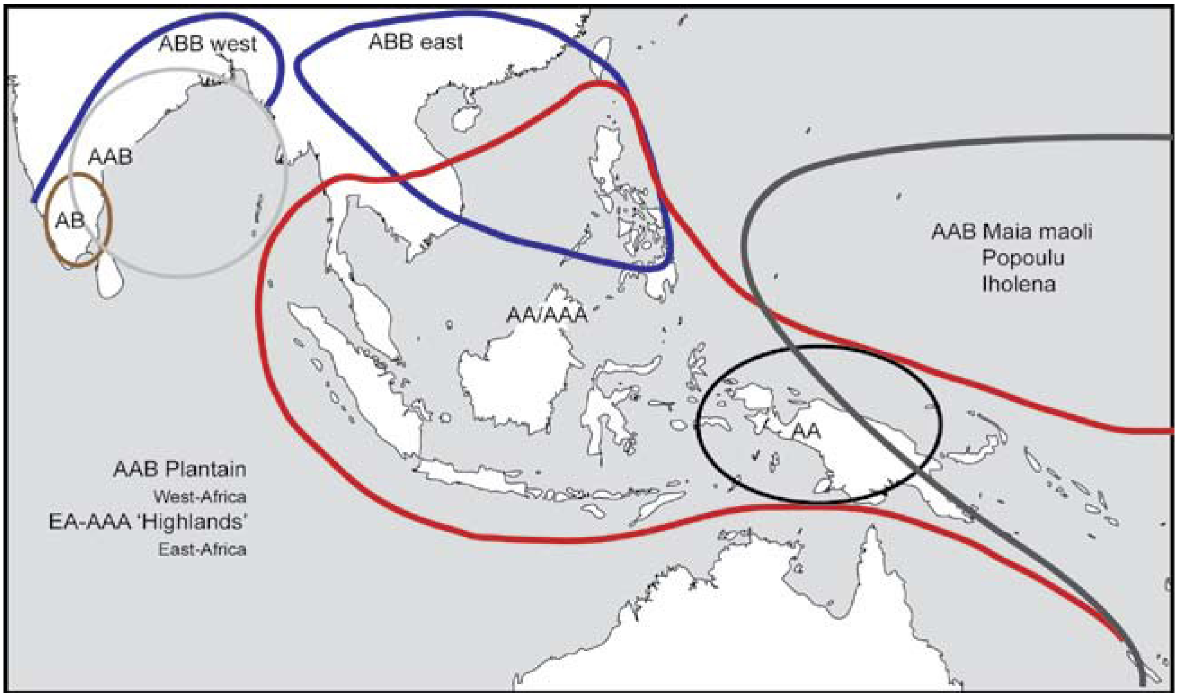

Figure 2. Distribution of the main banana cultivar groups (taken from De Langhe et al., 2009).

Guinea (black oval);
(2) Highland AAA bananas in the Great Lakes region of East Africa (East African Highland Bananas: EA-AAA 'Highlands'; area not shown on map in Figure 2);
(3) AAB plantains in the rainforest zone of Africa (area not shown on map in Figure 2);
(4) AAB Maia Maoli-Popoulu-Iholena cultivars in Oceania (dark grey line);
(5) AB (brown oval) and other AAB (pale grey circles) cultivars in South India;
(6) Eastern ABB cultivars in the Philippines and Vietnam (blue line - closed);
(7) Western ABB cultivars in Northeast and South India (blue line - open).

Linguistic and cultural evidence indicates that West Africa was the earliest centre for growing AAB plantains, while specimen of the AAA group were the first grown in East Africa (De Langhe and Maret, 1999; De Langhe et.al., 2009; Blench, 2003). The great diversity of cultivars in these areas and Iron Age phytoliths of banana found in Cameroon support this evidence (Mbida et al., 2000).

Origin and migration routes of banana species from natural habitat to other continents

Recent DNA and fingerprinting analyses of more than 400 wild and cultivated accessions, in addition to samples taken from Cameroon and Nigeria to better represent the diversity found in Africa, revealed that the islands of Southeast Asia and Western Melanesia likely are the main centre for the hybridization between different *M. acuminata* subspecies which generated edible diploids cultivar subgroups (AA cultivars; Perrier et al., 2011). Banana domestication passed through two stages: first the translocation from wild to edible diploids by hybridization of *M. acuminata* during the Holocene in New Guinea (Simmonds, 1962; Perrier et al., 2011) and subsequently the development of edible triploids (AAA) from edible diploids (AA) via spontaneous triploidizations (Perrier et al., 2011). Most domesticated bananas are triploid, including the widely distributed commercial Cavendish group (Perrier et al., 2011). Lastly, Perrier et al. (2011) used genetic, linguistic and archaeological data to determine the locations of banana groups. They suggested three contact areas of *M. acuminata* subspecies where the development of domesticated diploids took place: the Northern contact area with *malaccensis, microcarpa* and *errans* in South East Asia, Borneo and the Philippines; the eastern contact area with *errans* and *banksii* between the Philippines and New Guinea; and the Southern contact area with *banksii*, *zebrina* and *microcarpa* located between New Guinea and Java. It seems clear that the islands of Southeast Asia are the origin for all bananas and subsequently the different groups migrated to different areas of the world (Perrier et al., 2011). Based on this, Perrier et al. (2011) suggested two independent introduction events for triploid subgroups to Africa:

(i) AAA Mutika Lujugira and associated AAcv moved from the region between New Guinea and Java (Southern contact area) to East Africa;
(ii) AAB African Plantains moved from the Philippines and New Guinea (Eastern contact area) to Africa.

These hypotheses were also supported by Blench (2009) who mentioned that based on the botanical and linguistic evidence West African plantains (AAB) arrived from Southeast Asia earlier than 3000 BP. Similarly, Fuller and Madella (2009) hypothesized that the major diffusion of banana cultivars occurred in the later Iron Age, 2000 years BC. This is based on textual sources and historical linguistics from South Asia and China.

Geography of the Arabian Peninsula and early agriculture

The Arabian Peninsula is natural point of contact between the continent of Africa from the West and the Levant and Europe from the north and the continent of Asia from the east (Boivin and Fuller, 2009). In most of the Arabian Peninsula, the desert climate is considered the most important agro-ecological factor to determine landuse. The Arabian Peninsula is located between two main rainfall patterns: the winter rains of the Mediterranean region and summer monsoon rains (Boivin and Fuller, 2009). Digging wells and extracting water from aquifers supported agriculture in lowland oases and coastal regions which have insufficient rainfall (Edens, 1993; Blau, 1999). The later development of the *aflaj* system (Magee, 2005) leads to increased use of oases for agriculture and allowed the cultivation of different crops. Agricultural and accompanying maritime activities in the Arabian Peninsula have been triggered to a large extent by changes in climatic conditions over the Holocene period.

The early and middle Holocene (9000 to 2500 before Christian, BC) periods were characterized by relatively high rainfall intercepted by pronounced dry periods, in particular between 4000 to 4500 years BC (Boivin and Fuller, 2009). During this period, settlements were established in the desert areas such as the Eastern Sahara or Arabian Desert from northern Egypt to Eritrea in the south and parts of Sudan and Ethiopia, which were in habitated by Egyptian/Sudan groups (Hassan, 1997; Fuller, 1998).The Thar desert or Great Indian Desert (arid region in the north-western part of the Indian subcontinent) was settled by Mesolithic groups from India / Pakistan (Fuller, 2006). Similarly, the An Nafud or Al-Nefud settlement (located in the Northern part of the Arabian Peninsula) was established and with vegetables and fruits were grown (Boivin and Fuller, 2009).

In the mid-Holocene (6000 to 5900 BC), the conditions were wetter than at present and this was also the case for An-Nafud in the north of the Arabian Peninsula (Lézine et al., 1998). Potts (2008) mentioned that in the seventh millennium BC, Arabia was more attractive to the people than the Levant and Mesopotamia and this might have contributed to their migration to Arabia and the associated transfer of cultivated plant species from the Levant to Arabia. Evidence from northern Oman, the United Arab Emirates and the An-Nafud region indicates a period of aridity around 3800 BC called the 'Dark Millennium' during which even well established settlements collapsed (Uerpmann, 2003). Additionally, evidence from the Awafi palaeolake in the United Arab Emirates indicates that during the period from 3900 BC and 3200 BC, two arid periods led to a general decline of vegetation and its disappearance in Eastern Arabia (Parker et al., 2004, 2006).

Introduction of crops to the Arabian Peninsula in the Bronze age

The fertile periods in the early and middle Holocene experienced by the Arabian Peninsula and the establishment of agricultural settlements such as An-Nafud encouraged the entry of various agricultural crops including banana. Hammer et al. (2009) reported that about 21.3% of plant species in the Arabian Peninsula came from South and Southeast Asia, 20.6 % from the Near East and East Mediterranean and 15.4% from South America. This data supports the view of Boivin and Fuller (2009) who considered that most of the plants and animals in the Arabian Peninsula region are not native to this region. Despite the limited archaeological evidence of agriculture in the Arabian Peninsula the presence of agricultural equipment (Potts, 1994), of ancient (3200 BC) irrigation systems in the highlands of Yemen (Harrower, 2008) and the great areas of wheat and barley cultivation in some areas of the Arabian and Persian Gulf region indicate that agriculture has been practiced in this region for a long time. Taking into accounts the geographical distribution of banana genotypes (Figure 2), it seems that the Arab/Swahili and Malagasy-Malay (after 600 AD) trade played a vital role in the early dispersal of banana across the Indian Ocean and Red Sea to the Arab world. Similar banana varieties are found in Oman and Egypt (Castillo and Fuller, 2012). This trade route dispersal theory is supported by the discovery of remains of banana peels from the Arab trading period in Quesir al-Qadim located on the coast of the Red Sea (Van Der Veen, 2011).

In general, data indicate that the early third millennium saw the introduction of different crops including banana from Africa, South and Southeast Asia to the Arabian region (Boivin and Fuller, 2009). This has been confirmed by intensive presence of bread wheat in the Persian Gulf and the presence of the same variety in Asia particularly in the Indus region (Fuller, 2003, 2006). This indicates the starting of crop migration from South Asia to the

Arabian Peninsula. Also, in Yemen, Egypt and Nubia emmer wheat was dominant until the first millennium BC (Fuller, 2004), suggesting genetic exchange between the Arabian Peninsula and North Africa.

According to Robinson (1996), banana is mentioned in the Holy Koran as the 'tree of paradise' and the name of the genus (*Musa*) is derived from the Arabic word Mouz. Ancient Egyptian drawings already show bananas and it is believed also that the Assyrian civilization, which extended its authority to the Nile, introduced bananas to the Middle East (Attif and Muhammad, 2000). In 327 BC, the first accurate description of bananas appeared in Greek books after the invasion of India by Alexander the Great; however, it is believed that Arabs introduced bananas from India to the Middle East and North Africa (Attif and Muhammad, 2000). Kinder and Hilgemann (1974) mention that the arrival of Muslims in India, where a great variety of bananas exists, may have contributed to the introducing of bananas to the Arabian Peninsula.

Despite the long and ancient history of banana cultivation in the Arabian Peninsula, the archaeological and historical evidence is still limited. The exact origin, entry date and routes of banana introduction to this region remain a source of speculation. Since edible bananas reproduce vegetatively and not by seeds, their spread is particularly difficult to track (Vrydaghs et al., 2009). Potts (1994) mentioned that banana arrived in south-eastern Arabia by the 9th Century. Historical and cultivation evidence suggests that the origin of the banana planted in Dhofar and Yemen described in Medieval times (Varisco, 1994) was New Guinea/Indonesia (Kennedy, 2008) and the Valley of the Indus (Fuller and Madella 2001). Archaeobotanical evidence from Oman (Muweilah, Mleiha, Hili Bat, Ras al-Hamra, Ras al-Jinz), United Arab Emirates (Dalma, Umm an-Nar, Tell, Abraq, Muweilah, Mleiha, and Rumeilah and Yemen (Sabir, Hajar Bin Humeid, Hajar al-Tamrah, Haja al-Rayhani, Baraqish, Raybun and Khawlan sites: al-Raqlah, Jubabat al-Juruf, Wadi Yanaiim, Dhamar sites: Hayt al-Suad, al-Massanah) indicates that plants were domesticated in Arabian Peninsula between 1500-5000 BC, (Boivin and Fuller, 2009) and bananas could therefore have been introduced even earlier than in the 9th century BC.

