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Diversity and nutritional properties of Pakistani dates: implications for sustainable value chain and decent living perspectives of rural households

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Diversity and nutritional properties of Pakistani dates: implications for sustainable value chain and decent living perspectives of rural households

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Summary

Date palm (*Phoenix dactylifera* L.) occupies almost three percent of the total worldwide cultivated area, with an annual production of seven million tonnes (t). Pakistan is an ideal place for the cultivation of date palm due to its sandy loam soil and semi-arid climate. In 2012, Pakistan produced 600,000 t of dates, on an area of 95,000 ha. Baluchistan province is the country's top date producer, followed by Sindh, Punjab and Khyber Pakhtunkhwa (KPK) provinces. More than 300 date varieties are known to exist in Pakistan and some commercially important cultivars are: Karbalaen, Aseel, Muzawati, Fasli, Begum Jhangi, Hillawi, Dashtiari, Sabzo, Koharaba, Jaan Swore, Rabai and Dhakki. Six districts from the four provinces of Pakistan (Jhang, Muzaffargarh and Bahawalpur (Punjab), Dera Ismail Khan (KPK), Khairpur (Sindh) and Panjgur (Baluchistan)) with largest area under date palm cultivation were selected to conduct socio-economic surveys including the income sources of date palm growers. A structured questionnaire with open-ended and closed questions was used for face-to-face interviews of 170 date palm growers. At each location after selection of a first farmer through a local guide, the former was requested to provide names and addresses of three other date growers in his area. From these three names, one was randomly selected for the next sampling. Additionally, date palm fronds and fruits of all available cultivars were collected for morphological and nutritional analyses. Soil samples were collected from the groves for subsequent chemical and physical analyses. Almost all farmers used dates as a food item for their families and some were using low quality dates as a feed for their livestock. Apart from dates, other date palm components (trunk, spadix, frond, inflorescence and seed) were used by date palm growers as a raw material for making many by-products for their families. Date palm had a major contribution in the income of households, 24% received 91-100% of their income from date palms. More than half of the surveyed farmers had date palm groves, but scattered plantations, home gardens and intercropping systems with cereal and other fruits were also present. Dhakki, Muzawati, Aseel, and Karbalaen were the most important commercial cultivars grown in the provinces

of KPK, Baluchistan, and Sindh. Aseel, Karoch, Haleni, Karbalaen, and Muzawati cultivars had the most firm fruit and good total soluble sugar, calcium and magnesium contents. The amount of magnesium found in dates of studied cultivars ranged from 0.143 to 0.876 mg g^{-1}. A great variation in frond morphology was recorded among the cultivars. Fruit length and fruit weight was highest in Dhakki date, making it visually more attractive for customers in addition to its good nutritional properties. The seed weight of the studied cultivars ranged from 0.7-2.0 g, while Desi dates had largest seed, making them less attractive for marketing. However, in terms of nutritional value and fruit size, most of the investigated varieties can compete with globally important commercial dates.

Zusammenfassung

Die Dattelpalme (*Phoenix dactylifera* L.) nimmt fast drei Prozent der weltweiten Anbaufläche ein, wobei die Jahresproduktion bei sieben Millionen Tonnen (t) liegt. Aufgrund seiner sandigen Lehmböden und des semi-ariden Klimas ist Pakistan ein ideales Anbaugebiet für Dattelpalmen. Im Jahr 2012 produzierte Pakistan 600.000 t Datteln auf einer Fläche von 95.000 ha. Die Provinz Baluchistan ist der Spitzereiter unter den Anbauregionen, gefolgt von den Provinzen Sindh, Punjab und Khyber Pakhtunkhwa (KPK). In Pakistan existieren mehr als 300 bekannte Dattelsorten, darunter auch einige kommerziell wichtige Sorten wie: Karbalaen, Aseel, Muzawati, Fasli, Begum Jhangi, Hillawi, Dashtiari, Sabzo, Koharaba, Jaan schwor Rabai und Dhakki. In den vier genannten Provinzen Pakistans wurden jene Bezirke (Jhang, Muzaffargarh und Bahawalpur (Punjab), Dera Ismail Khan (KPK), Khairpur (Sindh) und Panjgur (Baluchistan)) ausgewählt, welche die größte Anbaufläche für Datteln aufweisen, um sozio-ökonomische Studien inklusive einer Erhebung der Einkommensquellen von Dattelpalmbauern durchzuführen. Zu diesem Zweck wurden 170 Dattelpalmbauern mit einem vorstrukturiertem Fragebogen befragt. An jedem Befragungsort wurde der jeweils erste Dattelpalmbauer nach Abschluß des Interviews aufgefordert, Namen und Adressen von drei weiteren Dattelbauern aus dessen Region zu nennen. Aus diesen drei Namen wurde ein weiterer Dattelbauer nach dem Zufallsprinzip für die nächste Stichprobe ausgewählt.Die Dattelpalmwedel und -früchte aller verfügbaren Sorten wurden morphologisch ausgemessen und Nährstoffanalysen an Dattelfrüchten durchgeführt. Von jedem Dattelpalmhain wurden Bodenproben zur späteren chemischen und physikalischen Analyse gesammelt.

Fast alle Dattelbauern nutzten Datteln zur Nahrungsversorgung ihrer Familien, und einige verwendeten Datteln niedriger Qualität als Viehfutter. Neben der Dattelfrucht selbst dienten andere Dattelpalmbestandteile (Stamm, Wedel, Blütenstand und Samen) als Rohstoff für die Herstellung von zahlreichen Nebenprodukten für den Eigenbadarf. Die Dattelpalme trug bei 24% aller befragten Dattelbauern 91-100% zu ihrem Familieneinkommen bei. Mehr als die

Hälfte der befragten Bauern kultivierten Dattelpalmen in Hainen, aber Streuobstplantagen, Hausgärten und Mischkulturen mit Getreide und anderen Früchte waren ebenfalls zu beobachten. Dhakki, Muzawati, Aseel, und Karbalaen waren die wichtigsten kommerziellen Sorten, die in den Provinzen KPK, Baluchistan, und Sindh angebaut wurden. Aseel, Dhakki, Karoch, Haleni and Karbalaein, und Muzawati Sorten hatten die festesten Früchte und hohe Gehalte an gute löslichem Zucker, Kalzium und Magnesium. Die Magnesiumgehalte reichten in den untersuchten Sorten von 0.143 bis 0.876 mg g^{-1}. Die Wedelmorphologie zeigte eine hohe Variation zwischen den untersuchten Sorten. Dhakki zeigte die größte Fruchtlänge und das größte Fruchtgewicht, was sie, neben den guten Nährstoffeigenschaften, attraktiv für den Verbraucher macht. Das Samengewicht der untersuchten Sorten reichte von 0,7 bis 2,0 g. Den höchsten Mittelwert wies die Sorte Desi auf und sie ist damit weniger attraktiv für die kommerzielle Vermarktung. Jedoch konnte gezeigt werden, dass die meisten untersuchten Dattelsorten aufgrund ihrer guten Nährwerte und Fruchtgrößen mit kommerziellen, global wichtigen Dattelsorten konkurrieren können.

Chapter 1

General introduction, objectives, and hypotheses

1.1 General introduction

1.1.1 World cultivation of date palm

Date palm (*Phoenix dactylifera* L.) is one of the earliest cultivated plant species and approximately 100 million date palms belonging to different cultivars are planted worldwide (Zaid and de Wet, 2002). In 2012, global date production was about 7 million t, equivalent to a market value of >1 billion US$ (FAO, 2014). Most of date palms are grown in the world's arid regions between 15°N and 35°N, from India in the east to Morocco in the west (Zaid and de Wet, 2002). Since 1962 date production has increased worldwide from 1,809,100 to 6,914,300 t in 2012 (FAO, 2014). In 2012 the leading ten date producing countries were Egypt (23.5%), Iran (17.0%), Saudi Arabia (16.8%), Algeria (12.6%), Pakistan (9.6%), Iraq (8.1%), Oman (4.2%), UAE (3.0%), Tunisia (2.7%), and China (2.4%; FAO, 2014).

Distribution of date palm by region shows that Asia stands first with the 60 million date palms mostly grown in Saudi Arabia, UAE, Bahrain, Iran, Iraq, Oman, Kuwait, Pakistan, Yemen, and Turkmenistan; Africa comes second with 32.5 million palms grown in Algeria, Egypt, Morocco, Mauritania, Libya, Mali, Niger, Sudan, Chad, Tunisia, and Somalia. USA and Mexico have 600,000 date palms followed by Europe (Spain) with 320,000 and Australia with 30,000 date palms (Zaid, 2001). The UAE has about 1.5 million palms with an annual date production of 8400 t and the world's largest tissue culture laboratory for date palm where >100,000 date palms are produced annually to meet the demand which cannot be fulfilled by the natural offshoot (sucker) production (Date Palm Tissue Culture Laboratory, 2006).

From 1999-2001, Iran, Iraq, and Saudi Arabia harboured almost half of the harvested area of date palm in the world (Botes and Zaid, 2002). About 93% of the dates are consumed locally in date palm growing countries whereby the quality of the majority of these dates is not of export quality (Botes and Zaid, 2002). Over the past 40 years the world's total export of dates has experienced an annual increase of 1.7% (El Hadrami and Al-Khayri, 2012). Rapid increase in export has been noticed in the UAE, Oman, Egypt, and Pakistan. Date palm

export has been decreased in Morocco (due to phytosanitary problems) and in Iraq (due to the trade embargo; Botes and Zaid, 2002).

The focus on cultivation of few cultivars with high fruit quality such as 'Deglet Nour' has caused a large imbalance between these few and medium to low fruit quality cultivars (Rhouma, 1994). Furthermore, deleterious event such as abandonment of groves due to the aging of farmers and low productivity of dates (Bouguedoura *et al*., 2015) as well as wars in the Gulf region are said to have additionally resulted in the loss of genetic diversity since large groves were destroyed (Khierallah *et al*., 2011). In North Africa, date palms are currently in danger due to a severe wilt caused by *Fusarium oxysporum* f. sp. *Albedinis* (Dihazi *et al*., 2011). The dominant fungi responsible for decline and death of date palm in Iraq were *Fusarium oxysporum*, *Ceratocystis radicicola*, *Phomopsis phoenicola*, and *Diplodia phoenicum* (Rattan and Al-Dboon, 1980; Mousiri *et al*., 2000). These developments are likely to also result in genetic erosion of valuable but underutilized genetic resources and well adapted date palm ecotypes.

1.1.2 Cultivation of date palm in Pakistan

Nature has bestowed Pakistan with distinctive climatic and soil conditions, which provide a great diversity in the agricultural sector (Wasim, 2011). Around 63% of the total population in Pakistan is living in rural areas and has direct or indirect links with agriculture, which contributes >21% to the GDP and engages 45% of the labour force (Raza *et al*., 2012). A large variety of fruits are grown in Pakistan on an estimated area of 735,000 hectares with an average production of about 5,712,000 t annually, in which groves play a major role (Government of Pakistan, 2004). Citrus (*Citrus* spp.), mango (*Mangifera indica* L.), dates, and banana (*Musa paradisiaca* L.) are major crops grown in the country, which not only provide food for the community, but as in other countries also support the overall economy (Wasim, 2011).

In 2012, Pakistan had a date production of 600,000 t (FAO, 2014). The main date palm growing areas of Pakistan are: Muzaffargarh, Jhang, Bahawalpur, and Dera Ghazi Khan (Punjab), Turbat and Panjgur (Baluchistan), Dera Ismail Khan (Khyber Pakhtunkhwa), and Khairpur and Sukkur (Sindh; Abul-Soad, 2010). More than 300 date palm varieties are grown of which the twelve commercially important are: Karbalaen, Aseel, Muzawati, Fasli, Begum Jhangi, Halawi, Dashtiari, Sabzo, Koharba, Jaan Swore, Rabai, and Dhakki (Ata, 2011). However, some cultivars, grown in specific areas, such as Dhakki in Dera Ismail Khan, Aseel in Khairpur, and Begum Jhangi in Panjgur, have a particularly high market demand and some of them have the potential to compete with the world's best quality dates (PHDEB, 2008). Dates are important as a subsistence crop in Pakistan and marketed all over the country. Its utilization is at peak during the month of Ramadan in Muslim countries and during the celebrations of Diwali in India. Even in drought and salinity affected areas, date palm is a component of agricultural development and considered a symbol of life (Zohary and Hopf, 2000). Date production fetches maximum returns to the community living in areas which are characterised by adverse climatic and soil conditions (FAO, 1982; Diallo, 2005).

In Southern Punjab, dates and their by-products are the third most important contributor to people's food and income (Ata *et al*., 2014). Date Palm is also an important fruit crop of Sindh province, where 85% of total dates are produced in the Khairpur district. There is a rapidly increasing demand of the offshoots of the locally grown cultivar Dhakki in Dera Ismail Khan (Abul-Soad, 2010). The diverse uses of date palm in Pakistan demonstrate the importance of this fruit in the daily lives of rural communities (Ata *et al*., 2014).

In Pakistan, monsoon rains occur during July, August, and September, which coincides with the date ripening season in the country's date palm growing areas. From fruit set to maturity, date palm usually takes 180-210 days. Date palm is particularly sensitive to rainfall from maturity (*khalal*) up to ripening stage (*rutab and tamar*). Rainfall can deteriorate dates within 1-2 days; at late *khalal* stage rain can cause crakes in the epicarp of dates in even a few hours. Rain does not damage the dates at the early *khalal* stage and even may have a

beneficial effect by washing away sand and dust particles from the fruits. The major damage occurs when either the rainfall is early, or dates are late in ripening (Abul-Soad, 2010). The amount of rain is less important than the conditions under which it occurs. A light shower accompanied by high relative humidity and a prolonged period of cloudy weather may cause more severe damage than heavy rain followed by dry winds and clear weather (Zaid and de Wet, 2002).

Date palm is dioecious in nature, bearing male and female flowers on separate palms. In the absence of insect, bee or human pollination this leads to the development of parthenocarpic dates without commercial value. Pakistani date palm growers are aware of the importance of the human pollination for better fruit set and yield as practiced for millennia. The pollen has metaxenia effects, in that it not only influences the size of dates and their seed but also the time of ripening. Hence, this effect could also be used to speed up the date maturity to avoid rainfall damage at the end of the fruit development stage (Swingle, 1928).

Improper fruit harvesting is another problem in the groves as it affects date quality and is one of the major reasons for low demand of Pakistani dates in the international market. According to FAO (2011), Pakistan is exporting dates at a price of 565 $/t, which is very low as compared with other date producing countries (Tunisia, 2433 $/t; Iran, 1430 $/t; Saudi Arabia, 1109 $/t; Egypt, 1186 $/t; and Oman, 1257 $/t). Pakistani dates are harvested and marketed at three stages (*khalal*, *rurtab*, and *tamar*) of their development. The choice for the harvesting stage depends on cultivar characteristics, climatic conditions, and market demand (Abul-Soad, 2010).

1.1.3 Socio-economic and traditional importance of date palm and its by-products

Date palm is socio-economically important for local inhabitants wherever it is cultivated (Jain *et al*., 2011). In the past date palm groves facilitated nomadic people to settle and initiate farming. Later such communities became a hub for the trading and marketing of plant and

animal products. Until today in many oasis-based societies dates are one of the most appreciated and demanded products for short- and long-distance trade because of their use as a food and feed item. Soft and dry dates are eaten fresh, can be sliced, press-packed, and used as raw material to prepare other products which are either consumed locally or exported to other countries. Semi-industrial date products include bread, cakes, pudding, cookies, candy bars, ice cream, cereals, paste, spread, jam, jelly, juice, vinegar, syrup, and alcohol (El Hadrami and Al-Khayri, 2012). Poor quality dates are often dehydrated, crashed, and mixed with straw and grains or soaked in water before usage as feed for domestic animals (El Hadrami *et al*., 2011). Besides the fruits of the date palm, terminal buds and young fronds are also valuable and can be used as vegetables. Fronds are often used to make sleeping and praying mats, baskets, ropes, hats, and hand fans. In some countries roasted and crushed date seeds are used as an additive to flour and coffee. In West and North Africa tapping the date palm to harvest its sugary sap for conversion into molasses, sugar, and other alcoholic beverages is common (El Hadrami *et al*., 2011).

1.1.4 Value chain and decent work

Value chain is a set of interrelated generic activities performed by different actors / stakeholders to add value to the raw materials through various processes and to sell finished products to the customers. The goal of these activities is to generate value that exceeds the total cost of making the product, thus generating a profit margin. According to Porter (1998) such activities include inbound logistics (include the receiving, warehousing, and inventory control of input / raw materials), operations (value-creating activities that transform the inputs into the final product), outbound logistics (activities required to get the finished product to the customer including order fulfillment), marketing and sales (activities associated with getting buyers to purchase the product, including channel selection, advertising, and pricing), and service (those activities that maintain and enhance the product's value including customer support and repair services). Sustainable value chain is regarded as fair distribution of

revenues / profits earned by different actors / stakeholders in the value chain (Schaafsma *et al*., 2014).

In order to achieve a significant contribution to decent work within the context of value chain development, several socio-economic criteria need to be taken into account such as industry growth prospects, employment and income creation, reducing incidences of child labour, promoting gender equity, improving occupational health and safety, social protection for families, enhancing skills, and poverty reduction (Herrand and Muzira, 2009).

Based on above mentioned constraints (1.1.1-1.1.3 section) in date palm cultivation and marketing, proper value addition in market chains of date palm can help to attain decent living in poor marginal areas of Pakistan.

1.1.5 Nutritional importance of dates

Dates are an ideal food item due to their contents of essential nutrients and resulting health benefits for humans (El Hadrami and Al-Khayri, 2012). Apart from a high percentage of carbohydrates (total soluble sugars, 44-88%), dates also contain fat (0.2-0.5%), protein (2.3-5.6%), dietary fiber (6.4-11.5%) and vitamins. The quantity of dietary fiber in dates depends on ripeness and variety. The flesh of dates contains 0.2-0.5% oil, whereas the seed contains 7.7-9.7% oil. Dates contain at least fifteen minerals whereby their concentrations vary from 0.1-916 mg/100 g dry matter (El Hadrami and Al-Khayri, 2012). Many date palm varieties have high concentrations of potassium in the flesh (0.9%) and seeds (0.5%). Other salts and minerals present in dates are boron, calcium, fluorine, magnesium, cobalt, copper, manganese, sodium, zinc, and phosphorous (El Hadrami and Al-Khayri, 2012). Dates contain flavonoids (ß-carotene, zea-xanthin, and lutein), which have the ability to protect cells in the body from harmful effects of free oxygen radicals and dates are an excellent source of iron (0.90 mg Fe/100 g of fruit; Rudrappa, 2015).

1.1.6 History of date palm cultivation

Date palm has a long and rich history as a fruit crop on the Arabian Peninsula, in the Middle East and North Africa. During the last centuries its cultivation extended into countries like Australia, Mexico, southern Africa, and the United States of America (Nixon, 1951). Date palm has been cultivated in the Middle East and North Africa for at least 5,000 years (Zohary and Hopf, 2000). The earliest record from Mesopotamia (present day Iraq) shows that date palm was cultivated there as early as 3,000 BC (Wrigley, 1995), while in Egypt, cultivation seems to have started only in the middle of the second millennium BC (Wrigley, 1995). Date palm cultivation was also portrayed on ancient Babylonian and Assyrian tablets including the well-known Code of Hammurabi, which contained laws for the date palm cultivation and sale. Written evidences related to the date palm culture were also found in ancient Syria, Palestine, and Libya (Nixon, 1951; Popenoe, 1973). The long history of date palm cultivation, exchange of cultivars among different regions, and its wide distribution make it difficult to determine the origin of this species, which most is in western India or Southern Iraq (Wrigley, 1995). In past, it was believed that wild ancestors of the date palm do not exist. However, recent archaeobotanical field research coupled with laboratory studies have found that the cultivated date palm is closely related to the feral and wild populations present in the Middle East and North Africa. Wild dates are considered to be the same species as date palm, because of their ability to hybridize with the named date palm cultivars, and are morphologically very similar to domesticated forms. The main distinguishing feature of wild dates is their smaller fruit size (Zohary and Hopf, 2000).

Table 1. Early occurrence of date palm in the Middle East.