Banana genetic diversity on the Arabian Peninsula

Despite of drought periods experienced by the Arabian Peninsula in successive millennia, bananas have not vanished. This was previously noted in the report of a survey by De Langhe (2002) in some Arabian countries. He pointed out the existence of large banana genetic diversity in this region. The bananas found in the Middle East (Jordan, Egypt and Oman), belong to the subgroups AA, AAA, AAB, AB and ABB (De Langhe, 2002). The crop may have undergone some modification over time, which made it more adapted to the arid regional conditions. Genetic mutations and human practices such as cultivation of banana under the shade of date palm in the Interior Governorate of Oman to provide humid microclimate could be one of the factors which have contributed to the survival of this crop in this region. As mentioned previously, Southeast Asia is the main source of banana; however the bananas present on the Arabian Peninsula today did not necessarily come directly from Southeast Asia, but may have travelled through Africa or India, before reaching the habitats on the Arabian Peninsula. However, this dispersal theory remains controversial. Buerkert et al. (2009) hypothesize that the AAA cultivar (cv. 'Umq Bir') recently discovered in the Upper Tiwi Valley of Oman reached there via East Africa, most likely Zanzibar, Madagascar or the Comoros islands where many AA and AAA cultivars are available.

De Langhe and Maret (1999) and Kennedy (2008) believe that *Musa sapientum,* which was planted in Dhofar and Yemen in antiquity, was introduced through Guinea/Indonesia, while others believe it came through the Indus Valley (Fuller and Madella, 2001). More than 31 accessions of banana were planted in 1997/1998 at the Salalah Agriculture Research Station of Dhofar Governorate, Oman. The origins of these accessions are the Comoros Islands, Zanzibar and India (De Langhe, 2002). Recently, nine hybrid cultivars (FHIA) were introduced by INIBAP and evaluated under southern (Dhofar Governorate) and northern Omani (North Al-Batinah Governorate, Sohar) conditions with respect to yield and tolerance to biotic and abiotic stresses, especially Sigatoka and Panama disease as well as salt and heat stress. When banana varieties are transferred from one area to another, their names sometimes remain the same and in this case it is easy to trace them (De Langhe, 2002). However, sometimes the names are changed immediately after arrival to a new place or after different generations which makes it more difficult to trace and identify them linguistically (Perrier et al., 2011). For example, in Yemen banana are called ‘Al-Mawaz Al-Hindi’ which means Indian Banana. In Egypt banana is also called ‘Hindi’. In Oman, the ‘Somali’ banana variety may have been introduced from Somalia by individuals while the ‘Malindi’ variety might have entered Oman from the town of Malindi located northeast of Mombasa, on the Indian Ocean. Similarly, the ‘Zanzibar’ variety likely is from the Island of Zanzibar (Tanzania). The ‘Fardh’ variety belongs to the Mysore group possibly having been introduced from near the town of Mysore in India, the plantain ‘Kenya’ from Kenya and ‘Abubaker Pilipino’ from the Philippines.

The role of the Arabian Peninsula in inter-regional and inter-continental exchange of crops

There has been a lot of discussion about the role of the Arabian Peninsula’s maritime ports in the transmission of plant materials, including banana, to different regions of the world. This role is supported through ancients tombs discovered in Bahrain and Kuwait, dating back to the second millennium BC and through Geniza records, pointing to an early contact of Arabs with South Asia (Nizami, 1994). The long presence of Arabs in India is reflected by the use of the word *Hindi* as the suffix to Arabic terms such as Mauz Hindi, Ud Hindi and Tamar Hindi (Nizami, 1994). Watson (1983) suggests that medieval Arab trade played a vital role in introducing banana to East Africa and Madagascar. This was confirmed by Sauer (1952) and Cleuziou and Tosi (1989) who believed that the Arabian Peninsula served as an intermediate region for the transmission of plant and animal materials from Asia and Africa throughout antiquity. Oman was the Gulf country to produce frankincense and copper and both trading goods likely played a major role in the inter-regional plant species exchange within in Arabian Peninsula as well outside Arabia (Hammer et al., 2009).

The ancient trade between Gujarat and Arabia was particularly important during the second millennium BC and is considered to have triggered crop exchanges between Africa and South Asia (Boivin and Fuller, 2009). The availability of African crops in Gujarat and Baluchistan during second millennium BC provides evidence that maritime contact between Gujarat and Oman and Dilmon extended to Yemen and Africa (Boivin and Fuller, 2009). The discovery of African crop species at 33 archaeological sites in South Asia, dating back to the Middle Bronze Age (2000 BC) and Iron Age (300 BC) indicates that the exchange of crops between the two continents went both ways (Fuller, 2003; Cooke et al., 2005). However, Boivin et al. (2009) believed that African crops did not transfer to the Arabian Peninsula in the Bronze Age due to the absence of agricultural communities during that time, unlike at the coastal region of Gujarat. However, Vansina (1990) believed that the introduction of AAB banana to the Upper Nile Great Lakes region of Africa occurred not from the coast but through North West Africa (Atiff and Mohamed, 2000).

THE ROLE OF MARITIME ROUTES IN TRANSFERRING PLANTS TO ARABIA

The Indian Ocean

The transfer and exchange of plants outside their natural habitats was not limited only to the land roads, but maritime routes played an essential role in the transmission process. However, the role of maritime routes in the transport of crop plants to new areas is still subject to much speculation. Blench (2003) suggested three maritime routes to transfer plants species between Africa and India. The first route was between Northwest India and Egypt, across Iran, the second was a shipping route (The 'Sabaean Lane') that linked Oman, Egypt, India and Africa, across the Sea Red and the Indian Ocean, and the third route run between the West Indian coast and East Africa across the open sea. The Arabian Peninsula has played an important role in maritime trade since the Bronze Age and therefore also in the exchange and dispersal of plant genetic resources across the Indian Ocean (Fuller et al., 2011). Furthermore, archaeological discoveries in the Arabian region support this hypothesis: Chinese coins found at Al-Qualify in eastern Saudi Arabia give evidence of the role of Arabian Gulf ports in ancient trade with the Far East (Cribb and Potts, 1996). Moreover, Fuller and Boivin (2009) viewed that the north-western Indian Ocean was one of the earliest long-distance maritime routes in the world. It allowed the significant exchange of livestock (e.g. cattle) and crops like bananas and taro (*Colocasia esculenta*) as early as 2000 BC. Also, the latter authors stated that the first biological exchange was in the Bronze Age / Chalcolithic (3000–1200 BC) along the circumference of the Arabia Peninsula and northern Indian Ocean where domesticated species were transferred between the Savannahs of India and northeast Africa and Yemen. Fuller and Boivin (2009) supported their view by claiming that at the end of the 3rd and 2nd millennium BC, there was a crop transfer between eastern Africa and South Asia through the Indian Ocean and along the southern coast of Arabia. This shows that the coastal ports contributed greatly to the exchange of plant resources between continents. The maritime ports between the Indian subcontinent (Figure 3) and Oman established in the middle of the 3rd millennium BC fostered the cultural and commercial relations and also contributed to the exchange of plant materials (Al Jarow, 2011; Al-Wagad, 2011). This is supported by archaeological discoveries in the port of Samahram in the Dhofar Governorate were Indian statues, pieces of pottery and coins dating from the 1st millennium BC (Albright, 1982) were unearthed as were Indian potteries in the port of Sohar (Al Jarrow, 2011) (Figure 3).

An intensive maritime trade between Gujarat and Arabia in the 2nd millennium BC is considered to be the starting point of plant species exchange between Asia and Africa. The evidence for this is the availability of African crops in Baluchistan during that period. This indicates that maritime trade between Gujarat and Oman was strong and extended to the west of the Arabian Peninsula towards Yemen and Africa (Fuller and Boivin, 2009). Blench (2003) mentioned that in the early medieval period, plants were introduced into West Africa by Arabs. Boivin and Fuller (2009) mentioned that the Indian Ocean was controlled by Arabic traders and hence these might be responsible for introducing and exchanging crops between eastern Africa Southeast Asian and India across Indian Ocean and along the southern coast of Arabia in the 2nd millennium BC. Also, Sauer (1952) and McMaster (1962) mentioned that the eastern coasts of the Arabian Peninsula contributed to the transfer of Southeast Asian bananas to Africa.

Figure 3. Ancient Indian ports with trade links to ports in the southern Arabian Peninsula (altered form Al Jarow, 2011).

Over centuries Omani coastal were a route of transit trade between the countries of the Far East (India, China and the East Indies) and the Arabian Peninsula countries as well as Iraq, the Mediterranean Sea countries and East Africa. Muftah (2011) also suggested that commercial ships in their trip between the coastal Omani ports and India to and on to China might have used three different maritime routes (Figure 3). The first route starts in Basra in Iraq, heads towards the Eastern coast of the Gulf, stops in Ciraf (Bu Shar) in Southern Iran, then reaches Sohar and Muscat to cross the Indian Ocean to Coolum Meli south of Almalbar on the Indian coast. The second route stretches from Muscat to Polien on the Indian coast, then continues to Serindep (Sri Lanka) and Kelah port and finally reaches Khanfo in China. The third route begins in the Omani ports of Dhofar and Merbat, goes to Kalikot or Coolum Meli and then directly to China (Figure 4).

Archaeological discoveries at Ras al-Jinz and Ras al-Had in the Sharqia North Governorate of Oman, dating back to the third millennium BC, yielded remains of boats and Indian rings from the Bronze Age to the 5th millennium BC (Jūtīlir et al., 1983). This provides evidence for ancient relations between Oman and the civilizations of Mesopotamia, Sindh and Africa. Michael (1994) mentioned commercial maritime routes to India from the Strait of Harmuz, through Ras al-Had in northern Oman directly to the Eastern Indian coast. This sea route linking Oman and India may have greatly contributed to the direct existence of banana diversity in Dhofar and coastal cities such as Sohar and Tiwi (Figure 5). This hypothesis is supported by Muftah (2011) who mentioned that India, China and Southeast Asian Islands were the main sources of commodities to the coastal Omani ports and then to other regions of Arabian Peninsula. He also added that bananas and coconuts (*Cocos nucifera*) were the most important fruit crops imported from India to Oman in Medieval times.

The Red Sea trade: Incense routes

Most scholars agree that the ‘Land of Punt’, a mining region in southern Egypt played an essential role in the maritime trade in the Red Sea during the 3rd millennium. Electrum, slaves, and particularly frankincense (*Boswellia sacra*) and myrrh (*Commiphora myrrha*) were traded from Punt via the Red Sea (Boivin and Fuller, 2009). The Arabian frankincense species is native to Dhofar in Oman and Hadhramout in Yemen, while other species of frankincense are native to northern and western Ethiopia and Eritrea (*B. papyrifera*), some areas of Sudan and West Africa (Boivin and Fuller, 2009), Somalia (Hepper, 1969) and the Island of Socotra (Boivin and Fuller, 2009). The genus of Myrrh tree (*Commiphora*) is native to southern and eastern Ethiopia, Somalia, Yemen, southwest Saudi Arabia and the coastal plains of Oman (Boivin and Fuller, 2009). All of these countries also cultivate banana and it is therefore likely that there was an intensive exchange of banana germplasm between these countries. Archaeological evidence from Barbar, Umm-an-Nar, Tall Abraq, Hili, Wadi Suq, Ras al-Hamra,

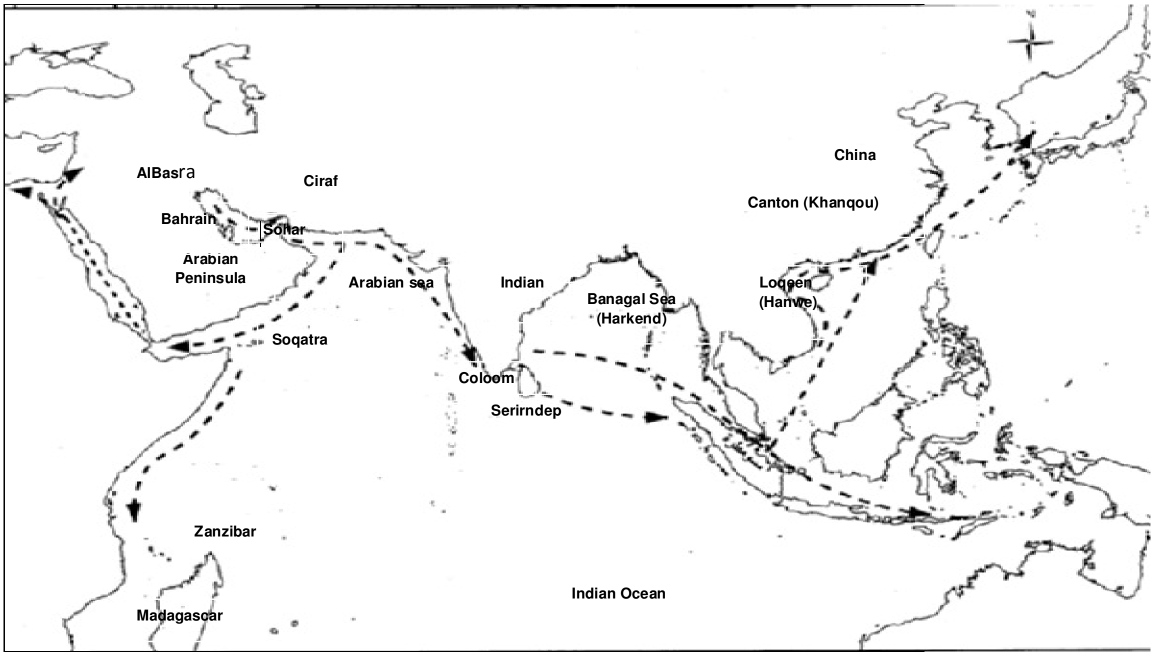

Figure 4. Trade routes and sea ports between the Arabian Peninsula, India and China (altered from Al-Wagad, 2011; Muftah, 2011).

Figure 5. Regional distribution of banana cultivars groups in Oman (De Langhe, 2002; Al-Saady, 2010).

Ras al-Hadd, Ras al-Jinz, and as-Suwayh confirm the prosperity of the Red Sea trade during the 3rd millennium (Boivin and Fuller, 2009). It can therefore be hypothesized that trade of frankincense and myrrh via the Red Sea contributed to the exchange of plant genetic sources such as bananas between Africa, India and the Arabian Peninsula.

CONCLUSIONS

While the debate on the origins of banana domestication is on-going, evidence presented in this chapter suggests that the islands of Southeast Asia and Southern China are the primary sites of banana domestication followed by subsequent phases of pre-historic cultivation and translocation to other parts of the world. Owing to the desert climate conditions in many areas of the Arabian Peninsula and based on linguistic, genetic, archaeological and maritime route data, it can be concluded that domesticated banana cultivars presently found in this area are not indigenous to the region. Humankind maintained these varieties over the ages, despite unfavourable climatic conditions. Whether domesticated banana varieties were introduced directly from their natural habitat or arrived via Africa or India cannot be clearly determined at this stage. The ancient commercial relations between the Arabian Peninsula, East Africa and India may have played a key role in introducing banana to the Arabian Peninsula. The Gulf ports, in particular those of Oman, seem to have effectively contributed to the exchange of plant genetic resources including bananas between the Arabian Peninsula and the Indian subcontinent, Africa and China. Oman's strategic location and its wealth of frankincense and copper were factors that made it an important transit centre for the exchange of plant genetic resources, including different banana subgroups. Further studies are needed to verify the truth of banana domestication on the Arabian Peninsula.

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Growth variability in *Argania spinosa* seedlings subjected to different levels of drought stress

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Argan tree, the only representative species of the tropical family Sapotaceae in Morocco is distributed in arid and semi-arid areas. Tolerance to drought remains poorly described for this species; we applied five levels of drought stress and monitored growth variables and biomass production of seedlings in pot and in field propagated from seeds of eight genotypes from three geographical origins. Drought stress decreased seedlings height, basal diameter, leaf number, leaf area, and biomass production and water content but increased root / shoot length. Even under moderate or severe drought stress (1/4 and 0 FC), some genotypes (mother-trees) sustained shoot growth, they have taproots exceeding 50 cm, which are accompanied by a large number of lateral roots, more leaves and great leaf areas. But others showed an increase below-ground length and biomass indicating a higher root / shoot ratio under drought stress conditions. So, in order to enhance the survival rate and conserving rate of seedlings planting, appropriate human intervention is required to reduce the damage to Argan seedlings resulting from drought.

Key words: *Argania spinosa*, water stress, aridity, shoot, root, seedling biomass production.

INTRODUCTION

Argan tree, the only representative species of the tropical family Sapotaceae in Morocco is distributed in arid and semi-arid areas. It plays major roles against soil erosion, desertification and preservation of biodiversity and in the daily life of local populations (Emberger, 1924; M'Hirit et al., 1998; Msanda et al., 2005). Currently, it is proven that the adult tree is drought resistant, survives in its area for many years (Emberger, 1925, 1955; Boudy, 1952) and produces branches, leaves, flowers and fruit with a rainfall exceeding 100 mm (Ferradous et al., 1996; Zahidi, 1997a, b; Bani-Aameur, 2001). In this ecological environment quite fragile, degradation of Argan is a dynamic process progressive owing to increasing population, high demand for agricultural and overgrazing. Therefore, conservation and regeneration of this tree are a regional priority for protection against the increased desertification (Bani-Aameur, 2007). Argan tree is regenerated by seed and release. Regeneration by seedlings allows preservation of genetic diversity of this species. However, fruit harvesting, livestock grazing of few seedlings issued from germination of some remaining kernels (Boudy, 1950, 1952), action of aridity on seed germination and difficult conditions of seedlings survival after germination are factors limiting natural regeneration from seed (Zahidi and Bani-Aameur, 1998; Bani Aameur and Alouani, 1998).

Artificial regeneration is the only possibility that can ensure the survival and maintain an appropriate level of genetic diversity of the species. If germination has been very successful, since percentage of germinated seeds was more than 80% (Bani-Aameur and Alouani, 1999), testing in field of transplanted seedlings grown in nursery

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was always doomed to failure. Traditionally, observed reforestation failures can be explained by the difficulty of seedling establishment after transplantation. Some techniques to improve transplantation rate have been tested on a small scale (Harrouni et al., 1995). They sometimes lead to improved success rates; however, they will remain below an acceptable level. In arid or semi-arid areas, during periods of drought, most plants are likely to be under stress, but differences in the degree of stress can have important implications for plant survival. One of the most general types of stress experienced by plants is water limitation. As a result of water limitation, plants express various responses and have developed a wide diversity of drought tolerance mechanisms from both morphological and physiological aspects (Blum, 1983; Loss and Siddique, 1994; Li et al., 2007). In field, the very definition of drought accepted by many authors includes a reduction in plant growth due to decrease in average precipitation amounts (Tucker and Goward, 1987). Water shortage can cause plants to reduce their metabolic activity, causing a decrease in photosynthesis, carbon fixation and ultimately growth (Younis et al., 1993; Li et al., 2007). Some studies have shown that drought stress can affect the growth of plant organs differently, which may result in the alteration of the morphological features of the plants (French and Turner, 1991).

The change in root to shoot dry mass ratio has been considered as one of the mechanisms involved in the adaptation of plants to drought stress. In order to diminish consumption and increase absorption of water, plants in dry conditions often decrease their growth rate and biomass production, and contribute more biomass to roots, so that they could maintain a higher root to shoot ratio (Yin et al., 2005; Villagra and Cavagnaro, 2006). Drought stress reduces both root and shoots growth. However, root growth seems to be less affected. Drought stress often leads to a decrease in leaf dry mass ratio (leaf dry mass/plant total dry mass) in many species (Turner, 1997). Several studies have concerned the adult tree and reported that Argan is xerophytic and can support low and irregular rainfall (Boudy, 1952; Ferradous et al., 1996). After a prolonged drought biomass production stops and the tree loses completely leaves, flowers and fruits (Bani-Aameur, 1997; Zahidi, 1997). Stomatal regulation by closure of stomata contributes very little to avoid drought (El Aboudi et al., 1991). Very few studies have focused on seedlings, according to Zahidi and Bani-Aameur (1997a, b) root length can reach 27 cm before the cotyledons opening. In seedlings grown in nursery conditions for one year, root length varied between 138.4 and 10.7 cm, stem height between 69.3 and 6.5 cm. Seedlings grown for 16.5 months were longer four times than those grown for 4.5 months, but nine times greater than those grown only for 3 months. After six months, seedlings irrigated daily at field capacity showed a gain of 9.7 cm in stem height (Harrouni et al., 1995). The decrease in water regime leads to a reduction in seedling leaf number.

In addition, in non-irrigated seedlings, root was twice longer than those of irrigated seedlings after nine months (Kaabouss, 1992; Harrouni et al., 1995). However, to ensure extension and conserving genetic diversity, especially in areas where drought can be a very important environmental factor which limit the increase of survival rate of transplanted seedlings; evaluating seedlings responses to various degrees of water stress is the key to speed up forest restoration of Argan. No specific information is available on the tolerance of seedlings to drought or on variability of growth in the difficult conditions of their natural environment.

Our objective is to test morphological responses of Argan seedlings issued from eight selected genotypes grown for 14 months in nursery and in field subjected to five water regimes.

MATERIALS AND METHODS

Plant material and growth conditions

Seeds of eight selected trees of *Argania spinosa* were collected from three geographical origins; that is, Ait Melloul Argana and Ait Baha with ecological characterization (Bani-Aameur and Zahidi, 2005; Zahidi et al., 2013). Before germination, fruit were kept in cold for one month, and then scarified as described by Bani-Aameur and Alouani (1999) before sowing (March 20 first season) in vats containing sand in a mini-greenhouse. After emergence, seedlings were transplanted (May 20 first season) in pots containing 1/3 of peat, 1/3 of sand and 1/3 of Argan loam and placed in open air at the Faculty of Sciences, Agadir. Transplantation was done with five seedlings per pot reduced to two seedlings per pot after two months of seedling growth.

In early summer (June 6th first season), seedlings were irrigated daily by five water regimes [1 field capacity (1 FC = 200 ml), 3/4 FC (150 ml), 1/2 FC (100 ml), 1/4 FC (50 ml) and 0 FC (0 ml)].

Measurements and calculations

At the end of each month, seedling height or stem length (LT cm) and basal diameter (DT cm) were recorded. The seedlings were harvested at the end of the experiment (June 6th second season), the following characters were measured: LT: Seedling height (cm), NF: leaf number on the main stem, NE: spines number on the main stem, RS: number of secondary on the main stem, RT: tertiary shoots on the main stem, LR: root length (cm), RC: number of lateral roots. Each seedling was then divided into roots, stems and leaves and they were dried in an oven for at least 48 h at 70°C to constant weight for biomass determination (g). PFT: Fresh stem mass, PST: dry stem mass, PFR: fresh root mass, PSR: dry root mass, RPF: root / shoot fresh mass ratio, RPS: root / shoot dry mass ratio, PFF: leaf fresh mass, PSF: leaf dry mass, FWC: leaf water content, TWC: stem water content and RWC: root water content, were determined by difference between fresh and dry mass as follows:

$FWC = PFF – PSF; TWC = PFT – PST; RWC = PFR – PSR$

In order to determine leaf area (SF in cm^2), the first five units were observed in April 9th (second season). Leaves were photocopied on paper, surface of 1 cm^2 of paper (P) and the image of leaf (Fi) was weighed in grams. Leaf area was calculated using the specific

Table 1. Variance analysis for stem diameter and stem length in Argan seedling grown for 14 months under five water regimes.

Source of variation	DF	Mean square	
		Stem diameter (cm)	Stem lenght (cm)
Block	3	0.017ns	205.74**
Water regime	3	5.72**	27571**
Duration of regime	10	2.732**	6783.3**
Mother-tree	7	0.457**	4027.2**
Water regime × duration	30	0.05**	172.74**
Water regime × mother-tree	21	0.095**	536.58**
Duration of regime × mother-tree	70	0.001^{ns}	7.63^{ns}
Water regime × duration of regime × mother-tree	210	0.002^{ns}	10.62^{ns}
Water regime × duration of regime × mother-tree × seedling	352	0.98^{ns}	42.18^{ns}
Error	2096	0.008	53.31

DF: Degree of freedom; ns: not significant; *: significant at 5%; **: significant at 1%.