Site	Period	Dating	Part of date palm	Reference
Tell el-Oueili, Iraq	Ubaid period	4700-4200 BC	Seeds & stem/leaf fragments	Neef, 1991
Eridu, Iraq	Ubaid period	4000 BC	Seeds	Safar *et al*., 1981
Tepe Gaz Tavila, Iran	Neolithic	5400-4800 BC	Seeds	Costantini, 1985
Shahr-i Sokhta, Iran	Bronze Age	2700 BC	Stem/leaf fragments	Costantini, 1985
Tepe Yahya, Iran	Bronze Age	2400-1800 BC	Seed	Costantini, 1985
Hili 8, UAE	Bronze Age	3000-2000BC	Seeds & stem/leaf fragments	Cleuziou, 1997; Tengberg, 1998
Umm an-Nar, UAE	Bronze Age	2700-2200 BC	Impressions on mud brick	Willcox, 1995
Tell Abraq, UAE	Bronze Age	2500-400 BC	Seeds, stem/leaf fragments & impressions on mud brick	Willcox and Tengberg, 1995; Tengberg, 1998
Dalma 11, UAE	Neolithic	5290-4940 cal BC & 4810-4540 cal BC	Seeds	Beech, 2003
Nud Ziba, UAE	Bronze Age	2000 BC	Seeds	Kennet and Velde, 1995
Muweilah, UAE	Iron Age	800-600 BC	Seeds, fruits & stem/leaf fragments	Tengberg, 1998
Rumeilah, UAE	Iron Age	800-400 BC	Seeds	Costantini and Costantini-Biasini, 1986
Mleiha, UAE	Late Pre-Islamic	400 BC-400 AD	Seeds & stem/leaf fragments	Tengberg, 1999; Pena-Chocarro and Barron Lopez, 1999
Ed-Dur, UAE	Late Pre-Islamic	100 AD	Phytoliths	Vrydaghs *et al*., 2001
H3, Sabiyah, Kuwait	Neolithic	5530-5320 cal BC	Seeds & phytoliths	Beech, 2003; Parker, 2010
Failaka, Kuwait	Bronze Age	2000-1500 BC	Seeds & stem/leaf fragments	Willcox, 1990; Rowley-Conwy, 1987
Saar, Bahrain	Bronze Age	1900 BC	Seeds, stem/leaf fragments & phytoliths	Gale, 1994; Nesbitt, 1993
Bat, Oman	Bronze Age	2500-2000 BC	Seeds, stem/leaf fragments & impressions on mud brick	Tengberg, 1998

Adopted from Tengberg, 2012

1.2 Research objectives and hypotheses

As date palm has the potential to improve people's nutrition and income under marginal and extreme environmental conditions, this study was based on the following overarching hypotheses:

1. In Pakistan, date palm plays a key role for the incomes of poor people in arid marginal areas, both as a subsistence crop and a market commodity.

2. Dates in Pakistan show substantial differences in nutritional properties that are cultivar- and site-specific and can be exploited in market-oriented value chains.

In view of the above the objectives of this study were (1) to review the knowledge about origin and domestication of date palm, (2) to analyze the socio-economic role of date palm cultivation in Pakistan and its marketing routes, (3) to identify the effect of soil chemical and physical properties on nutritional properties of dates, and (4) to examine potential effects of morphological variations of date palm on nutritional properties of dates.

Chapter 2

Domestication and origin of date palm in the Middle East, North Africa, and South Asia based on archaeobotanical, historical, and genetic evidence

2.1 Introduction

The date palm (*Phoenix dactylifera* L.) is characteristic for many oasis agro-ecosystems which are islands of agricultural productivity in desert environments. Date palm provides food and feed to a large part of the populations living in the drylands of the Middle East, southwestern Asia, North Africa, and the Arabian Peninsula. The dioecious, perennial, and diploid palm species is one of the fourteen species of the genus *Phoenix* belonging to the family Arecaceae (Dransfield *et al*., 2008). The genus name was inspired by the fabled bird of ancient Greek mythology and the species' name from the finger like appearance of the fruit. In the old world, the date palm was domesticated around 5000 BC, along with olive (*Olea europaea* L.), fig (*Ficus carica* L.), and grapevine (*Vitis vinifera* L.; Zohary and Spiegel-Roy, 1975).

Despite of the economic importance of this specie, little information is available on its ancient history, domestication, and origin. The difficulty of determining the wild status of unmanaged date palm populations is the main hindrance to a greater understanding of the history of date palm domestication (Barrow, 1998; Pintaud *et al*., 2010). Usually wild populations show a high genetic diversity, though this may be lost due to bottleneck effects (genetic drift and sampling effect) and subsequent selection effects (positive and negative) in cultivated populations (Pintaud *et al*., 2013). However, the identification of feral populations can be complicated by the potential existence of gene flow among cultivated and wild populations (González-Pérez *et al*., 2004; González-Pérez and Sosa, 2009).

Domesticated and wild populations of *Phoenix* are known to have extremely complicated genetic and morphological relationships (Pintaud *et al*., 2008; Second and Rouhan, 2008). Compared to other *Phoenix* species the genetic diversity of the cultivated date palm is isolated and geographically and phylogenetically well structured (Pintaud *et al*., 2010). As a result of selection some rare alleles associated with desirable traits are frequently present in the cultivated gene pool and absent in wild populations. These distinguishing allelic

frequency patterns will remain in the genome of a population to some level after cultivation has ceased and may therefore still be found in feral populations (Fig. 1a). Restored gene flow creates some complications which may include components of cultivated and feral populations of *P. dactylifera* and sometimes even components of different *Phoenix* species (Fig. 1b; Pintaud *et al*., 2013).

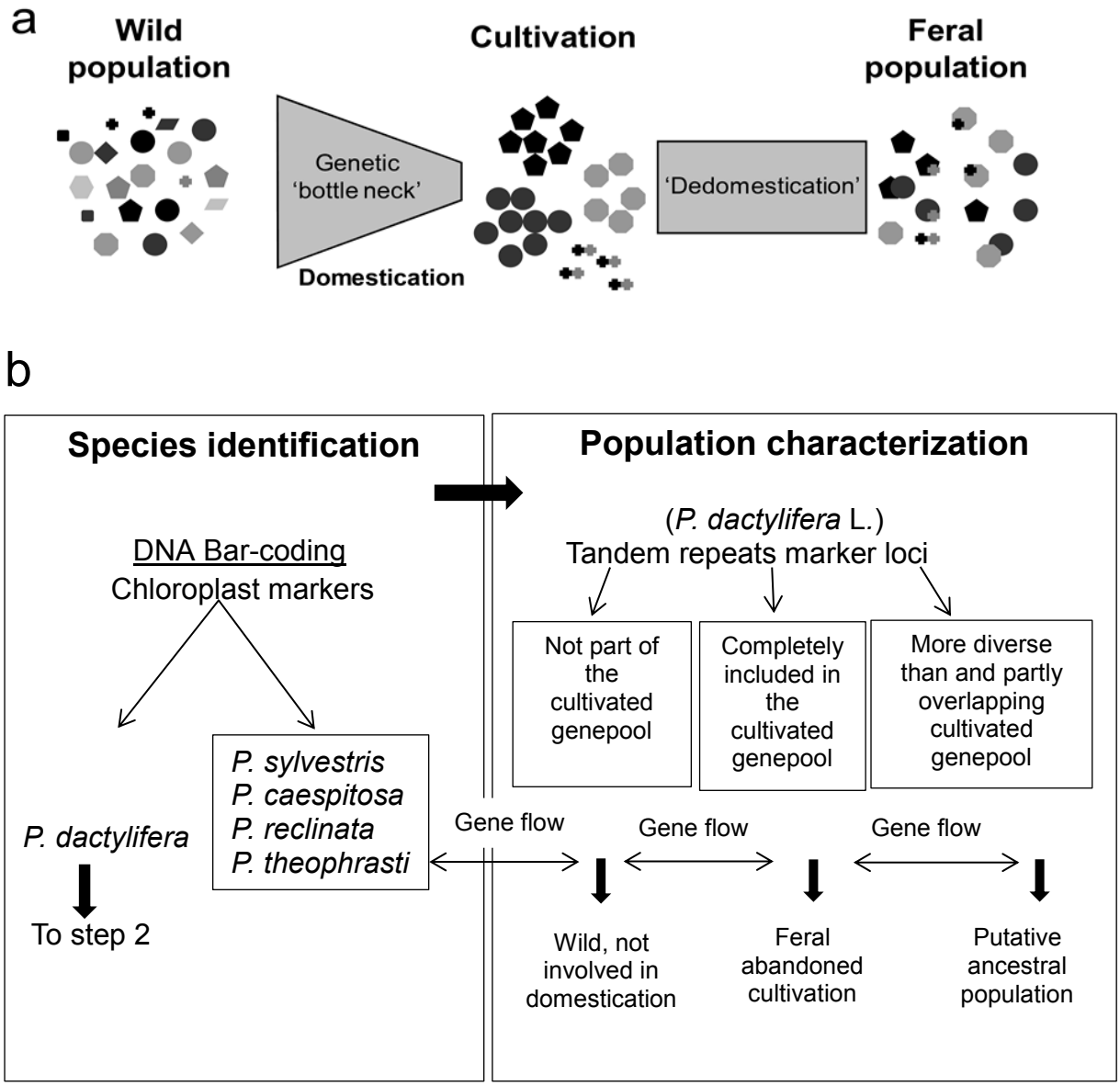

Figure 1. (a) Diagrammatic genetic relationships between wild, cultivated, and feral populations of date palm. Wild populations are characterized by a high genetic diversity. Cultivated populations have a reduced diversity and show the effects of selection, breeding, and clonal propagation. Feral populations differ from the cultivated ones by restored panmixy. (b) Steps for the genetic identification of a date palm population of unknown status (modified from Pintaud *et al*., 2010).

The main difficulty in finding the origins of domestication of *P. dactylifera* resides in the identification of its wild ancestor. Presently, no wild population of *P. dactylifera* has been discovered and it is possible that pure ancestors no longer exist. In the Middle East and North Africa, spontaneous populations were found, but their wild status is still debatable (Munier, 1973; Zohary and Spiegel-Roy, 1975; Zohary and Hopf, 2000).

According to recent studies, the domestication process of the date palm is similar to that of other fruit trees such as olive, fig and pomegranate (*Punica granatum* L.), as they were all domesticated in one early wave of domestication (Doebley *et al*., 2006; Meyer *et al*., 2012; Jaradat, 2015). Cultivated plants are phenotypically and genetically distinct from the ancestral gene pools because of their domestication process, which comprise processes of selection, breeding, migration, and admixture (Grassi *et al*., 2003; Arroyo-García *et al*., 2006). Humans have a notable contribution to domestication of plants by selection of different traits of productivity, quality, and fertility (Zohary *et al*., 2012). Knowledge related to the population genetics of cultivated plants and their domestication history is important for genetic improvement relying on the effective conservation and use of the germplasm represented by the wild relative populations and agrobiodiversity (Zehdi-Azouzi *et al*., 2015). Pintaud *et al*. (2010) studied the genetics and taxonomy of the genus *Phoenix* using Simple Sequence Repeat (SSR) markers and claimed that date palm has indeed been domesticated from wild population *P. dactylifera*. Pintaud (2010) established a domestication model, according to which only potentially widespread wild populations were involved in the primary domestication of date palm (Fig. 2). Later selection was made on the basis of the fruit quality and disease resistance. Some other factors including the exchange of vegetative propagules (offshoots), seed dispersal, and pollen played a strong role during the initial phase of the domestication and affected the genetic structure and gene flow of the date palm populations worldwide (Jaradat, 2015). Selected clonal varieties from oasis agricultural systems form bulk of the diversity of date palms presently cultivated at an industrial level (Pintaud *et al*., 2013; Fig. 2).

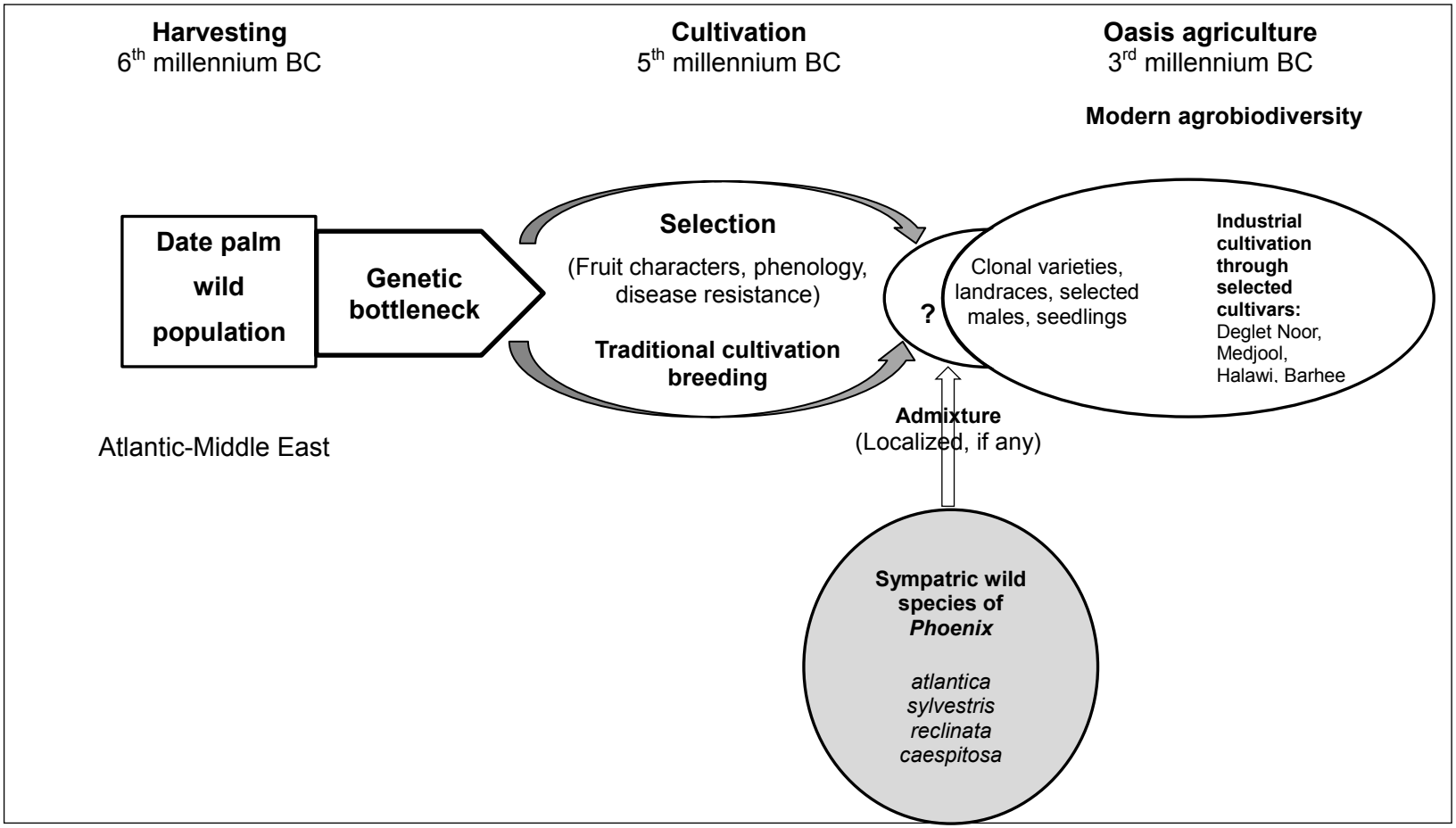

Figure 2. Domestication model of date palm (modified from Pintaud *et al*., 2013).

In many areas of the world with historical cultivation of *Phoenix*, date palm seems to be sympatric with other feral indigenous *Phoenix* species such as *P. theophrasti*, *P. atlantica*, *P. reclinata*, *P. sylvestris* and *P. caespitosa*, making morphological identification difficult (Pintaud *et al*., 2013). Several species of *Phoenix* have been tested cytogenetically and all showed identical chromosomal complements (Jones, 1995; Barrow, 1998). Beal (1937) studied the chromosomal status of *P dactylifera*, *P. canariensis*, *P. humilis*, *P. reclinata*, *P. honceana* (variety formosanum), and *P. sylvestris*. The haploid chromosome number was obtained from the staminate flowers of the male palms. Microsporocytes at first meiotic division of *P. dactylifera*, *P. sylvestris*, and *P*. *canariensis* showed 18 bivalents chromosomes with similarity in their range of form and size. Pollen of *P. sylvestris* and *P. canariensis* has been successfully used in crosses with *P. dactylifera*. Although both species had smaller chromosome, nevertheless, they breed truly with *P. dactylifera*.

Numerous hypotheses have been proposed to explain associations amongst *Phoenix dactylifera* and other *Phoenix* species (Munier, 1973). Date palm is known to inter-breed with all *Phoenix* species and produces fertile hybrids. It has been proposed that cultivated date palms were domesticated from these wild species or are a product of hybridization between two or more of these species. Recent genetic data rebuts this assumption by suggesting that more private alleles are present in cultivated date palm than previously thought suggesting to a likely descent of modern date palm from wild populations (Pintaud *et al*., 2010).

Thousands of date palm cultivars exist in different regions, from Morocco in the west to the Pakistani Iranian border in the east and from Syria in the north to Yemen in the south (Pintaud, 2010). Not only technical knowledge regarding cultivation practices of date palm, but also biological material seems to have driven the expansion of cultivation into the current areas (Popenoe, 1973).

In view of the above the objective of the present study was to review the current literature about the origin and domestication of date palm and its past and present diversity in the

Middle East, North Africa, and South Asia. This review is based on two types of information: (i) fossil and petroglyphic evidence obtained from the examination of archaeological excavations (archaeobotany), and (ii) genetic data of current date palm stands and their wild relatives.

2.2 Middle East

Date palm can grow in dry and hot climates, and tolerates alkaline and saline soils (Krueger, 2011). From fruit set to harvest date palm requires hot summers with an ideal temperature of 21-27 °C, but can withstand up to 50 °C with low rain and humidity, if access to abundant underground or irrigation water is assured (Krueger, 2011). Such environments are characteristic for many valleys and oases of the Middle East (Zaid and de Wet, 2002). The coastlines of Phoenicia (modern day Lebanon and the Governorates of Latakia and Tartus in Syria) not only flourish with *Phoenix dactylifera*, but also with grape (*Vitis vinifera* L.) vineyards, groves of figs, olives, and pomegranates. In Phoenicia, fronds were used to build momentary shelters and tents at Jewish festivals (Krueger, 2011).

Various studies investigating pre-historic oasis agriculture claim that date palm originated around the Persian Gulf where its consumption started in the Ubaid period (5,500-4,000 BC; Tengberg, 2012). According to comprehensive archaeological evidence oasis agriculture started to develop in the third millennium BC and spread around the Persian Gulf between the 2nd millennium BC and the Christian era (Newton *et al*., 2005). Use of wild date seeds as a fuel for melting metal started in the Persian Gulf region during the 6th millennium BC (Tengberg, 2012). Textural and archaeobotanical evidence show the cultivation of date palm with other fruit trees and vegetables throughout Mesopotamia (Tengberg, 1998; Beech and Shepherd, 2001). Date palm phytoliths from the first century BC to the first century AD were identified near the main entrance of the temple at ed-Dur (Emirate of Umm al-Qaiwain, United Arabic Emirates (UAE); Haerinck *et al*., 1998). A relief with a bronze ring seal shows a person holding a frond in hand, underlining the economic and symbolic importance of date

palm in the region (Beech, 2003). Earliest evidence in UAE are the date palm seeds and stem and frond fragments excavated from Hili 8, dated to 3,000 BC (Cleuziou and Costantini, 1980). Evidence of date palm cultivation during the 3rd millennium was also found at Tell Abraq, UAE (Potts, 1990). Two sites in the Middle East provide very early evidence of the use of date palm in the Persian Gulf and date back 6,000 years ago (Beech, 2003). One is Dalma 11, located on Dalma Island, 45 km off the coast of Abu Dhabi, UAE. It contained two carbonized date seeds in shell middens and post holes dated 4,810-4,540 and 5,290-4,940 BC, respectively, as estimated by Accelerator Mass Spectrometry (AMS; Beech, 2003). The second site, located in Sabiyah (Kuwait) contained three carbonized date seeds dated to the late 6th millennium BC (Beech, 2003) and date palm phytoliths (Parker, 2010). A more complete picture of date palm agro-biodiversity in the ancient Near East comes from Bahrain in the Persian Gulf and where in ancient times date palm groves were irrigated by artesian wells near today´s capital of Qal'at al-Bahrain. According to the archaeobotanical evidence in the Achaemenian age (c. 600-400 BC) there was a mixed plantation of different fruit trees: pomegranate, date palm, grapevine, and Christ's thorn (*Ziziphus spina-christi* (L.) Desf.) with coriander (*Coriandrum sativum* L.), cotton (*Gossypium hirsutum* L.), sesame (*Sesamum indicum* L.), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.; Tengberg and Lombard, 2001). Charred date stones dating to 1,900 BC were found at Saar (Bahrain; Nesbitt, 1993). Date kernels were also recovered from "Cave of the Treasure" (6200-6000 cal. BP) in Nahal Mishmar, Dead Sea Region, Jordan Rift valley (Bar-Adon, 1980).

In the inner Oman oasis agriculture started around 3,000 BC and since then symbolizes the agricultural economies of Eastern Arabia. Sub-surface water was the main source of irrigation for date palm groves due to the absence of rivers in this area (Tengberg, 2012). At Bat in the Hajar Mountains, Sultanate of Oman, date palm remains were found together with free-threshing barley and wheat plants dated to the early 3rd millennium BC (Willcox, 1995; Tengberg, 1998). Bat is the only mountain site that has so far seen intensive

archaeobotanical studies, but it is possible that in the early Bronze Age (3000-2100 BC) oasis agriculture was also practiced at Maysar, Bahla, and Bisya (Orchard and Orchard, 2007). In addition to common features in architecture and layout, these sites were famous for copper mining and long-distance trade which is confirmed by the presence of ceramics from Iran, Mesopotamia, and the Indus valley. Overall, there are about 200 date palm varieties present in Oman of which many originated from seedlings (Al-Yahyai, 2007; Al-Yahyai and Al-Khanjari, 2008).

Date palm is also one of the major fruit crops of Saudi Arabia covering approximately 72% of the total area under (irrigated) agriculture. More than 400 different date palm cultivars are reported to exist in Saudi Arabia and produce about one million t of dates annually (Anonymous, 2006).

The earliest remains of probably domesticated dates dating back to 4,000 BC was reported by Seton Lloyd in Ubaidian horizon at Abu Shahrein (Iraq; Gillett, 1981). Date palm was used to construct the temple of the Moon God in southern Iraq at Ur around 4,000 BC. Date palm remains of Ubaid period (5,500-4,000 BC) have only been excavated from two sites in Iraq: Tell el'Oueili where carbonized stem fragments date back to the Ubaid 4 period (4700-4200 BC) were found and Eridu where date palm seeds were retrieved with contexts dated back to 4000 BC (Safar *et al*., 1981; Neef, 1991).

Reliable archaeological records reveal the presence of date palm during prehistoric times in Daulatabad, South of Kerman (Southern Iran; 5,400-4,800 BC), and of charred date stone at Tepe Gaz Tavila, Iran (5,400-4,800 BC; Costantini, 1985). Further clues for the presence of date palm in southeastern Iran are all related to the Bronze Age. At Shahr-e Sokhta (Hilmand valley, Sistan-Baluchistan, Iran), a piece of date palm stem was dated to 2,700 BC (Costantini, 1985). From Tepe Yahya (Sog-hun valley, Kerman, Iran), an incomplete date seed dating to late third and early 2nd millennium BC was reported. In the south of Jiroft (Kerman) carbonized leftovers of both date palm wood and seeds dated to the first half of

the 3rd millennium BC were excavated at Konar Sandal. Despite the ample archaeobotanical evidence of early date palm use it is almost impossible to determine whether seeds or other date palm parts belong to domesticated or wild palm cultivars (Costantini, 1985).

Engravings on soft-stone vessels representing date palms (3rd millennium BC) were discovered in Konar Sandal valley, Iran. In most of these cases, engravings represented solitary growing date palm, but some cases also show a mother palm accompanied with suckers (Madjidzadeh, 2003). In the 3rd millennium BC, decorated stone vessels were important trade items in the Halil valley of Iran, in eastern Arabia and Mesopotamia. One vessel showing a date palm was discovered during the excavation of Shamash Temple (Mari, Syria) and dated to 2,550-2,250 BC (Aruz, 2003). This vessel shows the engraving of a man kneeling in front of a small date palm growing at the base of a tall palm tree.

In southern Iran, date palm groves are possibly as old as in Mesopotamia, but archaeobotanical and textual evidences are still too scarce to confirm. South-central and southwestern Iran also has hot plains which seem to have been suitable for the cultivation of date palm in prehistoric times, but no records are known from there (Aruz, 2003).

Beech (2003) compared the size of modern date palm seeds with Bronze Age and Neolithic counterparts and suggested that Neolithic dates were larger than today's (Table 1).

Table 1. Comparison of seeds sizes of different eras (adapted form Beech, 2003).

Archaeological site	Era	Seed length range (mm)	Seed breadth range (mm)	Seed thickness range (mm)
Dalma and Sabiyah	late 6th millennium BC	15.0-22.5	7.0-9.5	6.1-9.4
Ur, Hili 8, Failaka and Saar	3rd-2nd millennium BC	10.4-19.5	4.6-7.5	4.8-6.8
UAE*	present time (2002)	13.5-28.0	5.5-11.0	4.5-9.5

*70 modern varieties, total sample size = 752

Sumerians were cultivating date palm around 3,000 BC which then also symbolically appeared on seals, pottery and other objects. Date seeds dating back to 3rd millennia BC

were also found in the Royal Cemetery of Ur, but their origin is unknown (Ellison *et al*., 1978). An early 2nd millennium BC scene depicted on the palace of Mari (Syria), shows dates being harvested by two facing figures climbing the stem with ropes. Cuneiform texts show that the courtyard in the Mari palace was called “Court of the palm” perhaps due to the mentioned wall paintings as well as the presence of an artificial date palm for decorating this place (Luciani, 2010).

Zohary and Hopf (1988) claimed that the first domestication / cultivation of date palm occurred in lower Mesopotamia at Eridu, or in oases of the Near East. Considering all present records, it appears that date palm has been cultivated since the 5th millennium BC (Zohary and Hopf, 1988; Nesbitt, 1993) in southern Mesopotamia. Rhouma *et al*. (2008) applied random amplified microsatellite polymorphism markers (RAMPOs) on 40 accessions of date palm to measure the phylogenic relationships and genetic diversity of date palms. Results of their study support the Mesopotamian origin of date palm domestication. Weiss (2015) reported that date palm was probably brought into cultivation somewhere in the lower Mesopotamian or the southern fringe of the Fertile Crescent. However, according to some researchers (Wrigley, 1995; Barrow, 1998; Zohary and Hopf, 2000) Mesopotamia as center of origin of date palm is unclear. A multidisciplinary approach combining the cultural, historic, ecological, and archaeobotanical studies is needed to shed more light on this matter.

2.3 North Africa

After the start of oasis agriculture in the 3rd millennium BC, date palm spread all around Saharan Africa, whereby between the 2nd millennium BC and the Christian era spread was most pronounced in Egypt (Newton *et al*., 2005). In ancient Egypt, palm logs were used as construction material for royal tombs and dates were found in the tomb of King Tutankhamen. Dates were part of Egyptian culture since the dynasty of Queen Hatsu (1,450 BC). Early agricultural development in the Nile and Tigris / Euphrates valleys included date palm cultivation since the 5th millennium BC (Sanderson, 2001).

Terral *et al*. (2012) analyzed the biogeography of the modern and ancient date palm seeds by using geometric morphometry, but the authors were unable to identify a single center of domestication. They only succeeded in differentiating *Phoenix dactylifera* from other *Phoenix* seeds. Initially it was hypothesized that date palm had one single origin around the Persian Gulf, followed by the dispersal of the cultivated date palms toward the east up to India and west up to Morocco (Munier, 1973). But based to the geographic structure of the western and eastern pools, subsequently another hypothesis was suggested, which proposed the existence of two cultivation origins of date palm, one in the east and other in the west. The Persian Gulf may thus not have been the only domestication center of date palm. North Africa could also have been either a primary or secondary domestication center; after introduction of date palm genotypes from the Middle East and their crossing with local germplasm (Gros-Balthazard, 2012). Recent studies by Zehdi-Azouzi *et al*. (2015) confirmed this hypothesis on the basis of the existence of two chlorotypes which had the same frequencies in the Egyptian date palm samples. Such genetic relatedness of remote early cultivation / domestication areas may be explained by the geographical location of Egypt which nomads and pilgrims have to cross on their way from the Maghreb to the Middle East and *vice versa*. A high frequency of the Oriental chlorotype was also found in Algerian and Mauritanian date palm samples, which may, however, also be due to the import of accessions (Zehdi-Azouzi *et al*., 2015).

Mathew *et al*. (2015) conducted a genotyping-by-sequencing of 70 female date palm cultivar samples across the different date palm growing regions. Their study provided the first genome-wide evidence which confirmed the recent findings of date palm segregation into two main regions (North Africa and the Persian Gulf) with shared genetic background. Cherif *et al.* (2013) conducted a study on XY chromosome for tracing paternal lineages of date palm which showed two distinct Y alleles segregating between Western and Eastern date palm cultivars. Some studies using metabolomics or morphometry have not shown a clear separation between date palm cultivars of the two geographical groups (Khierallah *et al*.,

2011; Farag *et al*., 2014) and no particular genes indicating domestication have yet been identified. If different functional mutations can be identified in the same domestication gene for the date palm populations of the Persian Gulf and those of North Africa, this would increase the likelihood of independent domestication events (Zohary, 1999; Kovach *et al*., 2007).

Microsatellite data of wild, feral, and cultivated Tunisian date palm showed that different cultivars possess specific structures called “agrolineages” (Pintaud *et al*., 2013). Tunisian date palm genetically contained two types of males: those that grew from seeds of known cultivars and those from the unmanaged, seed grown “khalt” gene pool (Pintaud *et al*., 2013). In Algeria, the agrolineages are regionally limited with a strong east-west disjuncture. The agrolineage Medjool, represented by the cultivar Faggous, is limited to the West and shared with Morocco, while the Deglet Noor agrolineage is limited to the East and shared with Tunisia (Pintaud *et al*., 2013). Chlorotype frequency showed similar patterns, with the Oriental haplotype prominent in the western oases and the Occidental haplotype in the eastern oases. However, in the Algerian oases existence of two chlorotypes indicated the earliest admixture of the Occidental and Oriental gene pools (Pintaud *et al*., 2013). Both isolation and gene flow are vital evolutionary factors leading to a geographical structure in the agrobiodiversity of date palm at local to continental scales.

At the northwest coast of Africa *Phoenix canariensis* was considered to be a botanical variety of the date palm until 1882 when it was described as a distinct species by Chabaud (Johnson *et al*., 2013). In Spanish *Phoenix canariensis* shared the common name (dátil) with date palm. This creates uncertainty in evaluating historical documents about date palm cultivation in Africa (Johnson *et al*., 2013).

The chronology of date palm cultivation in the Maghreb is poorly known due to the limited archeological records in comparison with those of the Middle East (Tengberg, 2012). In the Tassili n’Ajjer and Hoggar of Algeria further important evidence of early date palm cultivation

comes from petroglyphs and cave paintings of date harvesting These images (600-400 BC) belong to the Saharan petroglyphs and wall paintings (Lhote, 1964).

In present day North Africa, about 244 different date palm cultivars are known from Morocco, 250 from Tunisia (Zaid and de Wet, 2002), and 400 from Sudan (Osman, 1984). Historically, also northern Sudan is well known for its large diversity in date palm cultivars where they have been grown for >3000 years, but today some are either on the verge of extinction or threatened (Osman, 2001; Elshibli and Korpelainen, 2008; Elsafi, 2012). Although most of the northern Sudanese date palm groves are located around the banks of the River Nile, some are also found in oases of Kordofan and Darfur (Yousif, 1995).

2.4 South Asia

Candolle (1985) claimed that in prehistoric times, date palm was grown between latitudes 15°N and 30°N, from Senegal (West Africa) to the Indus River basin in northern India. Today there are different perceptions about the date palm cultivation in the Indo-Pak subcontinent (present day India and Pakistan): some scholars believe that dates were introduced in the area by Alexander the great (Nixon, 1951) while others state that dates were probably introduced in Sindh (Pakistan) by the forces of Mohammed Bin Qasim in 712 AD (Popenoe, 1973). It was also speculated that the Arab gardeners working in the forts of the former rulers of Kachchh (India) might also have contributed to the import of date seeds and offshoots from Arab countries to the Indo-Pak subcontinent (Pareek and Sodagar, 1986). But according to historical evidence, dates were the main trading items of the Indus valley (Bronze Age civilization, 3,300-1,300 BC) from the onset of the frankincense trade with the Shara and Sabaeans of southern Arabia (Sanderson, 2001). In the Pakistani Indus valley *Phoenix dactylifera* has been cultivated since the 6th millennium BC, likely as a natural hybrid of *Phoenix sylvestris* (Pintaud, 2010).

Costantini (1985) reported the presence of two silicified, uncarbonised date-stones of 5,000 and 6,000 BC at the site of Mehrgarh (Pakistan). Being uncarbonised, their contextual

provenance and date may be questionable. Dates found during the excavation of the Mohenjo-Daro site (capital city of the Indus valley) also indicate date palm cultivation in the Pakistani Sindh Province as early as 2,000 BC (Jandan, 1974). Some archaeological data along with present day information even indicate that date palm may have been domesticated in southwest Asia. This speculation is based on the occurrence of wild forms of date palm (Weiss, 2015).

Howewer, evidence is too scarce to prove an early domestication role of the Indus valley and Panjgur (Baluchistan Province, Pakistan). More research on wild date palms in the Indus valley may be particularly rewarding (Sanderson, 2001). Today Pakistan harbours >325 varieties of date palm of which >85 varieties are being cultivated in the Khairpur District (Sindh), which is also the biodiversity centre of dates in Pakistan (Markhand and Abul-Soad, 2007; Jamil *et al*., 2010; Markhand *et al*., 2010; Khan and Bi Bi, 2012).

2.5 Conclusions and way forward

Apparently date palm domestication started later in North Africa than in the Middle East. If today's center of diversity indicate the likely center of origin for date palm, then it would likely be in Saudi Arabia, Iran, Iraq, Sudan or Pakistan. However, reliable data on related wild date palm populations and their distribution based on morphological (pollen, seeds, fruits, and phytoliths) and archaeological characteristics are lacking. To overcome the open questions on the early domestication and cultivation history of date palm, research combining archaeobotanical evidence, morphological analysis and molecular genetic work on seed and tissue material will be necessary. In recent years different molecular markers and approaches (Random Amplified Polymorphic DNA (RAPD), Inter Simple Sequence Repeat (ISSR), SSR, and Amplified Fragment Length Polymorphism (AFLP; Al-Mahmoud *et al*., 2012; Sabir *et al*., 2014) have been employed, but no single approach seems to take fully account of the complex nature of date palm diversity and to be sufficiently reliable for cultivar distinction (Sharma *et al*., 2012). Use of different genomic approaches combining mitochondrial (Fang *et al*., 2012), nuclear (Al-Dous *et al*., 2011; Al-Mssallem *et al*., 2013),

and plastid (Yang *et al*., 2010) material to characterize date palm cultivars has provided reference genomes. Subsequently Simple Nucleotide Polymorphism (SNPs) approaches may be used to better characterise diversity and genetic relationships among different cultivars. However, given the likely hybridization between different related species and in view of missing critical information on the exact domestication area progress in unraveling the origin of date palm may likely remain slow.

Chapter 3

Socio-economic characterisation of date palm (*Phoenix dactylifera* L.) growers and value chain of dates in Pakistan

3.1 Introduction

Date palm (*Phoenix dactylifera* L.) is one of the earliest cultivated tree species and presently about 100 million date palms belonging to 1,500 different cultivars are planted on 1 million ha worldwide (Zaid and de Wet, 2002). In 2012, global date production amounted to about 7 million t with a total market value exceeding 1 billion US$ and the top six date producing countries accounting for 75% of total production. Pakistan was the fifth largest date producer with an annual production of 600,000 t in 2012 and had an increase in the area under date palm cultivation from 41,240 ha in 1992 to 95,000 ha in 2012 (FAO, 2014). More than 300 date varieties are known to exist in Pakistan of which the twelve most commercially important cultivars are: Karbalaen, Aseel, Muzawati, Fasli, Begum Jhangi, Halawi, Dashtiari, Sabzo, Koharba, Jaan Swore, Rabai, and Dhakki (Ata, 2011).

Date palm has primary importance as a subsistence crop in Pakistan, particularly in its vast desert areas (Hassan *et al*., 2006; Ata *et al*., 2012). Dates are marketed all over the country as a highly appreciated fruit and confectionery product of which use peaks during the Muslim feast of Ramadan and the Hindu celebration of Diwali. The mineral, carbohydrate, and vitamin rich dates are an excellent source of food not only for humans, but also serve as a feed supplement for livestock at times of scarcity (Zohary and Hopf, 2000; Al-Shahib and Marshal, 2003; Hassan *et al*., 2006).

Date palm is dioecious in nature with separate male and female trees (Sudhersan and Abo El-Nil, 1999). Dates are usually wind pollinated, but there is also insect pollination. Successful fruit production is only possible if 60-80% of the female flowers are manually pollinated (Nixon and Carpenter, 1978; Zaid and de Wet, 2002). Different pollen sources have a xenia effect and influence the shape and size of the date palm seeds. Pollen also has a metaxenia effect affecting the shape and size of fruit, time of ripening and rate of development (Nixon, 1934; 1936). There are many varieties of dates that can ripen even un-

pollinated but their fruits are slender in size with imperfect seed (without embryo and endosperm) and ripen very late (Swingle, 1928).

The cultivation of date palm is performed in a large range of cropping and farming systems such as oases, groves, home gardens, as a mono-crop as well as an intercrop. Intercropping is one of the most important cropping techniques in sustainable agriculture where it yields additional income to the farmer, increases soil fertility, promotes land biodiversity, and diversifies agricultural products (Abouziena *et al*., 2010; Bhansali, 2010). Date palm provides sufficient space for intercropping even if it is fully grown whereby it only marginally competes with other crops (Akyurt *et al*., 2002). Date palm groves provide a favorable habitat for understory herbal crops and fruits by creating humidity, shade and reduction in weather extremes. They also prevent the soil from degradation and desertification (Sawaya, 2000; El-Juhany, 2010). Dates can be intercropped with other fruits, fodder, and vegetables (Morton, 1987; Mahmoudi *et al*., 2008; Shirazi *et al*., 2008). Groves, intercropping and scattered settings are the predominant cultivation forms of date palm in Pakistan (Memon *et al*., 2015).

Date palm has numerous usages and produces many useful products for human (Chao and Krueger, 2007). Leaves are used for making roofs, mats, staple dishes, hand fans, baskets, packaging material, and also for ropes and fences (PHDEB, 2008). Trunks can be used as a construction material for houses and bridges, and as packing material for local transportation of vegetables and fruits (Anwar, 2006). Terminal buds and young leaves can be cooked as vegetables while rachises are used for paper making (Khiari *et al*., 2011; El Hadrami and Al-Khayri, 2012). Moreover, date cultivation and production offers many jobs in groves during fruit harvest and processing (Jain, 2012).

The socio-economic conditions and food security status in date palm growing areas in Pakistan are, however, not satisfactory (Suleri and Haq, 2009). There are claims that better economic growth and rural income in developing countries like Pakistan can be achieved by efficient post-harvest and marketing systems (Goletti and Samman, 1999). Date growers in

Pakistan often depend on advanced payments and other informal credits from commission agents, wholesalers and contractors with unfavorable conditions (Ata, 2011). Furthermore, date palm growers face problems in marketing their products given their poor education (Khushk *et al*., 2009). The prevalence of traditional marketing structures therefore results in 30-40% deterioration of fresh produce before it reaches the consumer (PHDEB, 2008). Other limitations in date palm cultivation areas include low quality date palm cultivars, poor farm management, processing facilities, uncertainty in prices at the time of selling and shortage of qualified trained labour (Mahmoudi *et al*., 2008).

In view of the above this study was conducted to fill knowledge gaps about the value chain of date palm in Pakistan and its role in the income strategies of poor people in arid marginal areas, both as a subsistence crop and a market commodity and to develop recommendations for strengthening its contribution to daily incomes and improved income.

3.2 Materials and methods

3.2.1 Study area

For this study six districts within four provinces of Pakistan with large areas under date palm cultivation were selected: Jhang, Muzaffargarh and Bahawalpur districts in the province Punjab, Dera Ismail Khan (D. I. Khan) district in Khyber Pakhtunkhwa (KPK), Khairpur in Sindh, and Panjgur in Baluchistan (Table 1). Apart from date palm, these districts produce a variety of annual field crops and other perennials (trees and shrubs; Table 2).

Table 1: Biophysical characteristics of the six date producing districts in the tropical desert climate zone of Pakistan during 2012-2013.

District Name	Longitude (E)	Latitude (N)	Soil type	Average annual temperature (°C)	Average annual precipitation (mm)	Summer Climate	Winter Climate
Jhang	72°15'00"	31°25'00"	Loamy, clayey & sandy	24.7	180	Hot & dry	Cold & dry
Bahawalpur	67°43'00"	26°49'00"	Loamy, clayey & sandy	25.7	200	Very hot & dry with frequent dust storms	Cold & dry
Muzaffargarh	71°04'60"	30°19'60"	Loamy & clayey	25.6	127	Very hot with dust storms	Arid & mild
Dera Ismail Khan	72°19'41"	31°83'14"	Loam to clay loam	24.5	249	Hot desert	Mild
Khairpur	68°45'26"	27°31'50"	Loamy, clayey & sandy	26.9	178	Very hot & sunny	Mild to warm
Panjgur	64°06'00"	26°58'00"	Loamy & partly gravelly	21.7	109	Hot	Cold

Source: adapted from Beinroth *et al*., 1985
Source: www.namc.pmd.gov.pk/agromet-bulletins.php#. PMD, Pakistan Meteorological Department (accessed on 12 February 2015)

Table 2. Major annual and perennial field crops and fruits produced by 170 date palm growers in six districts of Pakistan, interviewed during 2012-2013.