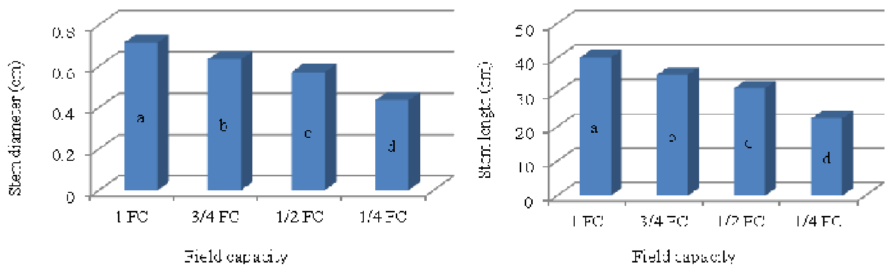

Figure 1. Stem diameter and stem length in Argan seedling grown for 14 months under five water regimes (letters indicate significant differences using LSD comparison).

surface area as proposed by Mosseddaq (1988) (S = Fi / P).

Field test

Preparation of seedlings is the same as the previous test. After germination, seedlings were grown in three types of containers measuring 17 cm in height: plastic sachets, jute sachets and seedling trays as is the case of forestry nurseries. Seedlings issued from eight genotypes grown in nursery for seven months at the Faculty of Sciences, Agadir were subjected to five water regimes [1 field capacity (1 FC = 200 ml), 3/4 FC (150 ml), 1/2 FC (100 ml) and 1/4 FC (50 ml) and 0 FC (0 ml)]. Those seedlings were then transplanted in two study plots located in the communal forests belonging to two adjacent cities: Ait Hamadi (Ouled Teima in February 2 second season) near Agadir and in Onagha near Essaouira (February 9 second season) (Water and Forests Services). Seedling height (LT) and basal diameter (DT) were recorded five times: on July 19, August 19, September 19, October 19, November 19 the second season, respectively.

Statistical analysis

In the first test, we adopt randomized complete block as experimental design. In each of the four blocks, 40 combinations (five water regime and eight varieties) are randomly distributed. Each pot is a variety and a water regime with two replications. In the second test, the experimental design is a Split-plot (Vessereau, 1988). Main water regime consists of eight mother-tree seed sources distributed in 36 plots and randomly allocated to each of the two blocks. The type of container in which Argan seedlings were grown is subsidiary water regime. Analysis of variance with four factors is adopted. All factors (block, mother-tree, water regime and observation date) were crossed. When significant differences were noted, LSD (least significant difference method) test was used to determine differences (Dagnelie, 1984). Calculations were performed using Statistix software.

RESULTS

During the pot test

Seedlings under 0 FC (field capacity) (0 ml) have dried completely after one month of stopping irrigation.

Stem characters

Water regime: Water regime is highly significant for the stem diameter and length during the test duration and at the end of the experiment (Table 1). The decrease in water amount leads to a reduction of stem diameter and stem length. Values varied respectively between 0.72 and 40.2 cm at field capacity (1 FC) to 0.43 and 22.5 cm at 1/4 FC (Figure 1).

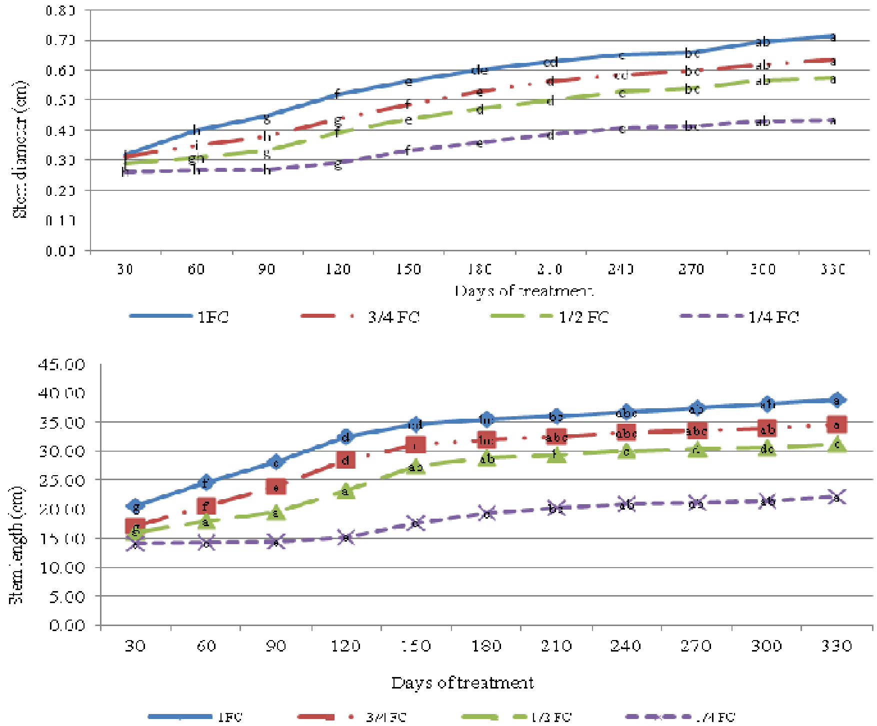

Figure 2. Stem diameter and length in Argan seedling grown for 14 months under five water regimes.

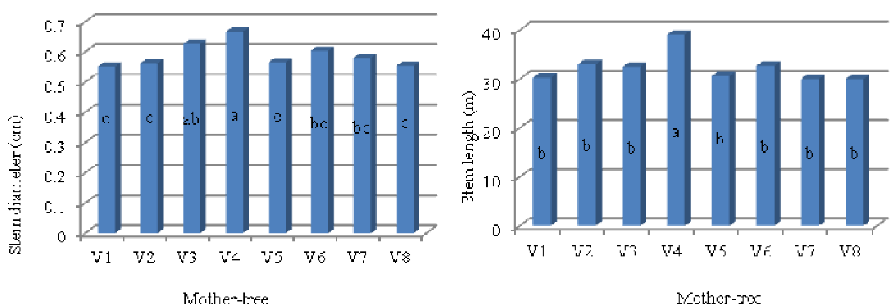

Figure 3. Stem diameter and length (cm) in Argan seedling grown for 14 months under five water regimes by mother-tree.

Duration of water regime: Duration of water regime and water regime × duration interaction influenced significantly stem diameter and length in Argan seedlings (Table 1). In seedling grown for 14 months, stem diameter remains very low at ¼ FC and ranged from 0.26 to 0.44 cm, whereas it increases in the other three water regimes and reaches 0.7 cm. Stem length increases rapidly during the first five months for water regimes 1, 3/4 and 1/2 FC and becomes slower after the fifth month (Figure 2). For 1/4 FC, stem length remains stable during the first four months, seedlings remain dwarf since length reaches only 22.5 cm at the end of the experiment.

Mother-tree: Mother-tree × water regime interaction and mother-tree were highly significant for the stem diameter and length in Argan, showing genetic variability for seedling reaction to water stress (Table 1). Diameter varied from 0.55 cm in seedlings of family V1 and V2 to 0.67 cm in family V4 (Figure 3). Stem length varied from 39.1 cm in seedlings of mother-tree V4 and 30.03 cm for V7 and V8.

At the end of experiment

Water regime

Water regime was highly significant for stem diameter

Table 2. Variance analysis for the stem, root and leaf characters in Argan seedlings grown for one year subjected to four water regime.

Source of variation	DF	Mean square											
		Stem characters							Root characters				
		DT	LT	RS	RT	PFT	PST	TWC	LR	RC	PFR	PSR	RWC
Block	3	0.015^{ns}	63.32^{ns}	8.86^{ns}	3.46^{ns}	7.73^{ns}	1.74^{ns}	2.14^{ns}	1119.4^{ns}	4.80*	2.17^{ns}	0.23^{ns}	1.13^{ns}
Water regime	3	0.886**	3582.1**	12.50^{ns}	3.22^{ns}	343.1**	112.17**	63.35**	7925.6**	11.28*	966.16**	266.10**	219.17**
Mother-tree	7	0.054**	289.95**	24.02**	0.80^{ns}	44.07**	19.4**	5.14**	3824.1*	0.75*	6.56*	2.76*	1.14*
Water regime × mother-tree	21	0.016^{ns}	74.056^{ns}	11.31^{ns}	1.49^{ns}	11.07*	4.49*	1.56^{ns}	1648.1^{ns}	3.26**	10.63^{ns}	3.09^{ns}	2.55^{ns}
Water regime × mother-tree × seedling	32	0.019^{ns}	50.97^{ns}	6.98^{ns}	1.43^{ns}	5.56^{ns}	2.17^{ns}	0.82^{ns}	1312.8^{ns}	1.11^{ns}	9.76^{ns}	2.65^{ns}	2.38^{ns}
Error	173	0.014	73.27	7.71	1.67	6.32	2.41	0.97	1476.6	1.63	10.128	3.14	2.11

Source of variation	DF	Mean square							
		Ratios			Leaf characters				
		RPF	RPS	RL (LR/LT)	NF	PFF	PSF	FWC	NE
Block	3	0.02^{ns}	0.04^{ns}	0.82^{ns}	10640^{ns}	1.99^{ns}	0.42^{ns}	0.78^{ns}	2247.2**
Water regime	3	2.93**	1.64**	4.64**	1654400**	146.69**	20.20**	58.09**	10514**
Mother-tree	7	2.66**	2.33*	7.61**	37321*	1.74^{ns}	0.26^{ns}	0.74^{ns}	1371.8**
Water regime × mother-tree	21	0.39*	0.31*	1.32^{ns}	64615*	1.68^{ns}	0.24^{ns}	0.77^{ns}	300.88^{ns}
Water regime × mother-tree × seedling	32	0.20^{ns}	0.17^{ns}	1.22^{ns}	34657^{ns}	1.93^{ns}	0.32^{ns}	0.77^{ns}	166.38^{ns}
Error	173	0.21	0.18	1.52	36343	1.41	0.26	0.52	274.23

DF: Degree of freedom, ns: not significant, *: significant at 5%; **: significant at 1%. Stem diameter (DT), stem length (LT), number of secondary on the main stem (RS), number of tertiary shoots on the main stem (RT), fresh stem mass (PFT), dry stem mass (PST), stem water content (TWC); root length (LR), number of lateral roots (RC), fresh root mass (PFR), dry root mass (PSR), root water content (RWC); root / shoot fresh mass ratio (RPF), root / shoot dry mass ratio (RPS), ratio length (RL = LR/LT); leaf number on the main stem (NF), leaf fresh mass (PFF), leaf dry mass (PSF), leaf water content (FWC) and spines number on the main stem (NE); Means followed by letters are significant..

and length, for spines number (EP), fresh (PFT), dry biomass weight (PST) and stem water content (TWC) at the end of experiment (Table 2). It was not significant for number of secondary, tertiary shoots on the main stem. Drought stress diminished biomass production, stems water content and reduced spines number (Figure 4).

Mother-tree effect

Water regime × mother-tree × seedling interaction was not significant for all stem traits. Mother-tree × water regime interaction was significant only for fresh and dry mass of the stem, which shows the individual response of each seedling to each water regime. Mother-tree factor was significant for all characters, except number of tertiary shoots (Table 2). Great variability was observed between all genotypes (mother-trees) for these characters. Dry mass varied from 4.5 g for mother-tree V4 to 2 g in seedlings of V1. The fresh mass in genotype V4 (7 g) was twice larger than that in seedlings from V1 (3.2 g). Stem water content varied from 2.5 g for mother-tree V4 to 1.2 g in seedlings of V1. Number of secondary shoots varied between 4.3 for mother-tree V3 to 1.5 in seedlings of V1 (Figure 5). Spines number varied from 62.6 in mother-tree V4 and 42.9 in seedling from mother-tree V1.

Root characters

Water regime

Water regime is highly significant for root length (LR), number of lateral roots (NRL), fresh (PFR), dry mass (PSR), root water content (RWC), fresh

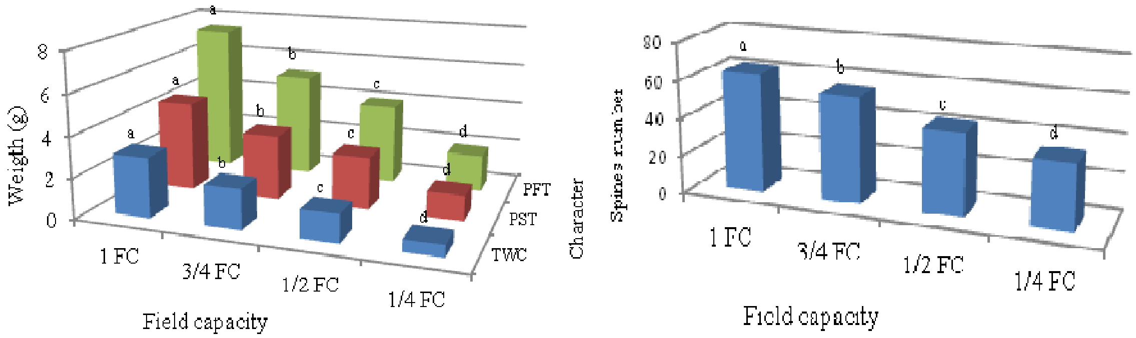

Figure 4. Fresh, dry weight and stem water content and spines number in Argan seedlings grown for 14 months by water regime.

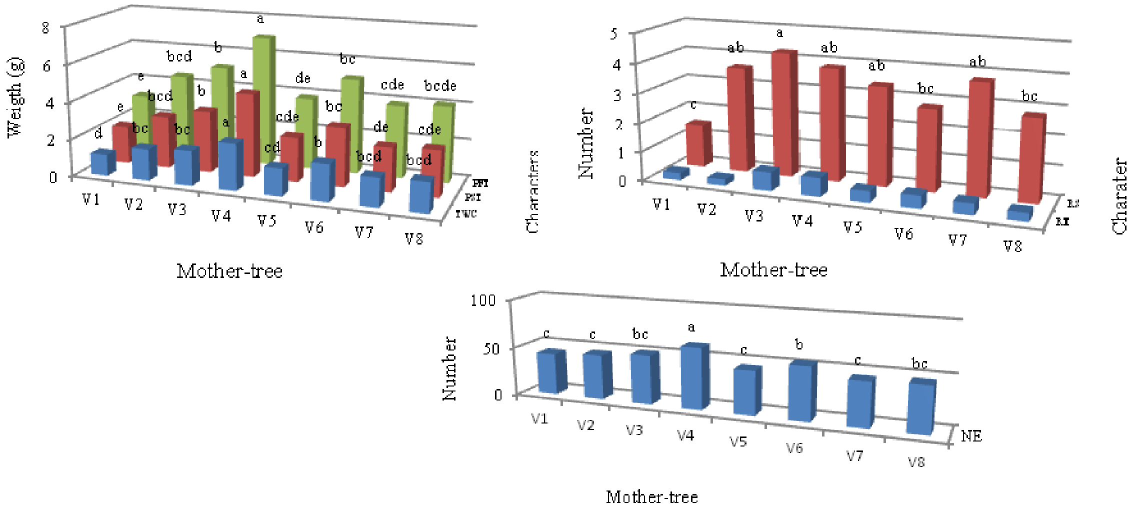

Figure 5. Fresh, dry mass, water content and number of secondary, tertiary shoots and spines on the main stem by mother-tree.

(RPF) and dry (RPS) mass ratio and length ratio (RL) (Table 2). Root length varied from 49.9 cm at ¼ FC to 73.4 cm at 1 FC, it is about twice the stem length (Figure 6). The decrease in the amount of irrigation water leads to a reduction in lateral roots number, root water content and root fresh mass. The fresh mass is at field capacity six times greater decreases also than that obtained in ¼ FC. Root dry biomass at field capacity is five times larger than that recorded at ¼ FC. The fresh and dry weight ratios varied from 1.7 and 1.6 at field capacity to 1.1 and 1.2 at 1/4 FC. Root / stem ratio of length (RL) varied from 2.4 at ¼ FC to 1.9 at 1 FC.

Mother-tree

Mother-tree × water regime was not significant for all root characters except number of lateral roots. This shows genetic variability in Argan seedling for water stress. Mother-tree × water regime × seedling interaction is not significant for all root traits. The production of root fresh, dry biomass and water content depends only on water regime. Mother-tree factor was significant for root length (LR), root / stem ratio of length (RL), fresh (RPF) and dry (RPS) mass ratio (Table 2). Thus, seedlings from genotype V1 have longer roots (82.3 cm) than seedlings from V4 which shows the shortest roots (53.13 cm) (Figure 7). Water stress induces the development of root to allow the seedling in search of water in depth. Thus, root / stem ratio varied from 2.9 in seedlings from mother-tree V1 to 1.4 in descendants of mother V4. Fresh and dry mass ratio varied from 2 and 1.9 in seedlings from V1 to 0.92 and 0.89 for descendants of V4.

Leaf characters

Water regime

Water regime is highly significant for leaf number on the

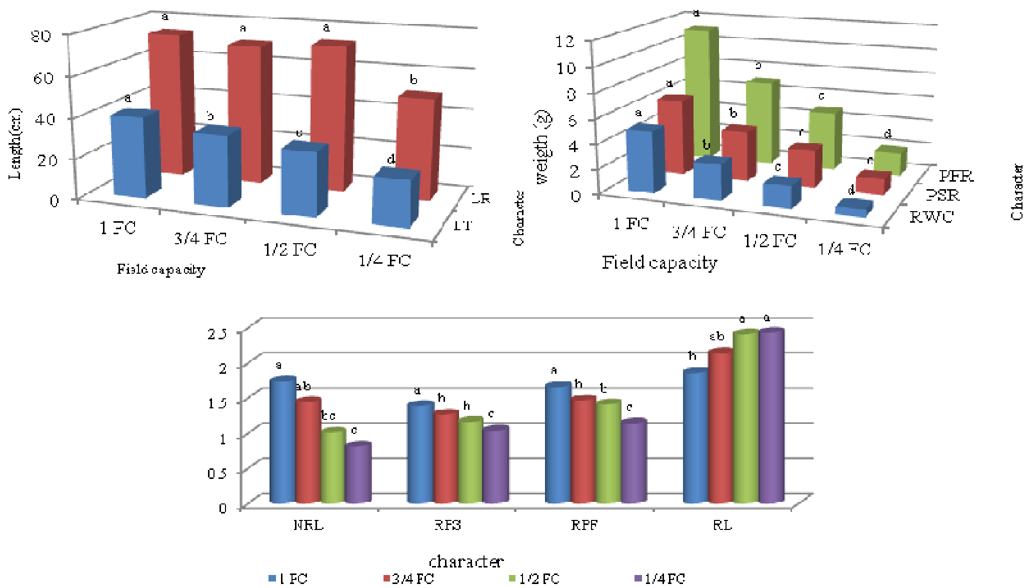

Figure 6. Stem and root length, fresh, dry mass and root water content and their ratios in Argan seedlings by water regime.

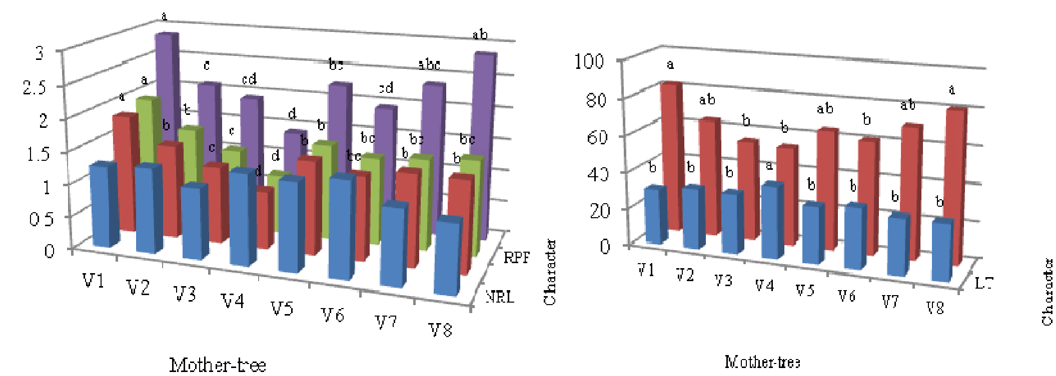

Figure 7. Root and stem length, root and stem ratio of length, fresh, dry mass and number of lateral roots in Argan seedlings by mother-trees.

main stem (NF), fresh, dry mass and leaf water content (Table 2). At field capacity, leaf number (584.6) is three times higher than that obtained at 1/4 FC (201.8) (Figure 8). Water stress induces a significant reduction of leaf biomass, since fresh weight at field capacity (4 g) was eight times greater than that obtained at 1/4 FC (0.5 g). Leaf dry mass does not exceed 0.3 g at 1/4 FC while it reaches 1.6 g at field capacity. Water content at field capacity (2.4 g) is twelve times greater than that obtained at 1/4 FC (0.2 g).

Mother-tree

Water regime × mother-tree × seedling interaction was not significant for leaf characters. Mother-tree and water regime × mother-tree were significant for leaf number but not significant for the three other characters (Table 2). Leaf number varied between 437.1 in seedlings of V4 and 319.3 in seedlings of V5. Fresh and dry biomass varied from 1.7 g, 0.78 g in seedlings of V5 and 2.36 g, 1.01 g in seedlings of V3. Leaf water content varied from 0.91 in seedlings of V5 and 1.34 in seedlings of V3 (Table 3).

Field test

Before transplanting

Seedling, mother-tree × seedling, water regime × seedling and water regime × mother-tree × seedling were

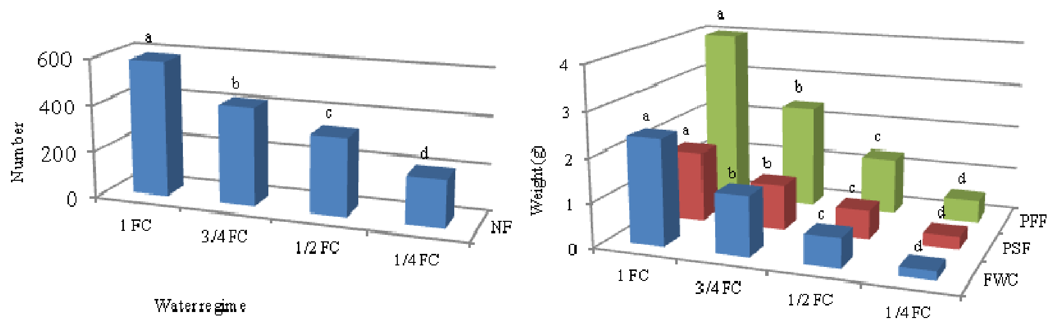

Figure 8. Leaf number on the main stem, fresh, dry mass and water content by water regime.

Table 3. Fresh (PFF), dry mass (PSF), leaf water content (FWC) and leaf number by mother-tree.

Mother-tree	PSF	FWC	PFF	NF
V1	0.82	0.99	1.81	380.4^{bc}
V2	0.95	1.16	2.11	413.1^{ab}
V3	1.01	1.34	2.36	379^{bc}
V4	1.01	1.29	2.3	437.1^{a}
V5	0.78	0.91	1.7	319.3^{d}
V6	0.88	1.26	2.14	388.1^{b}
V7	0.81	1.06	1.87	369.4^{c}
V8	0.85	1.21	2.06	390.4^{b}

Means followed by letters are significant.

Table 4. Variance analysis for seedling height (LT), basal diameter (DT) under five water regimes grown in three containers for seven months.

Source of variation	DF	Average	
		DT	LT
Block	3	0.005^{ns}	2.09^{ns}
Mother-tree	7	0.029*	330.95**
Water regime	4	0.56*	67.77*
Seedling	1	0.007^{ns}	25.34^{ns}
Water regime × mother-tree	28	0.005^{ns}	19.04*
Mother-tree × seedling	7	0.003^{ns}	4.02^{ns}
Water regime × seedling	4	0.001^{ns}	2.43^{ns}
Water regime × mother-tree × seedling	28	0.003^{ns}	7.11^{ns}
Error	236	0.004	10.79

ns: not significant; *: significant at 5%; **: significant at 1%.

not significant for stem diameter (DT) and stem length (LT). Water regime × mother-tree is significant for LT but not significant for DT. Mother-tree and water regime were significant for the two characters of seedlings grown for seven months under five water regimes in three containers (Table 4). Water stress causes a decrease in DT from 0.45 cm at field capacity to 0.21 at 0 FC. Stem length varied from 16.15 cm at 1 FC to 13.44 cm at ¼ FC (Table 5). Stem length and diameter varied in large proportions between mother-trees. Values ranged respectively between 0.29, 10.92 cm in seedlings of V8 and 0.37, 20.22 cm in seedlings of V4 (Table 6). Great variability in leaf area was observed between mother-trees and between water regimes for the same mother-tree. Values varied between 0.43 cm^2 in seedlings of V7 at 1 FC and 1.37 cm^2 at 0 FC in seedlings of V3 (Table 6).