District name	Annual field crops	Annual and perennial fruits
Jhang	Wheat (*Triticum aestivum* L.) Cotton (*Gossypium hirsutum* L.) Sugarcane (*Saccharum officinarum* L.) Rice (*Oryza sativa* L.) Maize (*Zea mays* L.)	Mango (*Mangifera indica* L.) Dates (*Phoenix dactylifera* L.) Ber (*Ziziphus jujuba* Mill.)
Bahawalpur	Wheat (*Triticum aestivum* L.) Cotton (*Gossypium hirsutum* L.) Rice (*Oryza sativa* L.) Sugarcane (*Saccharum officinarum* L.) Sunflower (*Helianthus annuus* L.) Mustard (*Brassica napus* L.)	Mango (*Mangifera indica* L.) Citrus (*Citrus* L.) Dates (*Phoenix dactylifera* L.) Guava (*Psidium guajava* L.)
Muzaffargarh	Wheat (*Triticum aestivum* L.) Cotton (*Gossypium hirsutum* L.) Sugarcane (*Saccharum officinarum* L.) Rice (*Oryza sativa* L.) Sunflower (*Helianthus annuus* L.) Mustard (*Brassica napus* L.)	Mango (*Mangifera indica* L.) Citrus (*Citrus* L.) Dates (*Phoenix dactylifera* L.) Pomegranate (*Punica granatum* L.)
Dera Ismail Khan	Wheat (*Triticum aestivum* L.) Sugarcane (*Saccharum officinarum* L.) Gram (*Vigna mungo* (L.) Hepper) Sorghum (*Sorghum bicolor* (L.) Moench) Millet (*Pennisetum americanum* (L.) R.Br.)	Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) Mango (*Mangifera indica* L.) Dates (*Phoenix dactylifera* L.)
Khairpur	Wheat (*Triticum aestivum* L.) Cotton (*Gossypium hirsutum* L.) Sugarcane (*Saccharum officinarum* L.) Rice (*Oryza sativa* L.)	Mango (*Mangifera indica* L.) Citrus (*Citrus* L.) Dates (*Phoenix dactylifera* L.) Banana (*Musa × paradisiaca* L.)
Panjgur	Wheat (*Triticum aestivum* L.) Rice (*Oryza sativa* L.) Barley (*Hordeum vulgare* L.)	Almonds (*Prunus dulcis* (Mill.) D.A.Webb) Pomegranate (*Punica granatum* L.) Grapes (*Vitis vinifera* L.) Peaches (*Prunus persica* Siebold & Zucc.) Pistachios (*Pistacia vera* L.) Dates (*Phoenix dactylifera* L.)

Source: adapted from Malik, 1994

3.2.2 Data collection

From June 2012 to October 2013 a structured questionnaire with open-ended and closed questions was used for face-to-face interviews with 170 date palm growers (Fig. 1). The questionnaire had been pre-tested with 14 farmers and modified as required; it covered the following major areas: (1) demographic household aspects (age, education, marital status), (2) list of incomes and expenditures, (3) date palm cultivation and distribution in the field, (4) value chain structures, and (5) irrigation sources and crops grown.

A snowball sampling scheme was employed. The first interviewed household (HH) growing date palm, selected by a local guide, was requested to provide names and addresses of three other HHs in his locality that cultivated date palm. From these three names, one was randomly selected for the next interview. The questions were orally translated from English into the local languages (Urdu, Punjabi, Saraiki, Balochi, and Sindhi) and translated replies noted down in English by the interviewer. One interview lasted 50 to 90 minutes. Interviews were also conducted with stakeholders involved in the supply chain of dates in the area. After each interview, the geographical location of each HH was recorded with a handheld GPS device (GARMIN® Vista HCxe Trex, GARMIN International, Inc., Olathe, KS, USA), except for the district Panjgur in Baluchistan, where security concerns prevented the use of GPS devices and position estimates were made based on Google Earth satellite images. For the estimation of date palm contribution to the income of local people, fresh fruit weight was measured and then multiplied with the local price of dates per kg. For measuring fresh fruit weight per date palm, the number of bunches were counted, from three of them dates were separated from the rachis, weighted, and subsequently average bunch weight was multiplied with the number of bunches per date palm.

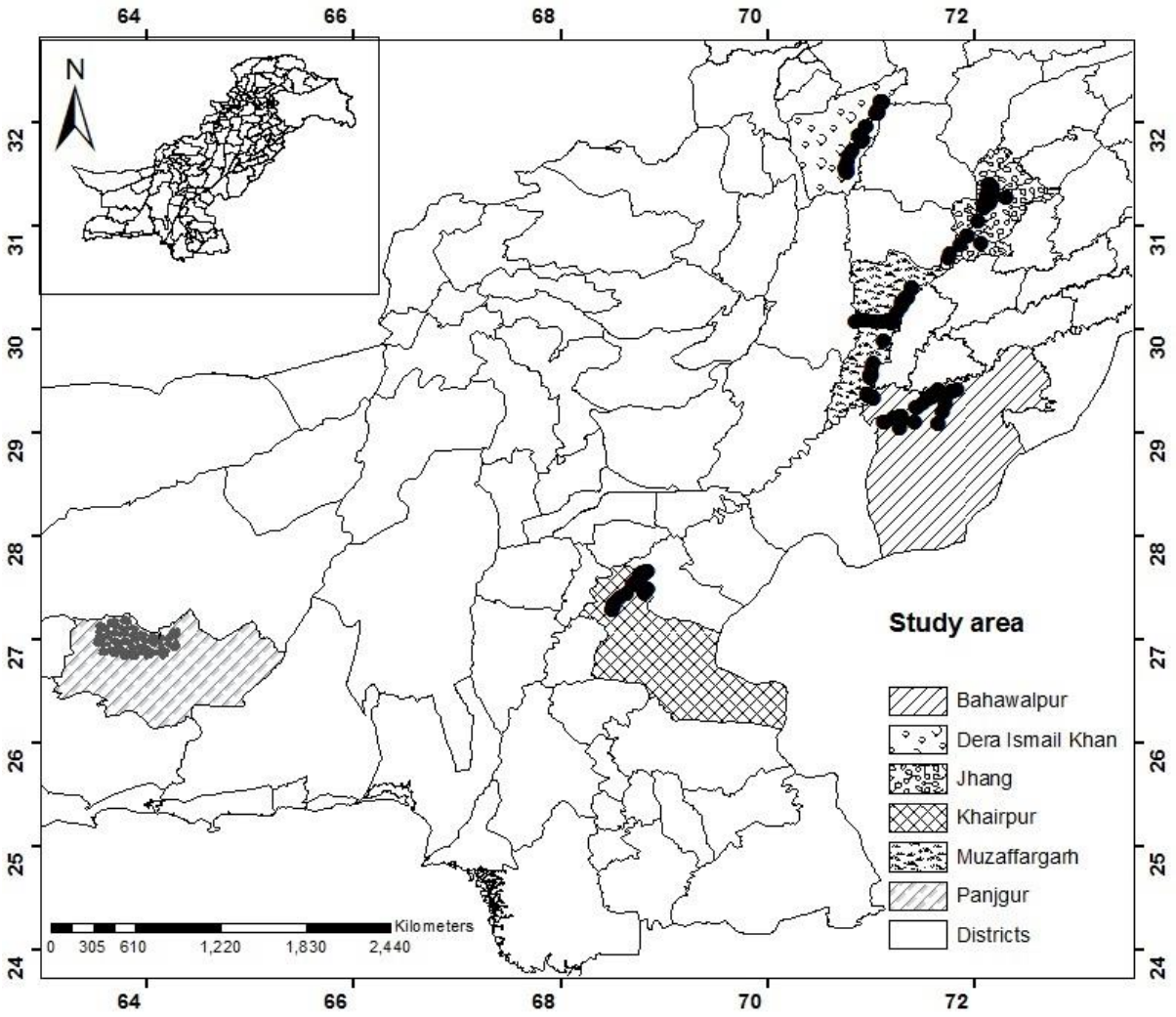

Figure 1. GIS-based map of the study area with the position of households in Pakistan, interviewed during 2012-2013. Black dots mark the household's location in the three provinces; Punjab, Khyber Pakhtunkhwa, and Sindh. Grey dots represent the rough locations of interviewed households in Baluchistan province, since the recording of GPS coordinates was not allowed in this region.

3.2.3 Statistical analysis

The data were tabulated, coded into numerical values, and descriptive analysis was conducted in Excel (Microsoft Office 2007). Initially the five most important variables (province wise distribution of date palm cultivars, number of mature date palms, planting types, yield, and income from selling of dates and by products) that characterized date palm growers were subjected to Spearman correlation analysis and key variables that were least correlated with each other were identified (Raza *et al*., 2014). Subsequently, a two-step cluster analysis was performed comprising both categorical and numeric data on socio-

economic household characteristics (Dossa *et al*., 2011; Abdulkadir *et al*., 2012; Abas *et al*., 2013). Kruskal-Wallis test and Chi² analysis were used to detect significant differences and to evaluate the effect of assessed variables (categorical and continuous) on the clusters (Rehman *et al*., 2013; Vazhacharickal *et al*., 2013). Because of the large differences in financial status (income and expenses) of households, they were divided into seven groups (Rehman *et al*., 2013). All statistical analyses were performed with SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). The significance threshold was set at $P \leq 0.05$.

3.3 Results

3.3.1 Grower characteristics

Agricultural production in date palm growing was mostly supervised by married, poorly educated, medium-aged male family heads with large families (Table 3).

Table 3. Household (HH) characteristics of 170 date palm growers in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

HH characteristics	Frequency (n)	Percentage (%)
Marital status		
Single	11	6
Married	125	74
Widowed	29	17
Divorced	5	3
Education		
Illiterate	68	40
Primary	29	17
Secondary	40	24
Intermediate	10	6
Bachelor	14	8
Master	9	5
Average age of HH head (years)		
≤30	8	5
31-55	105	62
>55	57	33
Type of date palm grower		
Small scale (SS)	121	71
Medium scale (MS)	30	18
Large scale (LS)	19	11

Based on the two-step cluster analysis, three categories of date palm growers were identified: (i) small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms and were earning 1786 (±3392) US$ annually, accounted for 71% of all HHs; (ii) medium scale (MS) growers with 812 (±237) mature date palms and were earning 18929 (±8135) US$ annually, represented by 18% of the all HHs, and (iii) large scale (LS) growers with 1721 (±244) mature date palms and were earning 26942 (±4490) US$ annually, making up 11% of the HHs (Table 3).

On average, SS date palm growers owned and leased more arable land (212±36 ha), they were also sharing land for the cultivation of other crops and fruit trees, followed by MS (22±15 ha) and LS date palm growers (18±7 ha). More MS growers rented land than SS and LS growers did (Fig. 2a, b and c).

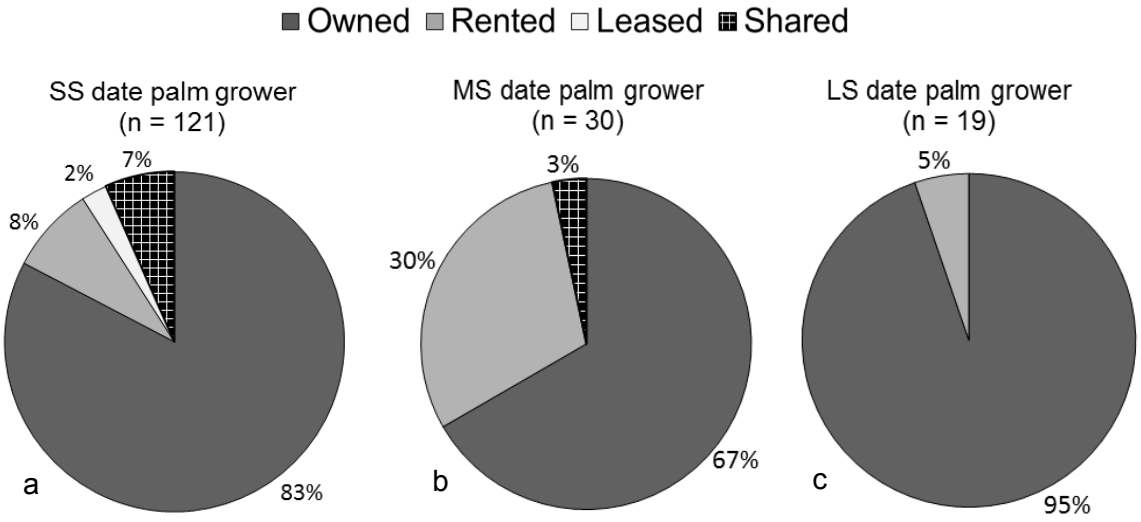

Figure 2a, b and c. Land ownership characterization of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

3.3.2 Income strategies

Agriculture was the main source of income for date palm growers, occasionally coupled with off-farm income (job, business, and labour). Among surveyed HHs, 24% were totally

dependent on date palm fruit and by-products for their living. Most of the HH earned <500 US$ per month and only 18% had a monthly income between >1000 to ≤2000 US$ whereby date sales contributed >50% to total income of 39% HHs (Table 4). Less than 20% HHs had a monthly income of ≥2000 US$, among them >10% were earning it from date palm cultivation (Table 4).

Table 4. Income characteristics of 170 date palm growers in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh and Baluchistan) of Pakistan, interviewed during 2012-2013.

Income characteristics	Frequency (n)	Percentage (%)
Occupation		
Agriculture	95	56
Agriculture + Government job	15	9
Agriculture + Labour	17	10
Agriculture + Business	29	17
Agriculture + Private job	14	8
Estimated monthly income (US$)		
≤100	4	2
101-200	14	8
201-300	29	17
301-500	43	25
501-1000	20	12
1001-2000	30	18
>2000	30	18
Estimated monthly expenses (US$)		
≤10	9	5
101-200	33	19
201-300	26	15
301-500	30	18
501-1000	14	8
1001-2000	53	32
>2000	5	3
Date palm share in income (%)		
≤10	56	33
11-30	23	14
31-50	24	14
51-70	12	7
71-90	14	8
91-100	41	24
Estimated monthly date palm sale (US$)		
≤100	77	45
101-200	26	15
201-300	3	2
301-500	10	6
501-1000	4	2
1001-2000	32	19
>2000	18	11

Different date palm cultivation practices were observed in the surveyed areas. Most of the HHs (85%) had date palm groves. This trend was more pronounced in MS growers and was rare in LS and SS producers whose palms grew scattered. 14% of the surveyed HHs intercropped date palm with different crops such as cereals, legumes, and fruit trees. This practice was common in LS holdings while only SS growers had dates in home gardens (Table 5).

Date palm usage differed among growers. Almost all HHs used dates as food for their families and also sold a fraction of their harvested dates. Most farmers used low quality dates as animal feed at the household and commercial level. Date palm by-products usage for household and commercial purposes varied from farmer to farmer (Table 5). Farmers regularly separated suckers from good date palm varieties and either grew them separately in their own grove or sold them commercially at an average price of 8 US$ per sucker.

Table 5. Farm type and usage of date palm fruit and by-products of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Variable	SS date palm grower (n = 121)	MS date palm grower (n = 30)	LS date palm grower (n = 19)
Farming type			
Groves	57	83	47
Scattered trees	34	3	0
Intercropped	5	7	32
Home garden	4	0	0
Household usage			
Fruit as food	100	97	100
Fruit as animal feed	50	43	42
Fuel from frond	39	27	26
Mats from frond	32	43	58
Huts from stem and frond	13	27	37
Hand fans from frond	9	13	5
Staple dishes from frond	11	7	16
Suckers	100	97	100
Commercial usage			
Fruit as food	61	100	100
Fruit as animal feed	2	0	0
Mats from frond	25	30	21
Huts from stem and frond	1	13	0
Hand fans from frond	3	7	0
Staple dishes from frond	14	3	5
Suckers	29	50	37

3.3.3 Value chain of date palm

Generally, date palm growers preferred to sell fresh dates because of scarce availability of labour, storage houses, and processing facilities. However, especially LS growers tended to process their dates prior to selling them; they either made *chuhara* - a special type of dried date which is prepared by boiling premature dates and adding Rang kat (sodium formaldehyde) - or sold dried dates. Most of the date palm growers were selling their dates

to contractors, commission agents or wholesalers in Punjab, Sindh and Baluchistan province (Fig. 3). Many HHs were bound to sale their dates to commission agents, because of the already taken loans from them with a 10-11% interest rate compared to agricultural banks charging 13-15%. It was observed that contractors had more knowledge of date palm sale, resources, and market access than growers. According to the contractors' response, prices of dates in wholesale market were under the control of wholesalers rather than fixed by the Pakistani government. In the date palm market chain, the wholesalers are working as intermediaries between growers / contractors and retailers / buyers. Exporters were either commission agents or owners of processing units and were mainly selling *chuhara* to India. Major players of wholesale market were commission agents, contractors, wholesalers, and retailers, whereby the two first bought highest quantities. Farmers gave various reasons for entering a contract agreeing to sell the entire production of their grove: particularly prominent was the distance to the next market (Table 6). The results also illustrate that only SS and MS date palm growers traded with commission agents while only MS sold fruits to hawkers, markets, and directly to consumers. SS date palm growers used a big portion of their dates for self-consumption (Table 6). Hawkers were buying dates directly at the farm gate or from small wholesalers within the district and were moving street to street for selling them. Most retailers who owned small nut shops were buying dates from small wholesalers within the district while retailers who owned hypermarkets or superstores were buying dates from big wholesalers within provinces (Fig. 3).

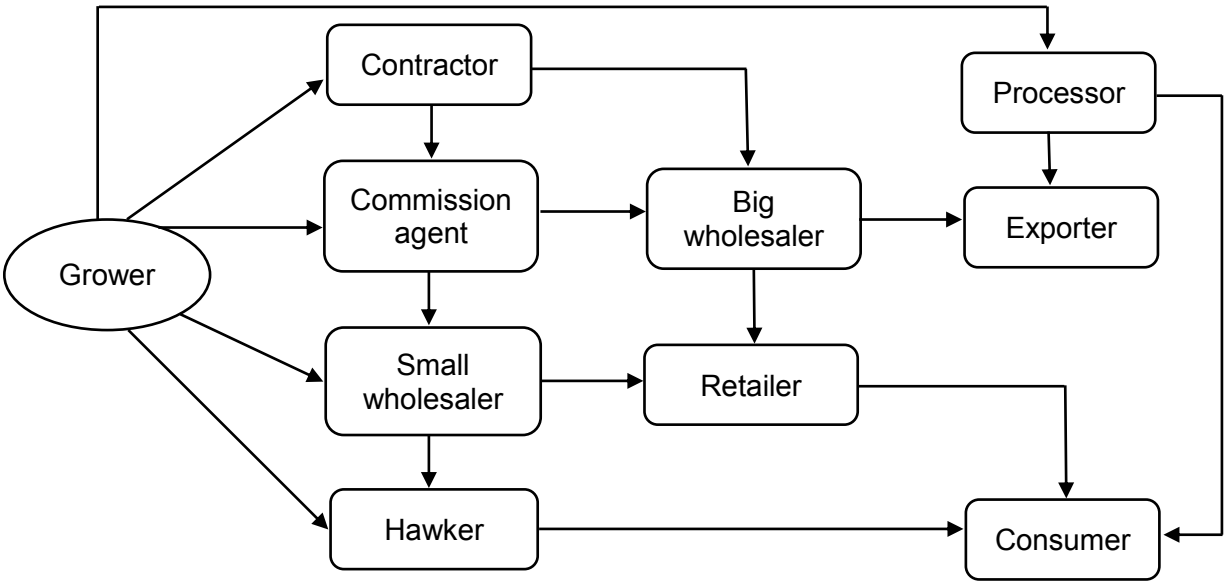

Figure 3. Structure of date palm value chain in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan during 2012-2013.

Table 6. Marketing of dates of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Variable	SS date palm grower (n = 121)	MS date palm grower (n = 30)	LS date palm grower (n = 19)
Consumer / buyer of dates			
Contractor	12	37	32
Wholesaler	14	43	68
Commission agent	32	11	0
Retailer	0	0	0
Hawker	0	3	0
Directly to consumer	0	3	0
Market	0	3	0
Self-consumption	42	0	0
Reasons for contract			
Shortage of money	26	33	42
Distance to market	54	27	37
Shortage of labour	10	13	5
Lack of time	10	27	16

HHs invested an average of 2597 US$ on the transportation of dates and date by-products to the market (Table 7) as the majority of LS (79%) did not own store houses and most of the

SS (69%) date palm growers did not have vehicles to transport their produce to the market. Therefore, most of the farmers stored dates in their homes and used wooden boxes of different sizes to package the dates. Average number of bunches of dates per date palm and average weight of fruit per bunch was significantly higher in the fields of LS and MS date palm growers (Table 7). Farmers received the highest average sales price of 1 US$ per kg for fresh dates because of the high demand for such fruits. In contrast, the average sales price of dried dates was only 0.33 US$ per kg, and that of *chuhara* was 0.56 US$ per kg.