After transplanting

Water regime was significant for stem diameter (DT), but

Table 5. Seedling height (LT) and stem diameter (DT) in Argan seedlings grown for seven months under five water regimes.

Water regime (FC)	Average	
	DT (cm)	LT (cm)
1	0.45[a]	16.15[a]
¾	0.38[b]	14.44[b]
½	0.33[c]	14.24[b]
¼	0.26[d]	13.44[b]
0	0.21[e]	13.90[b]

Means followed by letters are significant.

Table 6. Seedling height (LT) and stem diameter (DT) in Argan seedlings grown for seven months under five water regimes by mother-tree.

Mother-tree	Average	
	DT	LT
V1	0.31[cd]	12.49[cd]
V2	0.3[cd]	14.17[c]
V3	0.36[ab]	16.71[c]
V4	0.37[a]	20.22[a]
V5	0.31[cd]	14.22[c]
V6	0.33[bc]	13.97[c]
V7	0.32[cd]	12.76[cd]
V8	0.29[d]	10.92[d]

Means followed by letters are significant.

Table 7. Variance analysis for stem diameter (DT), stem length (LT) in Argan seedlings transplanted in two study plots (Ouled Teima and Essaouira).

Source of variation	DF	Mean square	
		LT (cm)	DT (cm)
Block	3	35.96[ns]	1.1[ns]
Mother-tree	7	2071.5**	1.31[ns]
Water regime	4	1125.7**	4.96**
Observation date	4	3769**	1.23[ns]
Mother-tree × water regime	28	178**	1.08[ns]
Mother-tree × observation date	28	3.8[ns]	1.03[ns]
Water regime × observation date	16	455.73**	1.06[ns]
Mother-tree × water regime × observation date	112	7.73[ns]	1.02[ns]
Error	1387	30.5	1.04

Ns: Not significant, **: significant at 1%.

mother-tree, observation date, mother-tree × water regime, mother-tree × observation date and mother-tree × observation date × water regime interactions were not significant for this character. Water regime, mother-tree, observation date, mother-tree × water regime, water regime × observation date interactions were significant for stem length (LT). Mother-tree × observation date and mother-tree × water regime × observation date interactions were not significant for this character (Table 7). The reducing of water availability causes a reduction of stem length since values are from 28.03 cm at field capacity to 14.08 cm at 0 FC. Stem diameter varied from 0.52 cm at ¾ FC and 0.21 cm at 0 FC (Table 8). Stem diameter and length varied in large proportions between families. Values ranged respectively between 0.3 cm, 17.44 cm in seedlings of V8 and 0.38 cm, 27.27 cm in seedlings of V4 (Table 9). Values reached in seedlings in field test remained lower than pot test even when they

Table 8. Stem length (LT), stem diameter (DT) in Argan seedling of eight mother-trees grown in field and subjected to five water regime.

Water regime (FC)	Average	
	LT (cm)	DT (cm)
1	28.03[a]	0.45[ab]
¾	24.17[b]	0.52[a]
2/4	20.8[c]	0.35[bc]
¼	15.09[d]	0.28[c]
0	14.08[e]	0.21[c]

Values followed by letters are significantly different.

Table 9. Stem length (cm) and stem diameter (cm) by mother-tree having undergone five water regimes.

Mother-tree	Average	
	LT (cm)	DT (cm)
V1	17.55[d]	0.32[c]
V2	20.29[c]	0.31[c]
V3	22.44[b]	0.37[a]
V4	27.27[a]	0.38[a]
V5	20.04[c]	0.33[bc]
V6	19.9[c]	0.35[b]
V7	18.43[d]	0.33[bc]
V8	17.44[d]	0.3[c]

Values followed by letters are significantly different.

were grown for the same period about 14 months (Table 10). Seedling, water regime × mother-tree, mother-tree × seedling, water regime × seedling and water regime × mother-tree × seedling were not significant for leaf area (SF). Mother-tree and water regime were significant for leaf area in Argan seedlings grown for seven months and subjected to five water regime (Table 11).

Leaf area decrease with water deficit, it varied between 0.71 cm^2 at 1 FC and 0.66 cm^2 except at 0 FC (0.76 cm^2) (Table 12). Some genotypes as V3 and V4 have greater leaf areas than seedlings from V7, V8 and V1.

DISCUSSION

The mechanisms adopted by Argan seedlings to withstand drought are still largely unknown. Here, we report data of experiments aimed at investigating the effect of water stress on Argan seedlings growth issued from eigth mother-tree originating from three populations in south west Morocco. In our study, the growth reduction in both seedling height and basal diameter of the stem was observed under moderate (3/4 FC) and severe stress (1/4 or 0 FC). The same result is obtained by Kaabouss (1992) since the stem length of Argan seedlings subjected to water stress did not exceed 22 cm after 160 days of transplantation. In seedlings of *Adenanthera pavonina*, Paliwal and Kannan (1999) showed that water deficit causes a reduction of the stem height. This result suggests that even at reduced soil water availability, the Argan seedlings are able to grow. Our results agree with the findings of Achten et al. (2010) in *J. curcas* since under medium stress (40% plant available water) the plants maintained a similar stem shape, although they grew at lower rate (stem length: 0.28 cm / day; dry biomass production: 0.64 g / day). Seedlings under extreme drought stress (no irrigation) stopped growing, started shedding leaves and showed shrinking stem diameter from the 12th day after the start of the drought treatment. This result showed that water withhold would arrest growth but maintaining plants at low soil water availability (40%) would allow them to continue growing, although at a slower rate than fully irrigated plants (Achten et al., 2010; Sapeta et al., 2013).

Decrease in irrigation level leads to a low level of shoot (secondary and tertiary shoots) and spines production which agree results obtained in adult trees since branching is very low in dry season than in wet season. In addition, the production of spines is not a response to drought (Zahidi, 1997). Drought stress leads also to the decrease of stem fresh mass, dry mass and stem water content in argan seedlings at the end of experiment.

Table 10. Stem length (cm) and stem diameter (cm) in transplanted Argan seedlings grown under five water regimes.

Observation date	Average	
	LT (cm)	DT (cm)
July 19	16.3^{e}	0.27
August 19	18.27^{d}	0.43
September 19	20.01^{c}	0.32
October 19	22.67^{b}	0.37
November 19	24.92^{a}	0.4

Values followed by letters are significantly different.

Table 11. Variance analysis for leaf area (SF) in Argan seedlings transplanted in two study plots (Ouled Teima and Essaouira).

Source of variation	DF	SF
Block	3	0.34^{ns}
Mother-tree	7	6.43**
Water regime	4	0.65*
Seedling	1	0.04^{ns}
Water regime × mother-tree	28	0.53^{ns}
Mother-tree × seedling	7	0.37^{ns}
Water regime × seedling	4	0.11^{ns}
Water regime × mother-tree × seedling	28	0.33**
Water regime × mother-tree × seedling × leaf (error)	1506	0.19

Ns: Not significant, *: significant at 5%, **: significant at 1%.

Table 12. Variation of leaf area by mother-tree and water regime.

Mother-tree	1 FC	3/4 FC	2/4 FC	1/4 FC	0 FC	Average
V1	0.63^{ab}	0.67^{a}	0.64^{ab}	0.56^{bc}	0.48^{c}	0.59^{cd}
V2	0.71^{a}	0.54^{b}	0.51^{b}	0.64^{a}	0.54^{b}	0.58^{cd}
V3	1.07^{ab}	0.82^{b}	0.77^{b}	0.99^{ab}	**1.35**^{a}	1.03^{a}
V4	0.93^{a}	0.88^{b}	0.85^{c}	0.87^{b}	0.96^{a}	0.89^{ab}
V5	0.79^{a}	0.64^{c}	0.77^{ab}	0.66^{bc}	0.8^{a}	0.73^{b}
V6	0.61^{cd}	0.64^{c}	0.91^{a}	0.51^{d}	0.84^{b}	0.7^{bc}
V7	**0.43^{d}**	0.48^{cd}	0.61^{a}	0.51^{bc}	0.57^{ab}	0.52^{d}
V8	0.55^{a}	0.46^{b}	0.45^{b}	0.57^{a}	0.51^{ab}	0.5^{d}
Average	0.71^{ab}	0.64c	0.68b^{c}	0.66b^{c}	0.76^{a}	0.69

Values followed by letters are significantly different.

Drought stress obviously diminished the biomass and their components, and reduced shoot percentages in *S. davidii* seedlings (Wu et al., 2008). Additionally, photosynthesis and growth (biomass production) are the primary processes to be affected by drought (Chaves and Oliveira, 2004; Sapeta et al., 2013). Drought not only changed plant growth and structure [shoot height (Ht), total biomass (Tb)] in *P. davidiana*, but also affected plant physiological properties and constitutes a very important limiting factor at the initial phase of seedling growth and establishment (Zhang et al., 2004). Drought changed also root growth, root to shoot length which is twice higher under sever stress (at 1/4 FC). Thus, water stress induces the development of root to allow the seedling in search of water in depth.

The decrease in the amount of irrigation water leads to a reduction in lateral roots number, fresh, dry mass, root water content, root to shoot fresh and dry mass ratio. Our results agree with the finding in other species, Wu et al. (2008) showed that drought stress diminished the root biomass and their components, but increased below-ground percentages. Drought stress significantly decreased plant total dry mass, but the proportion of changes differed among root and stem. The change in root to shoot dry mass ratio has been considered as one of the mechanisms involved in the adaptation of plants to drought stress (Turner, 1997). So, in order to diminish consumption and increase absorption of water, plants in dry conditions often decrease their growth rate and biomass production, and contribute more biomass to roots (Martin and Stephens, 2006; Wu et al., 2008).

Additionally, the importance of root systems in acquiring water has long been recognized as crucial to cope with drought conditions in acquiring water. A prolific root system can confer the advantage to support accelerated plant growth during the early growth stage after transplantation and extract water from shallow soil layers that is otherwise easily lost by evaporation especially in arid environments (Johansen et al., 1994). Water stress induces a significant reduction of leaf number, leaf biomass (fresh, dry mass) and leaf water content in Argan seedlings. In general, under drought stress (3/4, ½ and ¼ FC), all genotypes had lower values of leaf area than the well-watered regime (1 FC) except at 0 FC. However, drought resulted in a reduction of total leaf area in seedlings of several species. Reduced leaf number and area was a drought avoidance strategy for the seedlings by reducing transpiration. These results confirm the conclusion that drought constrains leaf growth to a much greater extent, indicating that this abiotic factor led to a more conservative balance between losing and obtaining water by different organs of plant (James and William, 1998; Liu and Stützel, 2004; Zhang et al., 2004; Villagra and Cavagnaro, 2006; Wu et al., 2008). Some genotypes as V4 and V3 unlike V1 and V8 are able to grow in length and diameter, able to produce more shoots, spines and biomass (fresh mass, dry mass) and with much water content in the stem even under water stress. These results suggest the existence of mechanisms of drought tolerance in these genotypes.

As proposed by Liu and Stützel (2004), conservative shoot growth during drought could be advantageous, especially if root growth is promoted. Genotypes that sustain shoot growth during drought may have greater marketability, which is particularly important for leafy vegetable crops. In Argan, under drought, genotype V4 and V3 have taproots exceeding 50 cm, which are accompanied by a large number of lateral roots, more leaves, a large biomass (fresh, dry mass and water content) and great leaf areas even under severe stress (1/4 and 0 FC). Those genotypes are promising for reforestation programs in an environment where drought is a limiting factor for the natural regeneration. Therefore, the most difficult in vegetation growth in this area appears in summer for newly planted seedlings, their survival or death will depend on adaptation to the habitat through this crucial period as reported for four shrub species in arid valley of Minjiang River of China (Li et al., 2007). Genotypes (mother-tree of seedlings) V1 and V8 have produced longer roots, higher root to shoot ratio and root biomass production (fresh, dry weight ratios and water content), lower leaves number, a relatively lower biomass (fresh, dry mass and water content) and smaller leaf areas than seedlings from genotypes V4 and V3. In many species,root system in acquiring water has long been recognized as crucial to cope with drought conditions (Kashiwagi et al., 2006).

The increased root (root length, root biomass production) and leaf characters (biomass and area) under drought stress observed in genotypes V1 and V8 is in line with the theory of the functional balance, which predicts that plants will react to a limited water availability with a relative increase in the flow of assimilates to the root leading to an increased root biomass. So, in order to diminish consumption and increase absorption of water, plants in dry conditions often decrease their growth rate and biomass production, and contribute more biomass to roots (Villagra and Cavagnaro, 2006). Partitioning more biomass to below-ground and maintaining higher root to shoot ratio may be beneficial to enhanced capacity of water uptake, by maintaining the shoot in a well-hydrated condition (Blum, 1996; Liu and Stützel, 2004; Zhang et al., 2004; Kashiwagi et al., 2006; Wu et al., 2008). At this stage of seedlings development, this case will be an adaptative response of the plant morphology which may be a primary mechanism by which this species can cope with the environmental characteristics of south west Morocco as reported for other species (Patterson et al., 1997; Achten et al., 2010; Sapeta et al., 2013).

Conclusion

The Argan seedlings grown in pot and field showed that water stress was a very important limiting factor at the initial phase of growth. Drought stress significantly decreased seedling height, root growth, leaf area and biomass production, but the proportion of changes differed among root, stem and leaf. Great genetic variability between seedlings to water stress. Even under severe stress, some genotypes increased root to shoot fresh and dry mass ratio and maintained higher investment in the taproot and lateral roots. This adaptive response in morphology may be a primary mechanism by which the Argan seedlings can cope with the environmental characteristics. For newly planted seedlings, the most difficult period for plants growth in this area appears from May to October since rainfall not exceeds 40 mm. So, in order to enhance the survival rate and conserving rate of seedlings planting, appropriate human intervention is required to reduce the damage to Argan seedlings resulting from drought. These results will be useful towards transplantation, and may serve as a guide to initiate effective measures in tree planting to enhance survival rate and conserving rate for Argan forest restoration.

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Full Length Research Paper

Growth and photosynthetic responses of *Lycoris haywardii* Traub to watering frequencies

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To seek a way to solve the slow growth of bulbs of *Lycoris*, a pot experiment with three replications was conducted to evaluate the effects of watering frequency on growth, net photosynthetic rate and bulb biomass of *Lycoris haywardii* under greenhouse condition. The results revealed that leaf number, leaf length and fresh bulb weight was increased by 67, 41 and 323% respectively, under the irrigation frequency of once a month, which were significantly greater than that of other treatments. And leaf number increase rate was positively correlated (r=0.97, *P*<0.01) with the irrigation frequency, so was fresh bulb increase rate (r=0.98, *P*<0.01). However, no significant differences were observed with regard to bulb number in all the treatments. The species with a good ability of drought resistance can get by under irrigation frequency of once in every three months. The maximum net photosynthetic rate reached 18.0 μmol/m^2/s or higher, and the light saturation point was near or higher than 2000 μmol/m^2/s, therefore, a full-light management was recommended for the cultivation of *L. haywardii*. It took about a week to recover the normal photosynthetic ability after a severe drought stress. On the contrary, short-term drought stress had no more negative effect on net photosynthetic rate but remarkable light compensation effect. Higher temperature (under 22℃) was favourable for photosynthesis. Cultivation management in dormancy stage was necessary for increasing bulb yield of *Lycoris.*

Key words: Watering interval, drought resistance, photosynthesis, biomass, cultivation.

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INTRODUCTION

Lycoris haywardii, a species of Amaryllidaceae, is a perennial herb with bulbs. Its leaves appear from early October to early May of the following year. Its perianth is reddish violet, a little lighter than that of *L. sprengeri*, and changes to ink-blue at the apex (Hsu et al., 1994). *Lycoris* spp. have a great ornamental value for their beautiful flowers and attractive foliage and important medicinal value in bulbs (Liu et al., 2012; Zhang and Cao, 2001). Species of *Lycoris* have a low reproduction rate, low field yield for bulb production and no technique for effective cultivation and it will take about five years to produce flowers from seedlings (Zhang and Cao, 2001). Slow growth of bulbs is a major problem in cultivation, which has not been solved effectively yet. It needs further exploratory cultural practices. We have conducted a series of studies on that problem, however, results revealed that fertilization does not increase bulb yield (Bao et al., 2012b). Species of *Lycoris* have nutrient strategies of slowly growing (Bao et al., 2012a; Chapin, 1980) and distinct eco-mechanism for retranslocation and conversion of nutrients (Bao et al., 2012a). In addition to fertilizer application, watering management is also important for cultivation. But *Lycoris* is usually regarded as a plant resistant to drought (Qin et al., 2003; Zhang

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Table 1. Soil Relative Water Content (SRWC) of the sand at different stages in early 2012.

Test date	SRWC (%)				
yyyy-mm-dd	A1	A2	A3	A4	A6
2012-01-03	61.9	52.3	2.7	2.6	2.4
2012-01-31	82.1	29.4	60.8	1.2	1.1
2012-02-28	75.2	67.0	32.9	46.4	2.3
2012-04-01	33.5	14.6	6.5	8.3	1.7
2012-04-30	20.5	17.6	13.4	2.7	17.1

and Cao, 2001). Furthermore, species of *Lycoris* are in dormant stage in hot summer when plants need more water management. As a result, very little attention is paid to the water management for *Lycoris* spp. Although there are many studies on the water effect on plant growth (Flagella et al., 2002; Rawson and Turner, 1983; Shan et al., 2010; Su et al., 2007; Xia et al., 2001), very limited information is available about the relationship between water and growth of *L. haywardii*. In order to develop a reasonable watering regime and evaluate the influence of irrigation on growth of *L. haywardi*, the effect of different watering levels on growth was comparatively studied.

MATERIALS AND METHODS

This study was conducted in a greenhouse at Hangzhou Botanical Garden (120°16'E, 30°15'N), Zhejiang Province, China. Seventy-five bulbs were selected from the Garden's nursery, which were as uniform in weight (≈15.5 g each bulb in wet weight), and every five bulbs were planted in each pot (20 cm in height, 20 cm in top width and 60 cm in top length) on 16 August 2010 with river sand as a medium, which had a total nitrogen content of 0.2 g/kg, a total phosphorus content of 0.07 g/kg, a total potassium content of 4.5 g/kg, an organic matter content of 2.4 g/kg, and a pH of 5.6.

With a randomized complete block design, the experiment was performed with one single factor at five levels (or five treatments) of watering intervals, viz. A1 (once every 1 month), A2 (once every 2 months), A3 (once every 3 months), A4 (once every 4 months), and A6 (once every 6 months) and three replications. The amount of water applied each time was 3.5 L per pot to ensure sand drenched. The first watering date was on 25 September 2010. Afterwards re-watering was implemented at the end or the beginning of a month according to the design until the last watering date on 30 April 2012.

Alive leaf length and number of each clump were first recorded on 9 March 2011 when leaves almost reached the stage of most vigorous vegetative growth in the first growing season after planting, followed by the second recording on 6 May, 2011 at the late stage of leaves. The following ten recordings were conducted in the second growing season from autumn of 2011 to spring of 2012, about once every 3 w during the leaf stage of all plants. The bulbs were harvested on 4 June, 2012. Samples were dried in an oven at 85℃ for 48 h after cleaning.

The net photosynthesis rate (Pn) was measured using a portable gas exchange system Li-6400XT (Li-COR，USA) at the middle-upper part of the second leaf from bottom of a randomly selected plant in each pot based on an open air path, natural atmospheric temperature and CO_2 concentration in the greenhouse. Air flowing speed and photosynthetic photon flux (*PPF*) were set at 500 μmol/s and 800 μmol/m^2/s, respectively. Totally 17 measurements were carried out from January to April 2012, just prior to re-watering and 3, 6 and 14 days after re-watering. Besides, a sand sample in 10 cm depth was taken just before re-watering to be dried in an oven at 105℃ for 24 h for the measurement of soil relative water content (SRWC). Dates for soil-sampled were shown in Table 1.

Light response curves were developed using the following *PPF*: 2000, 1800, 1600, 1400，1200, 1000, 800, 600, 400, 200, 100, 50 and 0 μmol/m^2/s at the middle-upper part of the second leaf from the bottom of a randomly selected plant for each treatment. Before recording, the system was adjusted for baseline for 30 min at 2000 μmol/m^2/s.

Data were analyzed using MS Excel 2003 and SPSS 16.0. Statistical significance was determined at $P \leq 0.05$. Differences between means were compared according to an LSD test.

RESULTS AND DISCUSSION

Watering interval and soil relative water content

SRWC is a ratio of soil water content to field saturated moisture capacity (Shan et al., 2010; Shangguan, 1997). SRWC of the medium just before re-watering at the end or the beginning of a month was shown in Table 1. The scope of SWRC of A1 was 20.5 to 82.1%. It indicated that treatment A1 could keep a higher SWRC in winter, but in early spring the interval might be too long. It was obvious that the longer a re-watering interval, the lower the SRWC. We estimated that it would be necessary to water when SRWC reached about 50%.

Impact of watering frequency on leaf number

The dynamic change in average leaf count per clump for each treatment was showed in Figure 1. It is obvious that the leaf number of treatment A1 was the highest, and A6 was the lowest. Analysis of variance (ANOVA) indicated that there was no significant difference among A1, A2 and A3, but there was significant difference between the group of A1, A2, A3 and the group of A4, A6 on 9 March 2011. Leaf number showed 3 levels on 16 November 2011 and 27 February 2012 in the second growing season, in which A1 had significantly more leaves than

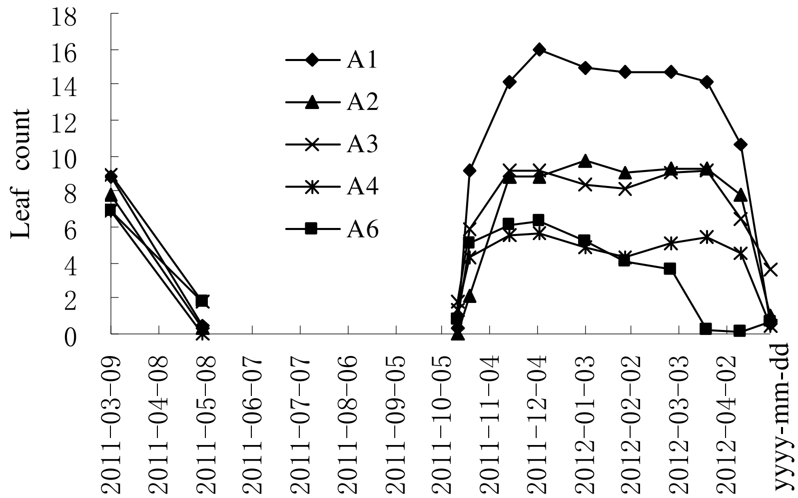

Figure 1. Dynamic changes in average leaf count per clump in different treatments.

A2 and A3, and the latter two also had significantly more leaves than A4 and A6. The ratio of the leaf number on 27 February, 2012 to that on 9 March, 2011 indicated the extent to which leaf number increased. The ratio of A1, A2, A3, A4 and A6 was 1.67, 1.19, 1.01, 0.75 and 0.52, respectively. The leaf number of treatments A1, A2 and A3 was increased by 67, 19 and 1% respectively. However, that of A4 and A6 was decreased by 25 and 48%, respectively. If watering frequencies were quantified (that is, A1, A2, A3, A4 and A6 were valued as 1, 1/2, 1/3, 1/4 and 1/6, respectively), it was known from regression analysis that the increase rate of the leaf number was significantly in positively linear correlation with watering frequency (correlation coefficient r = 0.97. P = 0.008), which indicated the higher the irrigation frequency, the more leaf number. The linear regression was shown as following:

Y =127.487X -54.572.