Table 7. Means (±SD) of major variables distinguished by three clusters of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Variable	SS date palm grower (n = 121)	MS date palm grower (n = 30)	LS date palm grower (n = 19)	χ^2	P*-value
Transport expenditure (US$)	94 ± 381	1377 ± 2368	1126 ± 1339	46.303	0.049
Storage expenditure (US$)	20 ± 108	337 ± 360	468 ± 269	5.046	0.080
Annual sale (US$)	1786 ± 3392	18929 ± 8135	26942 ± 4490	100.361	<0.001
Mature date palms	103 ± 99	812 ± 237	1721 ± 244	107.391	<0.001
Yield (number of bunches date palm^{-1})	14 ± 3	15 ± 2	17 ± 2	7.960	<0.001
Weight of bunch (kg)	9 ± 3	14 ± 3	13 ± 2	50.311	<0.001
Price of fresh date kg^{-1} (US$)	0.7 ± 0.79	1.4 ± 0.89	0.9 ± 0.26	27.086	<0.001
Price of dried date kg^{-1} (US$)	0.3 ± 0.39	0.2 ± 0.30	0.5 ± 0.29	5.964	0.051
Price of *chuhara* kg^{-1} (US$)	0.3 ± 0.59	0.9 ± 0.97	0.5 ± 0.33	17.944	<0.001

P = Significance value
*Kruskal-Wallis test

3.3.4 Cropping practices

The surveyed date palm growers cultivated a diversity of crops and fruits (Fig. 4). More than 50% of date palm growers regularly cultivated the cereals: rice and wheat in their fields. Most of the SS date palm growers cultivated fodder crops such as berseem (*Trifolium alexandrinum* L.; 40%), alfalfa (*Medicago sativa* L.; 35%), sorghum (36%), maize (70%), and mustard (50%), either for usage of their own livestock or for selling to other farmers and dairy farms. SS and MS farmers also grew other fruits such as mango (8%), ber (3%), citrus (4%), guava (5%), and pomegranate (2%). While in Punjab mangoes predominated, in Sindh there was more banana.

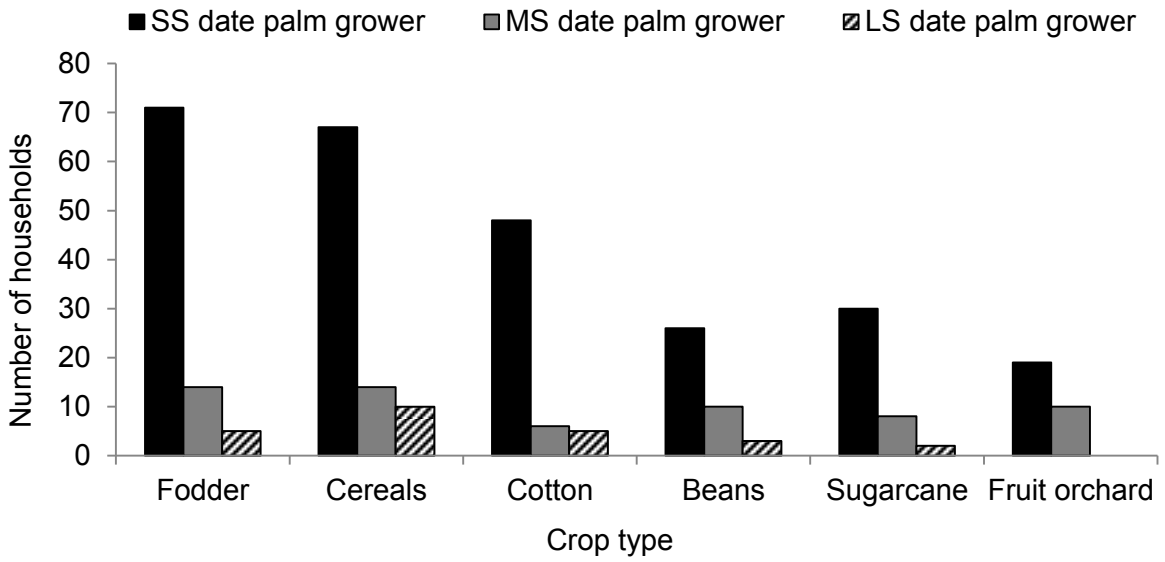

Figure 4. Major crops grown by different categories of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Depending on holding size, palm growers irrigated their crops with well water, canal water or a combination of both. In water scarce areas HHs irrigated their crops with sewage water and the majority of SS date palm growers also used Karez irrigation systems which channel water underground from mountain springs to agricultural fields (Fig. 5).

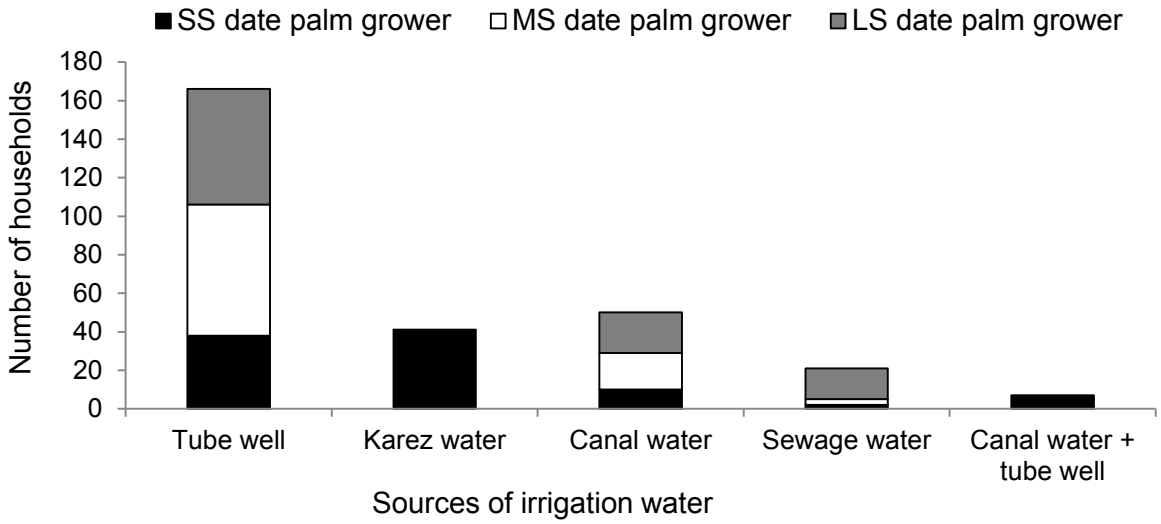

Figure 5. Major sources of irrigation water used by different categories of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchitan) of Pakistan, interviewed during 2012-2013.

For cropping in date palm growing areas, drill sowing was practiced more frequently by SS than by LS or MS growers; however, ridge sowing was also very common in the study area. The results also indicate that most HHs used chemical fertilizers (85%), while farm yard manure (FYM) was only used by date palm growers who kept livestock (55%). Most of the SS date palm growers applied pesticides on their crops while this practice was less prevalent in MS and LS growers (Table 8).

Table 8. Distribution of use of pesticides, fertilizers, and farm yard manure (FYM) by different categories of 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Variable		SS Date Palm Growers (n = 121)	MS Date Palm Growers (n = 30)	LS Date Palm Growers (n = 19)	χ^2	P-value
Use of pesticide						
	Yes	69	47	42	9.038	0.011
	No	31	53	58		
Use of fertilizer						
	Yes	98	77	79	18.484	<0.001
	No	2	23	21		
Use of FYM						
	Yes	66	63	37	6.010	0.050
	No	34	37	63		

3.3.5 Grower constraints

Date palm cultivation and management in the surveyed areas faced diverse constraints (Fig. 6). Most of the farmers reported problems with monsoon rainfall during the fruit ripening season (June to October) which usually destroyed fruits within 2-3 days by causing cracks in the epicarp. More than 50% of HHs complained about deficits in market infrastructure, while unavailability of credit, labour scarcity, transportation deficiency and lacking nurseries, processing plants, and storage houses were other main problems. Family members of most SS growers were working in family fields doing different tasks for which they were hardly paid. Growers were mostly sun-drying their dates due to unavailability of proper drying and processing units. A large number of the respondents were using suckers of date palm cultivars grown in their own grove / land and highlighted lacking of elite germplasm for quality production. Growers had local names for most of the date palm cultivars grown in their fields and were often unaware of their commercial name (Table 9). Manual pollination was also a problem for >60% farmers because of unavailability of male pollen and of skilled labour.

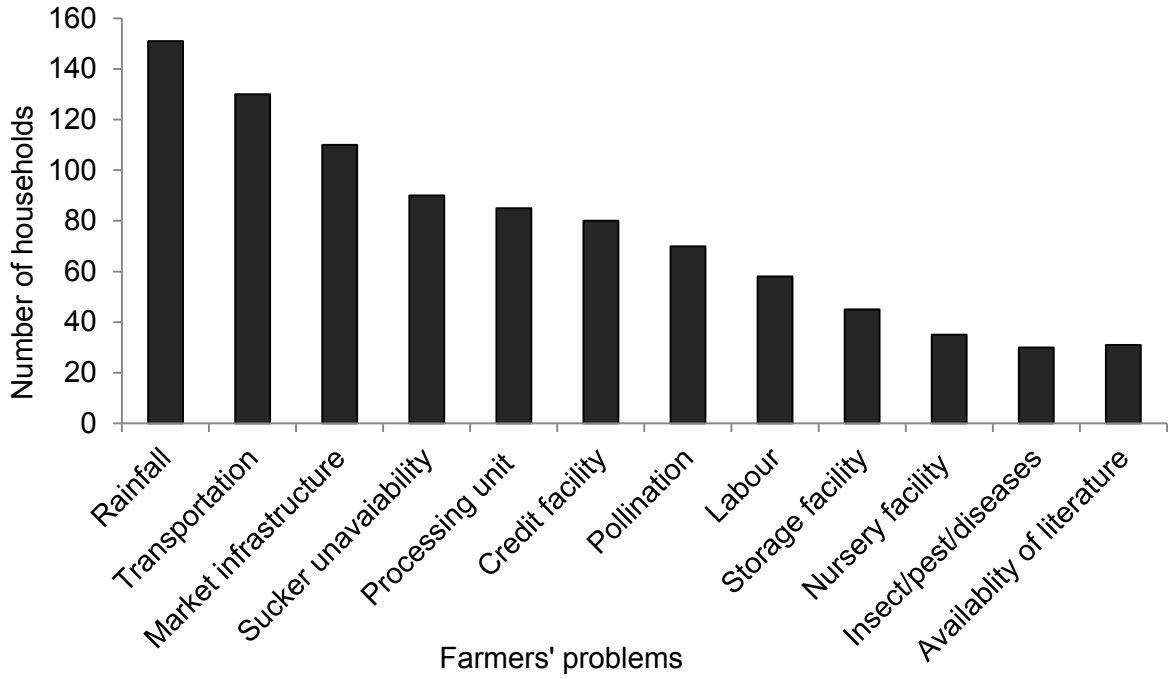

Figure 6. Major problems experienced by 170 date palm growers (small scale (SS) date palm growers who cultivated an average of 103 (±99) mature date palms; medium scale (MS) growers with 812 (±237) mature date palms, and large scale (LS) growers with 1721 (±244) mature date palms) in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

Table 9. Different date palm cultivars grown by 170 date palm growers in four provinces (Punjab, Khyber Pakhtunkhwa, Sindh, and Baluchistan) of Pakistan, interviewed during 2012-2013.

HH	Cultivar	% of cultivar
N = 1	Ajwa, Akhrot, Amber, Angoor, Barni, Begum Jhangi, Berehmi, Doki, Kalma, Kobra, Meeri, Patal, Pathri, Shershai, Zeerin	**38.5**
N = 2-6	Basra, Chohara, Daanda, Dandari, Halawi, Ketchen, Khudrawi, Kupra, Pori, Rati, Sabzo, Sawi, Shamran, Sufaida, Sundri, Zaidi	**41.0**
N = >6	Aseel, Desi, Dhakki, Haleni, Karbalaen, Karoch, Koharba, Muzawati	**20.5**

3.4 Discussion

3.4.1 Grower characteristics

The 8 ha average farm size of date palm growers was similar to the 6 ha reported by Jalal-Ud-Din (2011) for the cropping system in Mardan district, Pakistan, but average HH size in our study exceeded from the 4 members that was reported by Shrinivasan (2012) in the rural areas of India which reflects the extended family structure in rural Pakistan (Hagmann, 2012). In the current study, the literacy level of date palm growing HH heads was low compared with the results of Javed *et al*. (2008) who concluded that 82% of the respondents in Faisalabad had five years and 18% had ten years of formal education, respectively. Faisalabad is a more developed city as compared to our study areas which shows that education and improved infrastructure create awareness and help farmers to adopt modern farming practices and technologies (Burchi and Muro, 2007).

3.4.2 Income strategies

The majority of the growers in our study area had <150 mature date palms and were thus small scale farmers. Many authors claimed that >70% of the world's food especially in developing countries is produced by small scale farmers which underlines their role in using land efficiently for the cultivation of multiple crops and livestock (Berry and Cline, 1979). This practice may reduce the pressure on natural resources and diversifies the benefits per unit of land (Carter, 1984; Cornia, 1985; Heltberg, 1998).

Average annual income of date palm growers in our study area was 6000 US$ which is much larger than the average annual income of 1475 US$ reported for date palm growers in Southern Punjab by Ata *et al*. (2014). For almost half of the farmers of the present study, date palm was contributing 50% to total HH income. Chowdhury *et al*. (2008) also reported a significant contribution of date palm to the total income of farmers in date palm growing areas in rural Bangladesh. The low contribution of off-farm activities to date palm grower's

HH income is similar to data of Ata (2011) for the Pakistani Southern Punjab where crop sale was the primary and livestock rearing the secondary income source. All the respondents in our study area were using dates as a food and most of them were using other date palm parts (especially frond and trunk) for making mates, staple dishes, and huts for both household and commercial purposes. Hassan *et al*. (2006) reported the same usage of date palm in Punjab where dates and by-products were used and sold by the native community. Most of the respondents in the Jhang District (Punjab) used dates as animal feed. Such type of usage is also reported by Walsborn (2008) in Iraq where low quality dates are sold as animal feed to sheep herders, dairies, and to the companies making date syrup. This practice should be adopted in other date palm growing areas of Pakistan to increase HH income.

3.4.3 Value chain of date palm

The reasons for farmers taking informal loans from commission agents was lack of appropriate government-based credit facilities, a situation similar as reported by Ata (2011). Local banks demanded land as a guarantee for loans which many farmers felt overburdened by. A similar situation was reported by Mcegypt (2014) who analysed date value chains in Aswan (Egypt), where agricultural development banks were charging a 15-17% interest rate from farmers. In our study area, some commission agents had shops in big wholesale markets where they allowed growers to sell their dates in their shops with the condition that they will get 7% of the total sale (Ata, 2011). This was similar to date palm growers in Gaza (Palestine) who paid 6% of the value of their date sales to the wholesaler for allowing them to sell their produce (RUAF, 2014).

Contractors were also important parts of the marketing chain of dates in Pakistan. They estimated the potential yield of date palm grove and other costs for labour, storage, transportation, and processing of dates (Khushk *et al*., 2009). Contracts of date palm grove for instance, were made before the start of the harvesting season often at the pollination

stage. This again was similar as reported by RUAF (2014) for value chain of date palm in Gaza. In our study contractors payed (5%) more to date palm growers for their produce compared with commission agents. Some contractors were also taking loans from commission agents; they were either selling dates through them or were paying back loans and interest money after marketing their produce. Aujla *et al*. (2007) noted that the majority of the fruit growers (70-90%) in Pakistan sell the harvesting rights of their groves at the flowering stage to contractors, while more than 97% of the fruit contractors took loans from commission agents to pay the contract money to fruit orchard owners and labour working in the groves. This underlines the dependency of contractors on commission agents for credit resources in the study area of Pakistan.

In our study, there was uncertainty in prices of dates during the auction in wholesale markets. Often farmers travelled far to self-market their produce at higher rates compared with the farm gate, but when they reached the market place wholesale prices of dates had fell. Instead of the government, big wholesalers controlled prices according to offer and demand. Aujla and Jagirani (2002) reported that the main problem in marketing of horticultural crops in Pakistan is the sudden fluctuation in prices because of the dominance of the private sector in the market.

In our study area, processing and export were not part of a regular market chain. A similar situation was reported by Walsborn (2008) for the market chain of dates in Iraq. In our study, 69% of the date palm growers sold their produce to contractors, wholesalers or commission agents, mainly due to the unavailability of proper credit facilities and labour, and the large distance to the nearest market. The low revenues for the producer is a general characteristic of the fruit marketing sector in Pakistan, where farmer's share of the consumer price is about one-fourth while the remaining share goes to commission agents (7%), contractors (39%), wholesalers (9%) and retailers (19%; Mahmood *et al*., 1989; Khushk and Smith, 1996).

Our study indicates little value addition through grading, sorting, and processing occurred. At the grower's level there were large value losses of dates due to bird attacks, molds following monsoon rains, improper packing, and unavailability of good transport to the market. There was low value addition at each step of value chain of the date palm in study areas. Overall, improper post-harvest handling led to major losses in produce quality. Walsborn (2008) reported the same for the date palm groves of Iraq where farmers were not sorting and grading dates after harvest. In the current study, most growers threw harvested date bunches to the ground. This not only destroyed dates but also contaminated fruits with dust and sand, which was affecting their quality. Walsborn (2008) observed similar problems at the time of date harvesting in Iraq.

3.4.4 Cropping practices

Most date growers were engaged in cereal, fodder and cotton production, and the majority of HHs retained their cereals for home consumption. Similar results were reported by Singh *et al*. (2011) for the Indian Punjab, where rice-wheat cropping predominates. Contrasting results were shown by Jacobi *et al*. (2009) in India, where the majority of the HHs preferred short duration crops such as leafy vegetables to obtain high profits per unit area as compared to grain crops, however, their study took place in peri-urban areas. More than 80% of the HHs in our study area had date palm groves in their fields, which is different from the findings of Ata (2011) from Southern Punjab, who reported that only 2.5% of respondents had groves and 97.5% had scattered date palm populations. In our study, less than 15% of the HHs had intercropped date palm with other crops and fruits. Henrik *et al*. (2004) and Abouziena *et al*. (2010) stated that intercropping has potential for generating more stable yields, due to self-regulation in crops and balance farm income. To what degree, this is also the case in Pakistani date palm system which merit further study. It is nevertheless clear that date palm cultivation practices in Pakistan still have great potential for improvement.

Our study shows that date palm growers in Bahawalpur were using sewage water for irrigation, which likely has high loads of nutrients but possibly also microbial loads and heavy metals. Though this enhances the nutrient supply to date palm groves there may be health concerns, particularly at harvest when dates get in direct contact with the irrigation water. In our study, 85% of the farmers used mineral fertilizers, while the use of FYM was low (55%). Enhanced use of FYM may be an effective way to decrease production costs but is in conflict with widespread manure use as poor people's fuel.

3.4.5 Grower constraints

In our study, average fruit weight per date palm was 90 kg of which reportedly more than half was destroyed by rain, wind, and birds. Hence harvested yields were substantially smaller. Ata (2011) and Mcegypt (2014) also reported date palm yields of 50-90 kg, depending on the date variety and environmental conditions in Punjab and Aswan (Egypt), respectively. Yields of Pakistani and Egyptian date palm groves are lower than that those reported by RUAF (2014) for date palm cultivars grown in Gaza which were producing an average yield of 150 kg per date palm at harvest. Mauk and Sharabeen (2005) reported that Deglet Noor cultivars grown in California (USA) have a potential to produce 123 kg of dates per tree at intensive fertilization and manual pollination. A report by USAID (2008) from the Inma agribusiness program in Iraq claims that manual pollination of date palm has the potential to increase fruit yield by 60-80 kg per tree.

Only a few farmers in Punjab used improved varieties in intensively managed groves, which indicate the widespread marginal nature of date production. Interesting was that the locally used date cultivars were named either on the basis of the fruit shape ("Angoor" = grapes and "Akhrot" = walnut), on the basis of their color ("Sawi" / "Sabzo"= green date and "Rati"= red date) or on the basis of their origin ("Basra" and "Karbalaen") rather than fruit taste, preferred use or organoleptic properties. Mirbahar *et al*. (2014) reported that date palm cultivars developed in Pakistan are a result of continuous selection by the farmers which were given

folk names, but these are not consistent across locations (Kumar, 2011). Similar to the study of Ata (2011) in Dera Ghazi Khan and Muralidharan and Baidiyavadara (2013) in India germplasm exchange was rare among palm growers.