Here independent variable X was watering frequency on a monthly basis, and Y was the percentage of increased leaf number

It was illustrated that *L. haywardii* is strong in resistance to drought, because the leaf number of A3 was not decreased obviously one year after planting (Ratio = 1.01).

The difference in leaf number was not significant between A1 and A2 or A3 on 9 March, 2011. However, in the second growing season after dormancy (samples from 16 November, 2011) the difference was significant, indicating watering in the dormancy period was necessary. It may be the reason that bud differentiation requires certain moisture, for No Leaf Period (dormancy period) is the main period of leaf bud differentiation in *Lycoris* (Li and Zhou, 2005). Moist soil can ensure the bud differentiation, and generate more leaves.

Impact of watering frequency on leaf length

The dynamic change in leaf length of five treatments is shown in Figure 2. A1 had the longest average leaf length. In general, the impact on leaf length caused by water deficit was not obvious except in A6. In case of water deficit without replenishment for more than 4 months (A6), leaves started to wither from tip, but watering brought about new leaf emerging. Based on the analysis of variance of data from representative 5 December, 2011 and 27 February, 2012, leaf length in A1 was significantly greater than that in other four treatments, among which the difference were not significant with the data from 5 December 2011. Although leaf length in A1 was still significantly greater than that in other four treatments with the data from 27 February 2012, the leaf length in A2, A3 and A4 was significantly greater than that in A6. Compared with that on 9 March 2011, the leaf length of A1 on 21 March, 2012 was increased by 41%.

Dynamic change in net photosynthetic rate (Pn) and impact of watering frequency on Pn

The maximum of Pn in A1 was in January, and the minimum was in April (Figure 3). As a whole, Pn decreased over time with rising temperature and decreasing growth potential. However, Pn was positively correlated with air temperature before March when the air temperature in the leaf chamber (rTair) was below 15℃, and photosynthesis might be prone to inhibition when rTair was about higher than 22℃, for water deficit would take place if temperature is too high (Wang, 1997). It indicated that properly increasing air temperature in winter could increase photosynthesis, which was in line with that of *Lycoris aurea* (Bao et al., 2012b). We

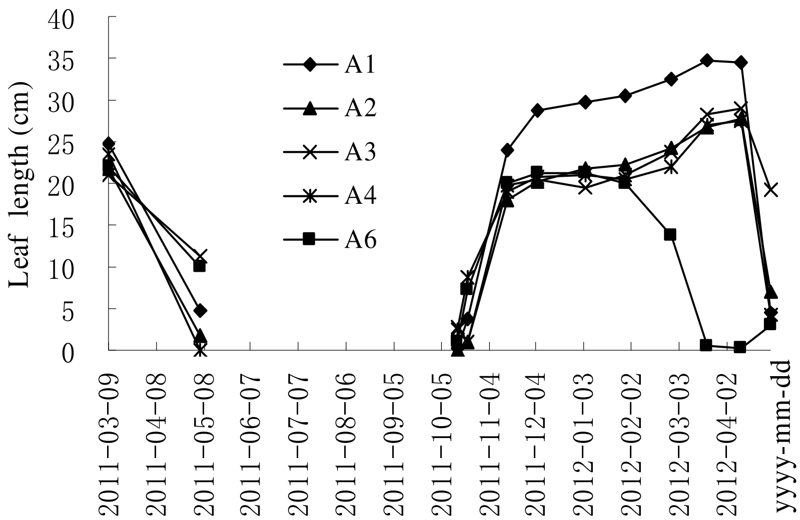

Figure 2. Dynamic changes in average leaf length per clump in different treatments.

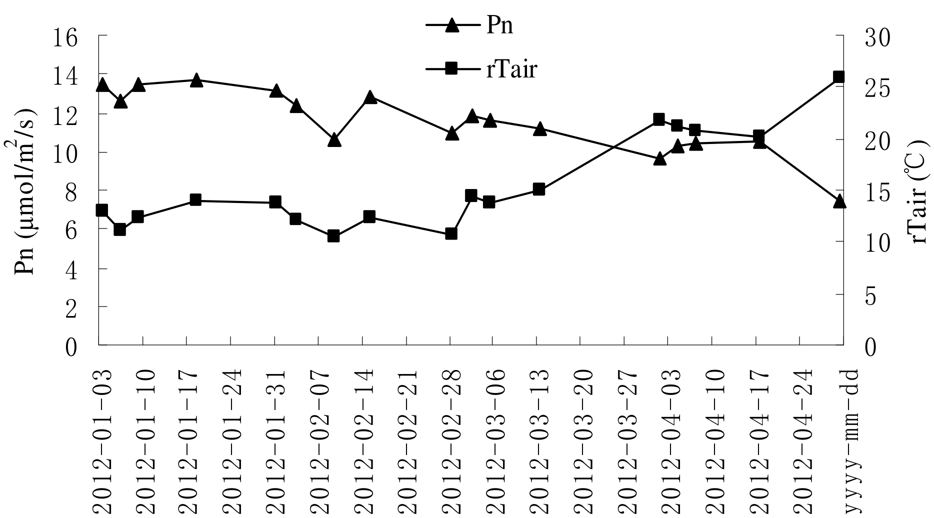

Figure 3. Dynamic changes in average Pn and rTair in Treatment A1. Pn: Net photosynthetic rate. rTair: Air temperature in the leaf chamber.

speculated that the best environmental temperature for photosynthesis should be about 22℃. And It would be better to cultivate this species in greenhouse to avoid low temperature at the leaf stage.

According to measurement, the total average Pn for A1, A2, A3, A4 and A6 was 11.55, 11.72, 11.28, 6.71 and 1.64 μmol/m^2/s, respectively. Impact of A2 on Pn was not obvious, but when watering interval was over 2 months, the effect was outstanding, such as that of A3 even in winter, and Pn appeared to be negative, but recovered to normal within six days after watering (Table 2). Pn could recover to normal photosynthesis even in treatment A4. It demonstrated that *L. haywardii* was in strong tolerance of drought and could maintain alive when relative lack of water and recovered photosynthesis after watering. As for A6, because leaves died, few new leaves appeared a week after watering, and the leaf was so long that it could be used for measurement of Pn half a month later when Pn reached a normal level again. On 30 April, 2012, RSWC of A1, A2, A3, A4 and A6 was 20.5, 17.6, 13.4, 2.7 and 17.1%, respectively, and the corresponding Pn was 7.48, 9.41, 10.34, 0.04 and 10.11 μmol/m^2/s. It indicated that *L. haywardii* had a good physiological capability for photosynthetic recovery, with which resistance to drought such as intensity of drought tolerance, recovery rate and recovery extent after watering was stronger than that of other plants, such as wheat, maize, *Leymus chinensis,* and sunflower (Liang et al., 2009; Lin et al., 2008;

Table 2. Re-watering effect on Pn recovery in five treatments from January to April 2012[z].

Days before or after re-watering	Pn (μmol/m²/s)				
	A1	A2	A3	A4	A6
The day just before re-watering	10.95	8.57	-0.09	0.33	(NL)
3 days after re-watering	11.81	11.49	10.57	7.86	(NL)
6 days after re-watering	11.52	11.77	13.61	13.04	(LTS)
14 days after re-watering	12.08	10.71	13.55	12.23	11.86

[z] Pn: Net photosynthetic rate; NL: No leaf; LTS: The leaf was too short to measure Pn

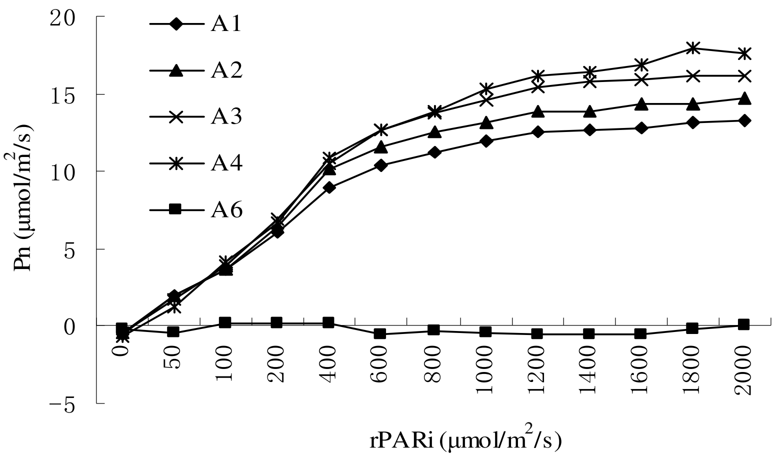

Figure 4. Light response curves of treatments on 14 February 2012. Pn: Net photosynthetic rate. rPARi: active photosynthetic radiation.

Shangguan, 1997; Yagoub et al., 2010).

Watering interval and light response

Treatment A6 had had no watering for 4 months on 14 February 2012, and the leaf was in wilting status, and total Pn was negative (Figure 4.). Photosynthesis of other treatments was normal (watered after 6 weeks for A3 and watered after 2 weeks for the others). The normal curve shape was like a parabola in line with that of *L. aurea*, *L. chinensis, L. longituba* and *L. sprengeri* (Bao et al., 2012b; Liu et al., 2012; Meng et al., 2008). The photosynthetic ability had no positive correlation with watering frequency. According to the average, photosynthetic capacity was in the following order: A4>A3>A2>A1. Lower watering frequency had a higher utilization of irradiance. That meant photosynthetic capacity was increased by watering after drought stress because of the light compensatory effect (Liu et al., 2004) We could infer that *L. haywardii* was heliophilous because of its light resistance. Light-inhibition phenomenon had not appeared at the active photosynthetic radiation (rPARi) level of 2000 μmol/m²/s, so full-light management was suggested in cultivation in certain conditions if temperature was not too high. The maximum of Pn in this test was 18.0 μmol/m²/s (from treatment A4).

Impact of watering frequency on bulb count and biomass

Results from ANOVA revealed that there was no significant difference in bulb number, but significant difference for dry bulb weight (Table 3). The ratio of the present fresh weight (PFW) to the initial fresh weight (IFW) represents an increase in biomass. Treatments A1, A2 and A3 were increased by 323, 164 and 47% in fresh bulb weight, respectively. However, that of A4 and A6 was decreased by 21 and 52% in fresh bulb weight, respectively. This indicated that fresh biomass was also positively correlated with watering frequency if quantifiedly regressed with watering frequency as leaf number (r=0.98, *P*=0.003). Watering once every 3 months could be regarded as a critical interval value. It could be seen that the wet bulb weight still increased at this watering frequency, and stopped increasing when the interval was longer than 3 months for bulbs became lighter and lighter. Additionally, the single average bulb biomass had a significant difference among treatments. The weight of a single bulb was negatively correlated

Table 3. Average fresh bulb weight ratio, bulb number and dry bulb weight and multiple comparison[y].

Treatment	PFW/IFW[x]	Bulb number	Dry bulb weight (g)
A1	4.23	8.7[a]	109.87[a]
A2	2.64	7.0[a]	70.67[b]
A3	1.47	8.7[a]	38.03[c]
A4	0.79	5.7[a]	23.82[d]
A6	0.48	7.3[a]	8.44[e]

[y]Different letters behind values in the same column indicate significantly different ($P \leq 0.05$). [x]PFW: Present fresh weight. IFW: Initial fresh weight.

with the watering interval. It is partly because the bulb gradually sacrificed the outside epimatium to maintain the survival of the inner short shoot, partly because the bulb tended to split into smaller new bulbs to survive under dry stress.

Our study revealed that within a certain range the more watering frequency, the more leaf number, leaf length and bulb biomass, which demonstrated the importance of water to plant (Yagoub et al., 2010). It was necessary to strengthen watering management even in no leaf period for *Lycoris* although *L. haywardii* is a drought-resisting species because of high water content in bulb. Since temperature was low in winter and evaporation was weak, watering once a month could ensure plant growth. But in early autumn or early spring, when temperature occurs to be a little higher, watering frequency should be higher. Roughly speaking, timely watering should be carried out when SRWC reached about 50%. While in a high temperature situation dry stress should be avoided to ensure leaf bud differentiation and leaf sprout. Since the minimum watering interval was once a month in this study, further study was needed to determine if there exists a shorter and better watering pattern.

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