3.5 Conclusions

The widespread use of diverse date palm products in the study area indicates the role of this crop for local farm HHs. The low literacy rate of farmers may hinder the adoption of farm innovations leading to more intensive production systems connected to post-harvest value addition for this crop. Improved market access, cooperative sale structures and / or quality-based labeling with direct sales to consumers may help to enhance the role of dates in HH income thereby strengthening local farmers' income in Pakistan. This will require enhanced government investments in rural extension, consumer and producer awareness of produce quality including the establishment of grading standards for dates and palm nurseries with high quality germplasm.

Appendix

Characteristics of date palm farming systems, categories, description, classification, and scale.

Category	Description	Classification	Scale (unit)
Age	Age of the HH head	Years	Scale
Gender	Sex of the HH head	0 = Male 1 = Female	Nominal
Education	Number of years of schooling completed by the HH head	0 = Illiterate 1 = Primary 2 = Metric 3 = Intermediate 4 = Graduation 5 = Masters	Nominal
Occupation	Occupation of HH family	0 = Agriculture 1 = Agriculture + gov. job 2 = Agriculture + labour 3 = Agriculture + business 4 = Agriculture + private job	Nominal
Family size	Total members in the HH family	0 = Male 1 = Female	Nominal
Monthly income	HH total income from different sources	Farm and off-farm income ($)	Scale
Monthly income from date palm	Contribution of date palm in farmers' income	Farmers' income from date palm fruit and by-products ($)	Scale
Total land	Total land cultivated by HH	0 = Own land 1 = Rented in 2 = Rented out 3 = Shared in 4 = Shared out	Nominal
Cropping system	Other crops and fruits grown by HH	0 = Cereal 1 = Beans 2 = Fodder 3 = Cotton 4 = Sugarcane 5 = Other fruits	Nominal
Irrigation sources	Irrigation type used by HH for cultivation	0 = Canal water 1 = Tube well water 2 = Sewage water 3 = Karez water 4 = Canal + tube well	Nominal
Pesticide	Pesticide used by HH on cultivated crops	0 = No 1 = Yes	Nominal
Fertilizer	Fertilizer used by HH on cultivated crops	0 = No 1 = Yes	Nominal

FYM	FYM used by HH on cultivated crops	0 = No 1 = Yes	Nominal
Date palm distribution	Type of date palm cultivation in fields of HH	0 = Grove 1 = Scattered trees 2 = Intercropping 3 = Home garden	Nominal
Mature date palms	Mature date palms grown by HH	Total number of mature date palms grown by HH	Scale
Date palm HH usage	Total Date palm HH usage (%)	0 = Fruit as food 1 = Fruit as animal feed 2 = Fuel from frond 3 = Mats from frond 4 = Huts from stem and frond 5 = Hand fans from frond 6 = Staple dishes from frond 7 = Suckers	Nominal
Date palm commercial usage	Total date palm commercial usage (%)	0 = Fruit as food 1 = Fruit as animal feed 2 = Mats from frond 3 = Huts from stem and frond 4 = Hand fans from frond 5 = Staple dishes from frond 6 = Suckers	Nominal
Selling of fresh dates	Type of dates sell by HH	0 = No 1 = Yes	Nominal
Rate	Rate of fresh date sold by HH	Rate of fresh date sold by HH ($ kg^{-1})	Scale
Selling of dried dates	Type of dates sell by HH	0 = No 1 = Yes	Nominal
Rate	Rate of dried date sold by HH	Rate of dried date sold by HH ($ kg^{-1})	Scale
Selling of *chuhara*	Type of dates sell by HH	0 = No 1 = Yes	Nominal
Rate	Rate of *chuhara* sold by HH	Rate of *chuhara* sold by HH ($ kg^{-1})	Scale
Selling of dates	To whom HH sell dates	0 = Contractor 1 = wholesaler 2 = Commission agent 3 = Retailer 4 = Hawker 5 = Consumer 6 = Do not sell 7 = Market	Nominal

Reasons	Reasons given by HH for date palm grove contract	0 = Shortage of money 1 = Shortage of labour 2 = Distance from market 3 = Lack of time	Nominal
Distance	Distance of date palm cultivation area from market	Distance from market (km)	Scale
Transport	HH has own transport for marketing of dates	0 = No 1 = Yes	Nominal
Expenditure	Transport expenditure paid by HH	Transport expenditure ($)	Scale
Store house	HH has own store house for storage of dates	0 = No 1 = Yes	Nominal
Expenditure	Store house expenditure paid by HH	Store house expenditure ($)	Scale
Yield	Yield of date palm grown by HH	Firstly, randomly selected 3 bunches per date palm, separated dates from bunches, took their average weight, than multiplied average weight of dates with total number of bunches on date palm	Scale
Grower constraints	Major problems faced by date palm growers	0 = Rainfall 1 = Transport 2 = Market infrastructure 3 = Sucker unavailability 4 = Processing unit 5 = Credit facility 6 = Pollination 7 = Labour 8 = Storage facility 9 = Nursery facility 10 = Insect / pest / diseases 11 = Availability of literature	Nominal

Chapter 4

Effect of soil characteristics and date palm morphological diversity on nutritional composition of Pakistani dates

4.1 Introduction

Date palm (*Phoenix dactylifera* L.) is an essential component of the farming systems in arid and semi-arid regions of the world (Al-Afifi and Al-Badawi, 1998). Estimates differ about the total number of the date palm cultivars (1,500-5,000) in the more than 40 countries where it is grown (Bashah, 1996; Al-Afifi and Al-Badawi, 1998; Jaradat and Zaid, 2004). The species occupies almost 3% of the total cultivated area on the globe, with an annual production of about 7 million t (FAO, 2014). Pakistan is an ideal place for the cultivation of date palm given the prevalence of sandy loamy sedimentary soils and a semi-arid climate. There date palm production and area has been increasing from 566,400 t on 90,100 ha in 2008 to 600,000 t on 95,000 ha in 2012 (Abul-Soad, 2010; FAO, 2014). Baluchistan province is the country's largest date producer, followed by Sindh, Punjab, and KPK provinces (Quraishi *et al*., 1997).

Date palm (2n = 36) is a perennial and dioecious monocotyledon of the Arecaceae family with a life span of more than 100 years (Wrigley, 1995). The adult palm has a crown of up to 100-125 glabrous and greyish green leaves (fronds) which are 3-6 m long and have a life span of 3-7 years (Chao and Krueger, 2007). Date fruits are typically cylindrical and fleshy with a colour ranging from pale yellow to dark red, depending upon the variety and growth conditions (Sakr *et al*., 2010). The number of fruit bunches varies from 3-10 with an average weight of 5-20 kg (Munier, 1973). Seeds are stony, acute at the apex, and longitudinally grooved from one side (Malik, 1984). The morphology of spines, leaves, and fruit is important in identifying cultivars. Vegetative parameters determine 28% of the total morphological variation among different date palm cultivars, while spathe and fruit morphology accounts for about 41% and 31%, respectively (Mohamed *et al*., 2004). However, these features are fully displayed only in mature palms and are sensitive to environmental factors (Sedra *et al*., 1993; 1996). Clear morphological descriptors, that can be helpful for the characterisation and identification of date palm cultivars, are still lacking.

There are five internationally accepted date fruit developmental stages: *hababouk* (immature and pea size), *kimri* (green, hard and containing 80% moisture), *khalal* (color stage, crunchy and contains up to 50-60% moisture), *rutab* (ripe stage, crisp to succulent, soft texture, and 35-40% moisture), and *tamar* (full ripe, dry flesh and <20% moisture; Al-Shahib and Marshall, 2003; Fadel *et al*., 2006). Fruit size, weight, diameter, length, and seed weight increase from *kimri* to *khalal* stage followed by a slow decline in *tamar* stage. Total soluble sugars (TSS) increases progressively from *kimri* to *khalal* and *tamar* stage. At the *khalal* stage 80-85% of the sugar is sucrose and it hydrolysed into reduced sugars (glucose and fructose) during *rutab* and *tamar* stages of ripening (Vandercook *et al*., 1980; Ahmed *et al*., 1995). Dates are also rich in vitamins and minerals; 15 dates can provide >80% of daily body requirement of magnesium, 70% of sulfur, 25% of potassium, 20% of calcium, and substantial amounts of iron, manganese, zinc, and copper (Robinson, 1967; Underwood, 1977).

Ripe dates can be classified into soft, semi-dry, and dry on the basis of their texture, associated water and sugar contents wherby some cultivars may fall into more than one class (Barreveld, 1993; Glasner *et al*., 2002). About 80% of a date's dry matter consists of inverted sugars (mixture of equal parts of glucose and fructose) in soft dates, 40% in semi-dry dates, and 20-40% in dry dates (Bender and Bender, 2005). Different ripening times in different date palm cultivars can lead to changes in the fruit's physico-chemical (carbohydrate, moisture, dietary fibre, small amounts of protein, fat, ash, polyphenol, ascorbic acid, tannins, β-carotene, total phenols, total flavonoids, and carotenoids) and organoleptic (smell, taste, and sight) properties (Dowson, 1982; Odeh *et al*., 2014).

Date palm has been closely associated with the survival and well-being of people in hot and desert climates, and sometimes constitutes the only available food for inhabitants during food shortage periods (Ali *et al*., 2010). It can withstand air temperatures of up to 50 °C for short periods and thrives at 45-50 °C and low air humidity for fruiting as long as water is available in the subsoil (Qureshi and Barrett-Lennard, 1998). Preferred soil conditions for

date palm are sandy to clay loamy soils while it is moderately tolerant to alkaline soils, and needs good aeration and drainage (Morton, 1987; Chao and Krueger, 2007). Date palm can tolerate soil salt concentrations of up to 4.0 dS m^{-1} (Ayers and Westcot, 1985) but an electrical conductivity of 17.9 dS m^{-1} in soil and 12.0 dS m^{-1} in water reduces yields up to 50%. Fruit production usually stops at about 15.6 dS m^{-1} (Marcar *et al*., 1995), whereas tolerance to salinity depends on the genetic potential of the date palm variety, the climate, as well as soil drainage and texture (Maas, 1986).

Date palm cultivation has a long history in Pakistan. Although during the last decades significant efforts have been made in date palm research and development, there are still knowledge gaps which need to be addressed to improve the quality of dates in order to allow Pakistani dates to compete with internationally traded elite cultivars. Low quality of dates in many date palm growing areas of Pakistan is partly due to the prevalence of germplasm that is sensitive to rain and high air humidity (Abul-Soad, 2010).

In view of the above the present study aimed at investigating the effects of date palm germplasm and selected soil physico-chemical properties in different regions of Pakistan on the nutritional properties of dates. To this end different date cultivars from major date producing areas in four provinces of Pakistan were studied.

4.2 Materials and methods

4.2.1 Study area

The study was conducted in the six districts with the largest area under date palm cultivation across four provinces of Pakistan: Jhang, Muzaffargarh and Bahawalpur (Punjab province), D. I. Khan (KPK), Khairpur (Sindh province) and Panjgur (Baluchistan province; Table1).

Table 1. Main climatic characteristics of the six date palm growing districts in the sub-tropical desert climate zone of Pakistan.

	Jhang	Bahawalpur	Muzaffargarh	D. I. Khan	Khairpur	Panjgur
Longitude (E)	72°15'00"	67°43'00"	71°04'60"	72°19'41"	68°45'26"	64°06'00"
Latitude (N)	31°25'00"	26°49'00"	30°19'60"	31°83'14"	27°31'50"	26°58'00"
Soil type	Clayey, loamy & sandy	Clayey, loamy & sandy	Clayey & loamy	Loam to clay loam	Clayey, loamy & sandy	Loamy & partly gravelly
Summer Climate	Hot & dry	Very hot & dry with frequent dust storms	Very hot with dust storms	Hot desert	Very hot & sunny	Hot
Winter Climate	Cold & dry	Cold & dry	Arid & mild	Mild	Mild-warm	Cold
Temperature (°C)	24.7	25.7	25.6	24.5	26.9	21.7
Precipitation (mm)	180	200	127	249	178	109

Sources: Table adapted from Beinroth *et al*., 1985 with the addition of recent climate data from the PMD, Pakistan Meteorological Department www.namc.pmd.gov.pk/agromet-bulletins.php# (accessed on 12 February 2015)

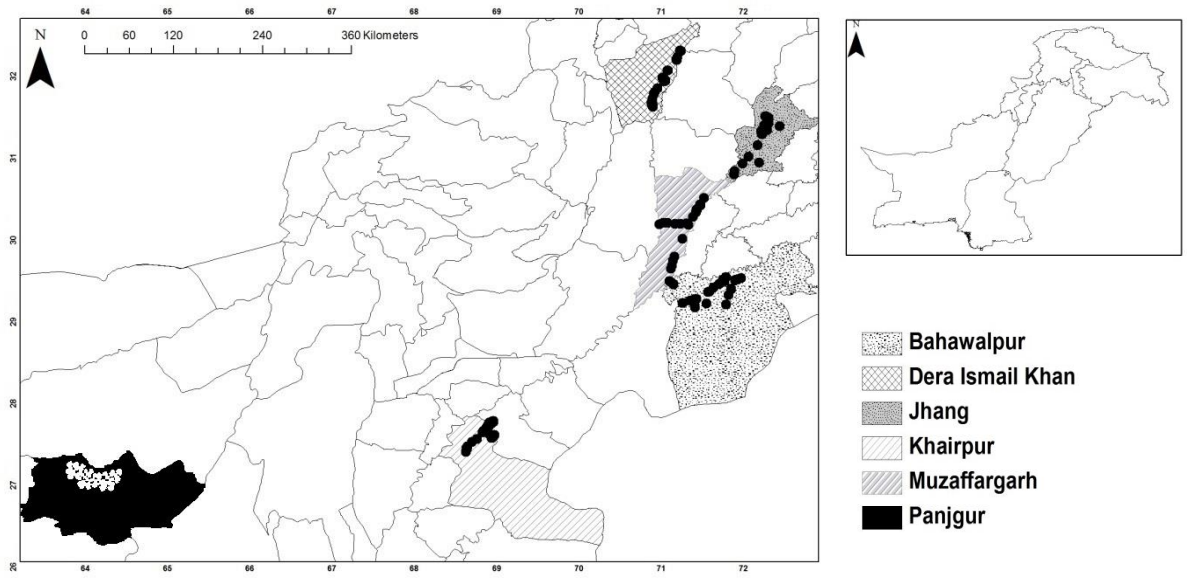

Figure 1. GIS-based map of the study area in Pakistan with the position of households interviewed during 2012-2013. Black dots mark the household's location in the three provinces Punjab, Khyber Pakhtunkhwa, and Sindh. White dots represent the estimated rough locations of interviewed households in Baluchistan province, since the recording of GPS coordinates was not allowed in this region (see also figure 1 in chapter 3).

4.2.2 Nutritional analysis of dates

For nutritional analysis at *tamar* stage 20 dates were directly harvested from each sampled date palm, without any preference to size (Nadeem *et al*., 2011; Table 2). Fruit samples were cleaned with a cotton cloth followed by seeds removal for the preparation of date juice. Date

flesh was cut into pieces and dried at 70 °C in an oven until weight constancy. After grinding with a mortar and pestle 40 g of the dried flesh was soaked overnight in 120 ml distilled water and homogenized in a blender followed by filtration with a Whatman® no. 1 filter paper. Filtrates were stored in plastic bottles at 6 °C until analysed (Ismail *et al*., 2006). TSS in the date juice was measured using a hand-held refractometer (Anon, 1990) and acidity was determined using 10 ml of juice, titrated against sodium hydroxide (NaOH), with phenolphthalein as an indicator (Makhloufi *et al*., 2013). A pH meter was used to check the neutrality point (Anon, 1990).

Fruit firmness was measured at three different points using a penetrometer (plunger size = 2 mm) at 25 °C (Harker *et al*., 1996). The mineral profile (calcium and magnesium) of the date juice was analysed with a flame atomic absorption spectrometer (Hitachi 170-50, Hitachi Ltd. Co, Tokyo, Japan).

4.2.3 Soil analysis

Comprising the date palm's root zone soil samples were collected at 0.9 m depth, air dried for one week, and passed through a 2 mm sieve. Chemical analyses (Table 2) were performed using the standard analytical methods described by the U.S. Salinity Laboratory 1954 (Al Rasbi, 2010). All calculations were made on the basis of oven dry soil weight. A saturated soil paste was prepared to more closely mimic the water content of the soil under field conditions. Saturation percentage was determined by drying the paste in an oven at 105 °C to constant weight and soil pH of the saturated paste was determined using a pH meter. Saturated soil extracts were obtained by a vacuum pump. The electrical conductivity (EC) of the saturation extract was measured using a conductivity meter (WTW conductivity meter 197i, WTW GmbH, Weilheim, Germany) after calibrating the instrument with 0.01 N potassium chloride (KCl). Calcium carbonate ($CaCO_3$) was calculated by the calcimetric method using a 6 normal (N) hydrochloric acid (HCl) solution. A five g soil sample was

treated with 1:1 HCl and the volume of CO_2 liberated from $CaCO_3$ present in the soil was noted (Moodie *et al*., 1959). $CaCO_3$ was determined according to the following formula:

$$\mathrm{CaCO_3\ (\%)} = \frac{\mathrm{CO_2\ released\ (mL)\ \times\ (0.00399)}}{\mathrm{weight\ of\ soil\ sample\ taken\ (g)}}$$

Soil organic carbon (SOC) was determined by titrating samples containing potassium dichromate ($K_2Cr_2O_7$), and sulphuric acid (H_2SO_4) using a ferroin indicator.

Olsen's method was used to calculate plant available soil phosphorus (P) content using sodium bicarbonate ($NaHCO_3$) solution as a extractant (Chapman and Pratt, 1961).

To determine cation exchange capacity (CEC), 5 g soil were saturated with 1 N sodium acetate (CH_3COONa) buffered to pH 8.2. Sodium in the extract was determined using a flame photometer (Jenway PFP-7) while keeping the Na^+ filter in place. CEC was calculated according to:

$$\mathrm{CEC}\left(\frac{\mathrm{meq}}{\mathrm{100\ g\ soil}}\right) = \frac{\mathrm{Na^+}\left(\frac{\mathrm{meq}}{\mathrm{L}}\right) \times\ 10000}{1000\ \times\ \mathrm{weight\ of\ soil\ (g)\ used}}$$

Phosphorous (P) in the soil was measured using a spectrophotometer, and total P was calculated using:

$$\mathrm{Total\ P\ (mg\ kg^{-1})} = \mathrm{mg\ kg^{-1}P\ (from\ calibration\ curve)} \times \frac{\mathrm{Perchloric\ Acid\ 60\% \times 50}}{\mathrm{weight \times volume}}$$

Soil bulk density (BD) was determined by the core method (Shakir *et al*., 2002) and soil hydraulic conductivity (HC) was measured in soils according to Ritzema (1994). Hydraulic conductivity was calculated using the following formula:

$$\mathrm{K} = \mathrm{C}\frac{\mathrm{H_o} - \mathrm{H_t}}{\mathrm{t}}$$

where

K = hydraulic conductivity (cm hr^{-1})
C = a geometric factor of the soil
t = time elapsed since the 1st reading of the level of the rising water in the hole (sec)
$H_o = H_t$ when t is equal to zero
H_t = depth of water level in the hole below the reference level at time t (cm)

4.2.4 Morphological analysis

Vernacular names of all cultivars were recorded in the fields of growers and their fronds were cut down to measure their length and width. Date palm fruits were collected at *tamar* stage. Fruit and seed parameters (Table 2) were measured at Institute of Horticultural Sciences, University of Agriculture Faisalabad, Pakistan.

Table 2. Nutritional and morphological parameters in dates and soil samples collected in the study areas of Pakistan during 2012-2013.

Nutritional parameter	Unit	Morphological parameter	Unit	Soil parameter	Unit
Acidity	mg l^{-1}	Frond length	cm	[2]HC	cm hr^{-1}
Firmness	g mm^{-1}	Frond width	cm	[3]EC	dS m^{-1}
[1]TSS	g $100g^{-1}$	Fruit length	cm	[4]Conc. $CaCO_3$	%
Calcium	mg g^{-1}	Fruit width	cm	[5]Conc. OM	%
Magnesium	mg g^{-1}	Fruit weight	g	[6]Available P	mg kg^{-1}
		Seed length	cm	[7]CEC	meq $100g^{-1}$
		Seed width	cm	[8]Total P	mg kg^{-1}
		Seed weight	g	[9]BD	Mg m^{-3}
				pH	

[1]Total soluble sugars; [2]Hydraulic conductivity; [3]Electrical conductivity; [4]Concentration of $CaCO_3$; [5]Concentration of organic matter; [6]Available phosphorous (Olsen): [7]Cation exchange capacity; [8]Total phosphorous; [9]Bulk density

Length and width of fronds, fruits, and seeds were determined using a measuring tape. Fruit and seed weight were recorded using a digital balance (accuracy of ±0.5 mg). To identify cultivars particularly attractive for marketing, with a high fruit size and high flesh content, ratios of length, width, and weight of fruit and seed were measured.

4.2.5 Statistical analysis

All data were tabulated and coded into numerical values before descriptive statistical analyses were conducted in Microsoft Excel. Prior to analysis, variables were tested for normality using the Kolmogorov-Smirnov test (Latifian *et al*., 2012); residuals of data were found to be non-normally distributed and thus non-parametric tests were conducted. Date palm cultivars with sample size ≥6 were used for further statistical analyses. Relationships

between independent variables (cultivar type and location) and dependent variables (nutritional properties: TSS, acidity, calcium, magnesium, and firmness; morphological parameters: leaf length, leaf width, fruit length, fruit width, fruit weight, seed length, seed width, and seed weight; soil properties: pH, EC, $CaCO_3$, OM, available P, total P, CEC, BD, and HC) were thus explored using the Kruskal-Wallis test (Montagna *et al*., 2015) in SPSS 17.0 (SPSS Inc., Chicago, USA). For all analyses the significance level was set to $P<0.05$.

A Canonical Correspondence Analysis (CCA) was used to investigate the effects of morphological properties of 12 date palm cultivars with sample size ≥6 and soil parameters on the nutritional properties of dates using the MVSP software (Orabi *et al*., 2011). CCA is a direct gradient analysis or ordination technique (ter Braak and Prentice, 2004) that performs well with unimodal and nonlinear species to environmental relationships (ter Braak, 1986) and is relatively insensitive to data transformation protocols (Jackson, 1993; 1997). In the resulting CCA biplot, the length and direction of arrows indicate the relative importance and relationship between environmental variables and nutritional fruit characteristics. All environmental variables (leaf length, leaf width, fruit length, fruit width, fruit weight, seed length, seed width, seed weight, pH, EC, $CaCO_3$, OM, available P, total P, CEC, BD, and HC) were included into the initial CCA. In addition, study sites (districts) were added as dummy variables to identify their possible effect on nutrition of dates. Short vectors (seed width, total phosphorous and organic matter contents) were not included in the final CCA biplot because of their low effect on fruit nutritional properties.

Species richness and biodiversity indices are frequently used to determine taxa compositional differences among sites. As diversity indices such as Shannon's diversity index and Shannon's evenness also account for abundance of one taxonomic group, both indices provide more information with respect to composition than simply richness (number of cultivars). Though comparatively less employed, the application of Shannon indices on cultivars was done for instance for banana across several villages in Uganda by Smale (2005). Thus, Shannon diversity index and Shannon's evenness of all date palm cultivars

were calculated with the Microsoft Excel based Diversity Add-In Calculator (SSC, Reading, UK).

4.3 Results

In the study region, 39 different date palm cultivars were grown by the surveyed farmers. In the district Jhang (Punjab), seven different cultivars were identified; most of the HHs were growing Desi date palms. Desi date palm was also very popular in Bahawalpur (Punjab) while other prominent cultivars of the area were Sundri, Sufaida, Pathri, Danda, and Ketchen. Date palm growers of the Muzaffargarh (Punjab) produced the greatest diversity of date palms with eleven cultivars identified. Half of the date palm growers had the Desi cultivar in their groves, whereas the remaining farmers grew other cultivars. The majority of HHs in D. I. Khan (KPK) cultivated Dhakki cultivar. Aseel cultivar was found dominant in the groves of >60% farmers in Khairpur (Sindh) followed by the Karbalaen cultivar. Farmers in Panjgur (Baluchistan) produced six different cultivars among which Muzawati (50%) was most frequent (Fig. 2).

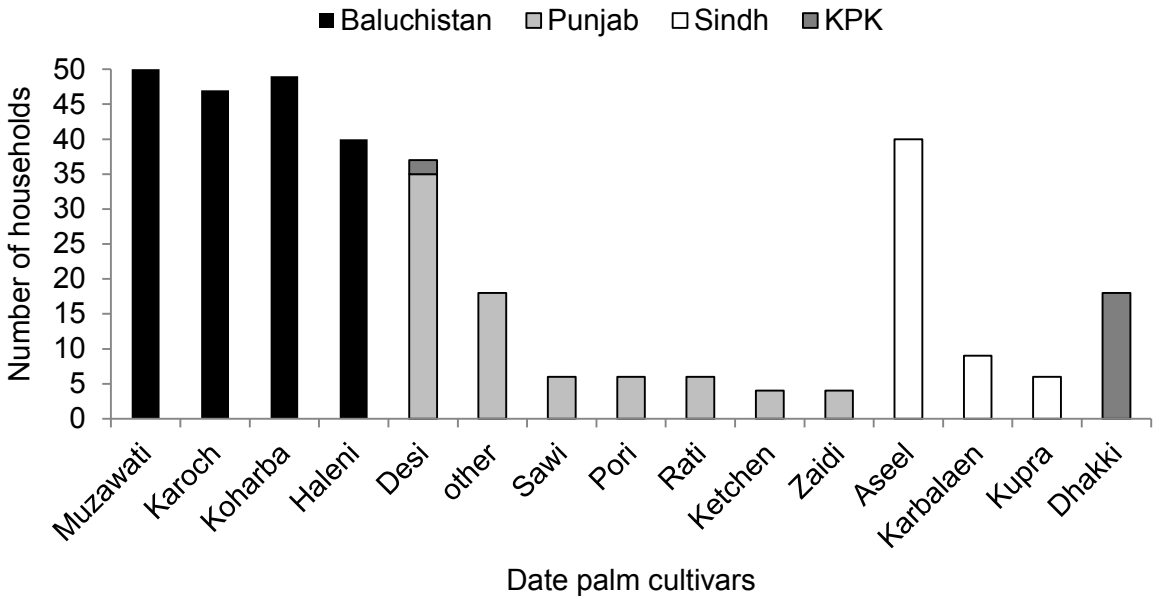

Figure 2. Number of surveyed households in the four provinces of Pakistan growing different date palm cultivars in 2012-2013 (Others = Ajwa, Akhrot, Amber, Angoor, Barni, Basra, Berehmi, Begum Jhangi, Chohara, Daanda, Dandari, Doki, Halawi, Khudrawi, Kalma, Kobra, Meeri, Pathri, Patal, Sundri, Shershai, Sabzo, Shamran, Sufaida, and Zeerin cultivars which had sample size ≤3).

The number of cultivars and Shannon's diversity was highest in Panjgur, whereas date palm cultivars grown in this district were more even as compared with other studied districts (Table 3).

Table 3. Mean number of cultivars, Shannon's diversity index, and Shannon's evenness index per household in six date palm growing districts of Pakistan during 2012-2013.

Districts	Mean number of cultivars	Shannon's diversity index	Shannon's evenness index
Jhang	2.0	0.42	0.35
Muzaffargarh	2.0	0.27	0.20
Bahawalpur	2.0	0.33	0.20
D. I. Khan	1.0	0	0
Panjgur	3.8	1.30	0.98
Khairpur	1.5	0.31	0.43

There were significant location-specific differences in soil $CaCO_3$, BD, CEC, EC, pH, OM, total P and Olsen P, but not in HC. Soil $CaCO_3$ and CEC were highest in Bahawalpur and

lowest in D. I. Khan and Panjgur. Sampled soils of Bahawalpur and Muzaffargarh district had the largest BD, while HC was highest in Bahawalpur, Muzaffargarh, D. I. Khan, and Panjgur. Total soil P was very high in the soil of Muzaffargarh while available P was highest in soil samples of D. I. Khan. EC and pH were highest in the soils of Panjgur and lowest in those of Jhang and Muzaffargarh. The soil samples of Jhang district had the highest OM contents (Table 4).

Table 4. Means (±SD) of soil characteristics of date palm groves in four provinces of Pakistan during 2012-2013.

District	$CaCO_3$ (%)	BD (Mg m^{-3})	HC (cm hr^{-1})	Total P (mg kg^{-1})	CEC (meq $100g^{-1}$)	EC (dS m^{-1})	pH	OM (%)	Available P (mg kg^{-1})
[1]Jhang	10.4 ± 3.54	1.3 ± 0.08	0.6 ± 0.11	302 ± 40.5	8.3 ± 1.56	0.9 ± 0.46	7.7 ± 0.11	0.8 ± 0.13	6.6 ± 1.46
[2]Bahawalpur	15.0 ± 1.74	1.4 ± 0.07	0.7 ± 0.09	306 ± 52.3	8.9 ± 1.31	1.1 ± 0.13	7.8 ± 0.34	0.7 ± 0.16	6.5 ± 2.01
[3]Muzaffargarh	11.5 ± 2.83	1.4 ± 0.14	0.7 ± 0.10	319 ± 43.6	8.6 ± 1.08	1.0 ± 0.13	7.6 ± 0.09	0.7 ± 0.14	7.8 ± 1.79
[4]Khairpur	10.1 ± 4.63	1.2 ± 0.17	0.6 ± 0.11	291 ± 38.0	5.7 ± 1.20	1.3 ± 0.34	8.2 ± 0.29	0.7 ± 0.13	6.6 ± 0.82
[5]D. I. Khan	7.2 ± 1.99	1.3 ± 0.09	0.7 ± 0.12	284 ± 38.0	5.6 ± 1.34	1.6 ± 0.13	8.0 ± 0.13	0.6 ± 0.08	6.5 ± 1.90
[6]Panjgur	11.2 ± 3.61	1.1 ± 0.08	0.7 ± 0.10	289 ± 40.8	5.6 ± 1.33	1.7 ± 0.18	8.3 ± 0.26	0.7 ± 0.11	6.0 ± 1.52
Effect* of location on soil properties (0.9 m depth)**									
Mean	10.8	1.3	0.6	300.6	6.7	1.4	8.0	0.7	7.0
SD	3.96	0.16	0.10	42.27	1.92	0.38	0.35	0.13	1.60
χ^2	42.4	81.8	8.6	12.0	85.0	110.1	108.8	15.7	14.7
P-value	<0.001	<0.001	0.128	0.034	<0.001	<0.001	<0.001	0.008	0.012

[1]20 samples were collected from 10 sites; [2]20 samples were collected from 16 sites; [3]20 samples were collected from 18 sites; [4]40 samples were collected from 18 sites;

[5]20 samples were collected from 7 sites; [6]50 samples were collected from 8 sites

Degrees of freedom (df) = 5

*Kruskal-Wallis test; as residuals of data were non-normally distributed

**For placement of location see Fig. 1

Dates from date palm cultivars grown in the different regions of the country had very diverse nutritional properties. TSS was highest in cultivar Muzawati followed by Koharba and Dhakki while Haleni had smallest concentrations of TSS. Cultivar Haleni, Muzawati, and Aseel had lower acidity values compared with the other cultivars. Across sites cultivar Muzawati, Karoch, and Aseel had the highest calcium concentrations among all studied cultivars. Magnesium concentration was highest in cultivar Haleni followed by Karbalaen and Karoch whereas Sawi and Desi cultivar were poor in magnesium. Rati and Dhakki cultivar had firmest dates (Table 5). Location also had significant effects on the nutritional parameters (TSS, acidity, calcium, magnesium and firmness) of the fruits (Table 6).

Table 5. Means (±SD) of different nutritional properties of 12 date palm cultivars (individual number per cultivar ≥6) grown in four provinces of Pakistan during 2012-2013.

Cultivar	[1]TSS (g 100g^{-1})	Acidity (mg l^{-1})	Calcium (mg g^{-1})	Magnesium (mg g^{-1})	Firmness (g mm^{-1})
Aseel	71 ± 6.9	4.3 ± 1.18	0.43 ± 0.04	0.30 ± 0.05	350 ± 140
Desi	53 ± 10.8	5.8 ± 0.32	0.33 ± 0.01	0.29 ± 0.05	500 ± 130
Dhakki	73 ± 5.8	4.4 ± 1.07	0.39 ± 0.07	0.32 ± 0.02	540 ± 80
Haleni	46 ± 11.6	3.1 ± 0.66	0.34 ± 0.02	0.49 ± 0.03	270 ± 20
Karbalaen	65 ± 4.2	4.9 ± 0.32	0.39 ± 0.05	0.47 ± 0.04	520 ± 10
Karoch	71 ± 3.7	5.0 ± 0.48	0.43 ± 0.06	0.43 ± 0.05	280 ± 30
Koharba	74 ± 2.8	5.0 ± 0.26	0.37 ± 0.04	0.35 ± 0.02	270 ± 10
Kupra	59 ± 2.1	4.6 ± 0.06	0.37 ± 0.02	0.51 ± 0.02	250 ± 40
Muzawati	75 ± 5.4	4.1 ± 0.31	0.44 ± 0.05	0.39 ± 0.03	340 ± 10
Pori	52 ± 15.3	5.4 ± 0.07	0.22 ± 0.08	0.30 ± 0.01	410 ± 30
Rati	62 ± 0.90	5.2 ± 0.07	0.29 ± 0.02	0.30 ± 0.01	570 ± 160
Sawi	48 ± 9.3	5.4 ± 0.21	0.26 ± 0.06	0.29 ± 0.01	450 ± 230

[1]Total soluble solids

Table 6. Effects of cultivars and locations on nutritional properties of 12 date palm cultivars (individual number per cultivar ≥6) grown in four provinces of Pakistan during 2012-2013.

Effect* of cultivar on nutritional properties of date palm					
	[1]TSS (g 100g^{-1})	**Acidity (mg l^{-1})**	**Calcium (mg g^{-1})**	**Magnesium (mg g^{-1})**	**Firmness (g mm^{-1})**
df	11	11	11	11	11
Mean	65.43	4.80	0.39	0.37	410
SD	11.93	0.99	0.96	0.84	140
χ^2	106.72	95.08	47.92	110.89	82.78
P-value	<0.001	<0.001	<0.001	<0.001	<0.001
Effect* of location on nutritional properties of date palm**					
df	5	5	5	5	5
Mean	64.77	4.91	0.38	0.36	410
SD	11.62	1.01	99.35	87.19	140
χ^2	82.68	87.97	33.82	120.69	65.49
P-value	<0.001	<0.001	<0.001	<0.001	<0.001

[1]Total soluble solids
*Kruskal-Wallis test
**For placement of location see Fig. 1

Frond, fruit, and seed morphological data of date palm displayed a high level of diversity among the studied cultivars. The length-to-width ratio of frond was highest in the Haleni cultivar and lowest in the Rati cultivar. The length-to-width ratio of fruit was larger in the Muzawati and Dhakki cultivar and smaller in Koharba and Haleni cultivars. Length-to-width ratio of seed was higher in cultivars grown in Punjab (Pori and Sawi) and than in cultivars of Baluchistan (Haleni) and Sindh (Aseel and Karbalaen). Aseel, Dhakki, and Karbalaen showed the highest fruit weight-to-seed weight ratio among all cultivars (Table 7). Location and cultivar significantly affected fruit size (length, width) and weight as well as seed size (length, width) and weight, but not necessarily frond length, and width (Table 8).

Table 7. Means of assessed parameters and calculated ratios of different morphological characteristics (FL (frond length, cm), FW (frond width, cm), FR (frond length-to-frond width ratio), FRL (fruit length, cm), FRW (fruit width, cm), FRR (fruit length-to-fruit width ratio), SL (seed length, cm), SW (seed width, cm), SR (seed length-to-seed width ratio), FWT (fruit weight, g), SWT (seed weight, g), FSR (fruit weight-to-seed weight ratio)) of 12 date palm cultivars (individual number per cultivar ≥6) in four provinces of Pakistan during 2012-2013.

Cultivars	FL	FW	FR	FRL	FRW	FRR	SL	SW	SR	FWT	SWT	FSR
Aseel	370	61	6.1	3.7	1.9	2.0	2.1	1.0	2.1	7.4	1.0	7.4
Desi	300	60	5.0	3.2	1.7	1.9	2.2	0.7	3.1	4.8	0.9	5.3
Dhakki	301	60	5.0	7.2	2.9	2.5	2.4	1.0	2.4	9.6	1.4	6.9
Haleni	309	47	6.6	4.0	2.4	1.7	2.0	3.0	0.7	9.4	2.0	4.7
Karbalaen	295	58	5.1	3.3	1.7	1.9	1.9	0.9	2.1	5.7	0.9	6.3
Karoch	299	61	4.9	3.3	1.8	1.8	2.3	0.8	2.9	3.1	0.8	3.9
Koharba	301	61	4.9	3.1	1.9	1.6	1.9	0.8	2.4	3.6	1.0	3.6
Kupra	288	59	4.9	2.8	1.4	2.0	1.9	0.8	2.4	4.0	0.8	5.0
Muzawati	297	58	5.1	4.2	1.4	3.0	2.3	0.9	2.6	7.2	1.9	3.8
Pori	255	58	4.4	3.3	1.6	2.1	2.4	0.7	3.4	4.5	1.1	4.1
Rati	300	70	4.3	2.9	1.4	2.1	2.1	0.8	2.6	3.7	1.1	3.4
Sawi	305	52	5.9	2.8	1.3	2.2	1.9	0.6	3.2	3.4	0.8	4.3

Table 8. Effects of cultivars and locations on morphological properties of 12 date palm cultivars (individual number per cultivar ≥6) grown in four provinces of Pakistan during 2012-2013.

Effect* of cultivar on morphological properties of date palm								
	Frond length (cm)	**Frond width (cm)**	**Fruit length (cm)**	**Fruit width (cm)**	**Fruit weight (g)**	**Seed length (cm)**	**Seed width (cm)**	**Seed weight (g)**
df	11	11	11	11	11	11	11	11
Mean	300.40	60.70	3.96	1.86	6.15	2.17	0.89	1.16
SD	24.60	10.24	1.36	0.48	2.54	0.27	0.65	0.48
χ^2	6.34	10.87	96.08	75.31	96.35	53.14	91.74	79.04
P-value	0.850	0.454	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Effect* of location on morphological properties of date palm**								
df	5	5	5	5	5	5	5	5
Mean	300.83	60.14	3.88	1.83	6.01	2.18	0.86	1.13
SD	25.04	10.53	1.30	0.46	2.48	0.26	0.62	0.46
χ^2	0.67	1.05	60.05	49.97	52.09	29.58	90.54	30.19
P-value	0.981	0.961	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*Kruskal-Walis test
**For placement of location see Fig. 1

The axis 1 and axis 2 explained 23% and 4% of the variation, respectively. All variables were analysed, but only those that were statistically significant were retained. Across the six districts bulk density tended to be weakly positively correlated to axis 1 while available phosphorous had a strong positive correlation to axis 1 and pH showed a strong negative correlation to axis 2 (Fig. 3). Among morphological properties of dates fruit length and seed length showed a strong positive correlation to axis 1 and axis 2, respectively. CCA indicated that the nutritional properties of the studied date palm cultivars were mainly affected by seed length and fruit length of dates and bulk density, available P, and pH of the soil (Fig. 3). Calcium concentration seemed to be more affected by the concentration of $CaCO_3$ and available P of the soil. TSS was positively affected by soil BD and CEC and fruit length and width, and seed length and was negatively affected by pH of soil. Fruit acidity was more related to seed length. There was no relationship between any soil or morphological properties of fruit and frond and firmness of the dates. Across cultivars, dates grown in D. I. Khan had a larger fruit length and width and were also high in TSS, calcium, and acidity (Fig. 3).

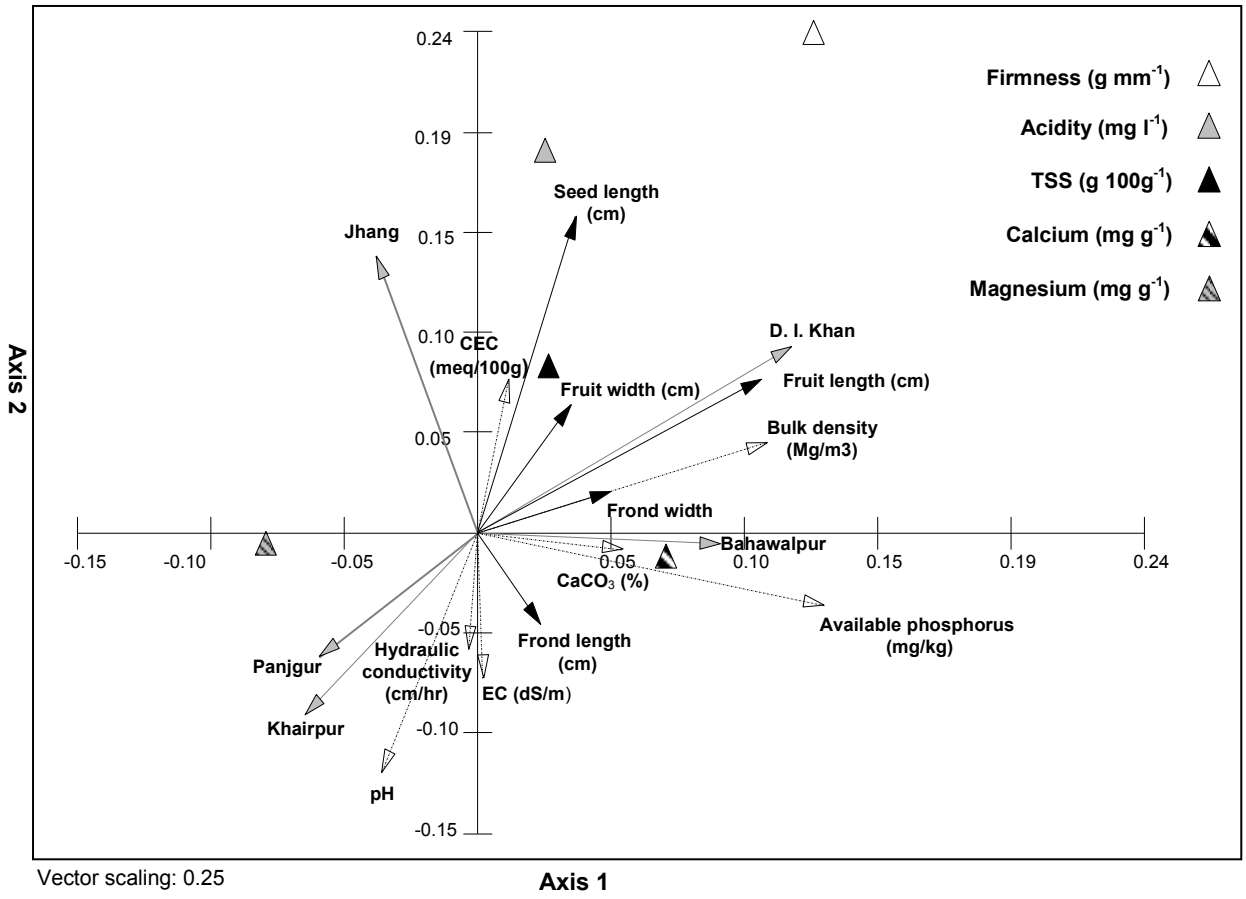

Figure 3. Canonical Correspondence Analysis (CCA) used to determine which location, soil or fruit and seed morphological factors of date palm are correlated with nutritional characteristics of the dates. Dotted line arrows show soil factors, black arrows show morphological factors, grey arrows show districts and triangles show nutritional properties of 12 date palm cultivars (individual number per cultivar ≥6) grown in four provinces of Pakistan during 2012-2013.

4.4 Discussion

Across our study area the chemical and physical soil properties varied widely. Organic matter ranged from 0.6-0.8%, which seems suitable for date palm cultivation. Reilly and Reilly (2012) recommended OM to range from 0.3-1.2% across a wide range of textures. Significant effects of OM on fruit length, weight, flesh weight, and TSS as well as non-significant effects on calcium and magnesium were observed previously for Zaghloul dates in Egypt (Marzouk and Kassem, 2010). Based on the results of the CCA, surprisingly OM did not seem to have a major effect on the nutritional properties of dates from the studied cultivars.

The effect of macro-nutrients (nitrogen, phosphorous, magnesium, calcium, and potassium) on the growth and yields of date palm have been reported in previous studies (Rouhani and Bassiri, 1977; Khayyat *et al*., 2007; Dialami and Mohebi, 2010). In our study, available soil P affected calcium contents but had little effect on date firmness which is, however, hard to explain. In contrast, Faust (1989) reported a strong correlation of soil P with firmness of apple (*Malus domestica* Borkh.). Furthermore, Stiles and Reid (1991) described that size, acidity, and color of the fruit were positively correlated with the application of P to soils during the early growing season of apple and pear (*Pyrus communis* L.) fruits. Poll *et al*. (2003) suggested that tart cherry (*Prunus cerasus* L.) production and fruit quality (titratable acidity, soluble solids contents, and color) can be improved by increasing soil P.

Low and high soil BD can affect nutrient uptake due to the resulting soil's low or high hydraulic conductivity and poor root to soil contact (Arvidsson, 1999). In our study soil BD affected the calcium contents and TSS of dates. There are no reports available describing the direct effects of BD on calcium and TSS of dates. Ibrahim and Fadni (2013) reported that an increase in soil OM decreased its BD which in return enhanced TSS, total protein, vitamin, and fruit water content of tomato fruit (*Solanum lycopersicum* L.). Hence, low BD might be also favourable for date palm. The average BD of Panjgur soils was similar as reported for the soil of Sra Ghurgai, Quetta, Baluchistan (1.08 t m^{-3}; Saeed *et al*., 2014).

The TSS concentrations in the investigated dates ranged from 60-75 g 100 g^{-1}, which is similar to the 60-84 g 100 g^{-1} reported by Pareek (1985) for date palms grown in India. The calcium concentrations in the studied dates ranged from 0.22-0.44 mg g^{-1}, with the majority of cultivars containing >0.30 mg g^{-1} which is comparable to the 0.25 mg g^{-1} reported by Jamil *et al*. (2010) for Burkavi dates. According to the findings of Al-Hooti *et al*. (1997), mineral concentrations of dates reflects the soil fertility status with is also indicated by our CCA. It is well known that the calcium uptake from the soil by the roots and its translocation to different parts of the plant, especially in the fruit is controlled by mass flow of water in response to the negative water potentials developed in leaves and fruits triggered by transpiration and

growth (Ho *et al*., 1993; De Freitas *et al*., 2011). The factors controlling this mechanism include calcium availability in the soil, root growth, root calcium uptake, competition of calcium with other nutrients in the root but also fruit and leaf competition for the available calcium in the xylem sap (Taylor and Locascio, 2004; De Freitas and Mitcham, 2012).

In the current study, all soils were alkaline (pH range: 7.6-8.3) and did not show strong effects on nutritional properties of dates. The soils of Jhang, Muzaffargarh, and Bahawalpur were slightly alkaline and those of Khairpur, D. I. Khan, and Panjgur were moderately alkaline. The pH range of Khairpur, D. I. Khan, and Panjgur soils was similar to the pH values reported in previous studies by Anwar and Chandio (2012) for soils of Kamber Taluka (Sindh), by Wasiullah *et al*. (2010) for the soils of Kohat (KPK) and by Naseem *et al*. (2009) for soils in Wadh (Baluchistan) ranging between pH 7.5-8.3.

The EC of all studied soils indicated only low constraints (0.9-1.7 dS m^{-1}) and is therefore unlikely to have any noticeable effect on the nutritional properties of dates. According to the findings of Tripler *et al*. (2011), date palm is tolerant to low salinity and responds to low EC (1.8 dS m^{-1}) with increased growth and 35-50% higher fruit production compared with higher EC (4 dS m^{-1}). However, there are also reports describing date palm as tolerant to higher EC (4 dS m^{-1}) and suggesting a yield reduction of 3.6% for every 1 dS m^{-1} increase in soil EC (Furr and Armstrong, 1962; Furr *et al*., 1966; Furr and Ream, 1968). Tripler *et al*. (2007) reported a 10% reduction in yield for every 1 dS m^{-1} increase in EC which is greater than that reported previously. In any case there is evidence that salinity tolerance in date palm is cultivar specific (Djibril *et al*., 2005). Average CEC of the studied soils was low (7.1 meq $100g^{-1}$) and apparently had only a minor effect on the dates' TSS in our study.

Our data show that Dhakki, Muzawati, Aseel, and Karbalaen were the most important cultivars grown in KPK, Baluchistan, and Sindh. The cultivars Aseel, Dhakki, Karoch, and Muzawati had the firmest fruits and high TSS, calcium, and magnesium. Firmness in dates is strongly correlated with fibre and carbohydrates (El Hadrami and Al-Khayri, 2012). Ismail *et al*. (2006) reported that physical and chemical characteristics of the fruits can influence

their rheological and mechanical properties, which determines their firmness and ultimately quality. Jamil *et al*. (2010) reported magnesium concentrations of Aseel (0.271 mg g^{-1}) and Dhakki (0.206 mg g^{-1}) cultivars which were lower than those observed in our study, indicating the presence of high quality dates in the studied date palm samples of Pakistan.

It is well known that a crop's nutrient uptake strongly affects fruit quality and economic outcome of production (Lipiec and Stepniewski, 1995) and it has been documented earlier that soil nutrients can strongly affect the physical properties of dates namely their length, weight, and diameter (Basha and Abo-Hassan, 1982; Hussein and Hussein, 1982). Morphological characteristics, specifically frond length and width can also be used to characterize date palm cultivars in addition to their nutritional properties (Asif *et al*., 1986). In the present study, a great variation in frond morphology was recorded among the studied cultivars. Frond length of date palm cultivars was in range of 280-370 cm, which is comparable to the three Saudi Arabian date palm varieties grown in the district Khairpur, Sindh (Abul-Soad *et al*., 2013). In literature there is no evidence of any relationship between frond size and nutritional values of dates. High variability in fruit attributes such as length, width, and weight has been reported by several researchers in previous studies (Mehana, 1999; Al-Doss *et al*., 2001; Azeqour *et al*., 2002; Mansour, 2005; Rizk and El-Sharabasy, 2007). Most of the studied date palm cultivars carried small sized dates (2.8-3.5 cm) and their size was similar to those of dates reported in a previous study on 85 date palm varieties grown in Pakistan (Markhand *et al*., 2010). We observed that across locations fruit length and fruit weight was highest in the Dhakki cultivar, making it visually more attractive for customers in addition to its good nutritional properties. Nadeem *et al*. (2011) also reported similar findings about the texture profile and phenol concentration of dates in 21 varieties of dates grown in the district Jhang. Many integrated factors play a role in determining color and size of fruit; one is metaxenia and exerted by the type of pollen grain and timing of pollination (Iqbal *et al*., 2004), others are irrigation, fertilization operations, and date palm head treatments (Markhand *et al*., 2010). According to Iqbal *et al*. (2011), larger fruit size and high weight in Dhakki cultivar can be attributed to genetic determination.

Muzawati and Haleni cultivars also had large fruits, which were also high in TSS, calcium, and magnesium concentrations.

The seed weight of the studied cultivars ranged from 0.7-2.0 g, while seeds of the Desi cultivar were largest, making fruits of this cultivar less attractive for marketing. In the current study, it was observed that, date palm cultivars with big seeds had low nutritional properties, as compared with those with small seeds. Nadeem *et al*. (2011) also reported that Desi dates have large and heavy seeds. In the current study all popular date palm cultivars had lower seed weight and good nutritional values than others. Such fruit and seed characteristics are important not only for the identification of cultivars (Eissa *et al*., 2009), but also for commercial grading, which is mostly based on the physical characters and general appearance of fruits (Sakr *et al*., 2010).

The CCA conducted to study possible effects of soil and morphological parameters of date palm on fruit nutritional properties was unsatisfactory as only 27% of the total variability was captured. A possible reason can be a too low sample size. Stevens (1986) recommended at least 20 times more samples as variables for such an analysis. Nevertheless, our data showed that soil properties can affect nutritional properties of dates, but differences in morphological and nutrition parameters of dates may certainly also be the result of variations in climate, irrigation, temperature, day length, and post-harvest handling (drying) of fruits (Nadeem *et al*., 2011). Since dates undergo several internal and external changes during their ripening process, nutritional composition is also mainly a function of timing (collection and measurement; Vandercook *et al*., 1977).

4.5 Conclusions

The date cultivars Aseel, Karoch, and Muzawati had superior nutritional properties and hence may have good potential for marketing. Across sites soil BD, CEC, $CaCO_3$, and available P affected the nutritional properties of dates, as well as fruit and seed length and weight. Further detailed studies are needed in order to better understand the effect of soil properties on nutritional contents of dates. In view of increasing opportunities for (inter-)

national marketing of dates, farmers may be well advised on growing commercial date palm cultivars which contain smaller seeds and desirable nutritional traits. This seems particularly important for groves especially in Punjab where Desi date palm cultivars produced very big seeds and had low flesh of poor nutritional properties. Rheological properties of elite cultivars of Pakistani dates merit further study to better understand the relationship between texture, structure and changes induced by processing which will help in quality control of dates.

Annex

Table 9. Means (±SD) of different morphological characteristics of 12 date palm cultivars (individual number per cultivar ≥6) grown in four provinces of Pakistan during 2012-2013.

Cultivar	Frond length (cm)	Frond width (cm)	Fruit length (cm)	Fruit width (cm)	Seed length (cm)	Seed width (cm)	Fruit weight (g)	Seed weight (g)
Aseel	370 ± 20.3	61 ± 10.8	3.7 ± 0.55	1.9 ± 0.16	2.1 ± 0.18	1.0 ± 0.25	7.4 ± 0.91	1.0 ± 0.13
Desi	300 ± 20.4	60 ± 8.1	3.2 ± 0.47	1.7 ± 0.27	2.2 ± 0.32	0.7 ± 0.11	4.8 ± 1.86	0.9 ± 0.19
Dhakki	301 ± 27.3	60 ± 10.1	7.2 ± 1.13	2.9 ± 0.28	2.4 ± 0.21	1.0 ± 0.09	9.6 ± 2.73	1.4 ± 0.41
Haleni	309 ± 21.8	47 ± 11.6	4.0 ± 0.10	2.4 ± 0.25	2.0 ± 0.10	3.0 ± 3.70	9.4 ± 0.44	2.0 ± 0.19
Karbalaen	295 ± 29.4	58 ± 10.0	3.3 ± 0.17	1.7 ± 0.17	1.9 ± 0.15	0.9 ± 0.03	5.7 ± 0.52	0.9 ± 0.03
Karoch	299 ± 38.9	61 ± 10.5	3.3 ± 0.12	1.8 ± 0.30	2.3 ± 0.11	0.8 ± 0.09	3.1 ± 0.17	0.8 ± 0.06
Koharba	301 ± 15.2	61 ± 8.6	3.1 ± 0.13	1.9 ± 0.07	1.9 ± 0.04	0.8 ± 0.04	3.6 ± 1.43	1.0 ± 0.26
Kupra	288 ± 17.7	59 ± 16.3	2.8 ± 0.14	1.4 ± 0.05	1.9 ± 0.57	0.8 ± 0.07	4.0 ± 1.03	0.8 ± 0.21
Muzawati	297 ± 22.7	58 ± 11.2	4.2 ± 0.20	1.4 ± 0.31	2.3 ± 0.10	0.9 ± 0.10	7.2 ± 1.31	1.9 ± 0.54
Pori	255 ± 42.4	58 ± 17.7	3.3 ± 0.57	1.6 ± 0.42	2.4 ± 0.71	0.7 ± 0.09	4.5 ± 2.00	1.1 ± 0.16
Rati	300 ± 35.4	70 ± 10.0	2.9 ± 1.06	1.4 ± 0.21	2.1 ± 0.64	0.8 ± 0.07	3.7 ± 2.04	1.1 ± 0.64
Sawi	305 ± 7.1	52 ± 2.8	2.8 ± 0.21	1.3 ± 0.14	1.9 ± 0.28	0.6 ± 0.07	3.4 ± 0.21	0.8 ± 0.25

Table 10. Means of assessed parameters and calculated ratios of different morphological characteristics (FL (frond length, cm), FW (frond width, cm), FR (frond length-to-frond width ratio), FRL (fruit length, cm), FRW (fruit width, cm), FRR (fruit length-to- fruit width ratio), SL (seed length, cm), SW (seed width, cm), SR (seed length-to-seed width ratio), FWT (fruit weight, g), SWT (seed weight, g), FSR (fruit weight-to-seed weight ratio)) of 27 date palm cultivars (individual number per cultivar <6) grown in four provinces of Pakistan during 2012-2013.

Cultivar	FL	FW	FR	FRL	FRW	FRR	SL	SW	SR	FWT	SWT	FSR
Ajwa	330	31	10.65	3.1	1.5	2.07	2.2	0.8	2.75	3.2	1.0	3.2
Akhrot	310	32	9.69	3.1	1.5	2.07	2.2	0.8	2.75	3.2	1.0	3.2
Amber	300	28	10.71	3.2	1.6	2.0	2.1	0.7	3.0	8.2	0.9	9.11
Angoor	340	32	10.62	3.1	1.5	2.07	2.2	0.8	2.75	3.2	1.0	3.2
Barni	330	80	4.13	2.9	1.5	1.93	1.9	0.8	2.38	3.1	0.9	3.44
Basra	318	60	5.3	3.9	2	1.95	2.2	0.7	3.14	4.4	0.8	5.5
Begum Jhangi	300	61	4.92	3.2	1.5	2.13	2.1	0.7	3.0	4.5	0.9	5.0
Berehmi	310	70	4.43	3.7	2	1.85	2.4	0.7	3.43	4.0	1.1	3.65
Chohara	325	70	4.64	3.1	1.2	2.58	2.2	0.5	4.4	1.5	0.8	1.88
Danda	300	50	6.0	3.2	1.6	2.0	2.1	0.7	3.0	6.0	1.2	5.0
Dandari	300	60	5.0	3.2	1.7	1.88	2.2	0.7	3.14	4.8	0.9	5.33
Doki	301	60	5.02	3.2	1.5	2.13	2.1	0.7	3.0	4.5	0.9	5.0
Halawi	300	65	4.62	3.5	1.5	2.33	2.2	0.6	3.67	5.5	0.8	6.88
Kalma	290	60	4.83	3.1	1.6	1.94	2.4	0.6	4.0	5.4	0.9	6.0
Ketchen	310	54	5.74	3.2	2.2	1.45	2.2	0.7	3.14	4.9	1.1	4.45
Khudrawi	280	60	4.67	3.6	1.5	2.4	1.9	0.8	2.38	7.0	1.8	3.89
Kobra	300	61	4.92	3.1	1.6	1.94	2.4	0.6	4.0	5.4	0.9	6.0
Meeri	295	57	5.18	3.2	1.6	2.0	2.2	0.7	3.14	5.3	0.6	8.83
Patal	295	57	5.18	3.2	1.6	2.0	2.2	0.7	3.14	5.3	0.6	8.83
Pathri	290	60	4.83	3.1	1.6	1.94	2.4	0.6	4.0	5.4	0.9	6.0
Sabzo	370	52	7.12	3.3	1.9	1.74	2.3	0.6	3.83	5.0	0.7	7.14
Shamran	280	60	4.7	3.1	1.6	1.94	2.3	0.6	3.83	4.5	0.9	5.0
Shershai	310	69	4.49	3.2	1.5	2.13	2.4	0.8	3.0	4.3	1.2	3.58
Sufaida	304	47	6.47	3.3	1.6	2.06	2.4	0.4	6.0	6.2	0.9	6.89
Sundri	305	60	5.08	3.2	1.7	1.88	2.4	0.6	4.0	3.0	0.7	4.29
Zaidi	225	45	5.0	3.1	1.8	1.72	2.3	0.6	3.83	5.4	1.0	5.4
Zeerin	300	68	4.41	3.2	1.5	2.13	2.4	0.8	3.0	4.3	1.2	3.58

Table 11. Means (±SD) of different morphological characteristics of 27 date palm cultivars (individual number per cultivar <6) grown in four provinces of Pakistan during 2012-2013.

Cultivar	Frond length (cm)	Frond width (cm)	Fruit length (cm)	Fruit width (cm)	Seed length (cm)	Seed width (cm)	Fruit weight (g)	Seed weight (g)
Ajwa	330 *	31 *	3.1 *	1.5 *	2.2 *	0.8 *	3.2 *	1.0 *
Akhrot	310 *	32 *	3.1 *	1.5 *	2.2 *	0.8 *	3.2 *	1.0 *
Amber	300 *	28 *	3.2 *	1.6 *	2.1 *	0.7 *	8.2 *	0.9 *
Angoor	340 *	32 *	3.1 *	1.5 *	2.2 *	0.8 *	3.2 *	1.0 *
Barni	330 *	80 *	2.9 *	1.5 *	1.9 *	0.8 *	3.1 *	0.9 *
Basra	318 ± 60.0	60 ± 14.1	3.9 ± 1.34	2.0 ± 0.07	2.2 ± 0.35	0.7 ± 0.07	4.4 ± 2.46	0.8 ± 0.16
Begum Jhangi	300 *	61 *	3.2 *	1.5 *	2.1 *	0.7 *	4.5 *	0.9 *
Berehmi	310 *	70 *	3.7 *	2.0 *	2.4 *	0.7 *	4.0 *	1.1 *
Chohara	325 ± 70.0	70 ± 8.0	3.1 ± 0.19	1.2 ± 0.09	2.2 ± 0.31	0.5 ± 0.50	1.5 ± 0.05	0.8 ± 0.05
Danda	300 ± 10.0	50 ± 9.0	3.2 ± 0.29	1.6 ± 0.09	2.1 ± 0.09	0.7 ± 0.80	6.0 ± 0.07	1.2 ± 0.06
Dandari	300 ± 21.4	6 ± 8.1	3.2 ± 0.47	1.7 ± 0.27	2.2 ± 0.32	0.7 ± 0.09	4.8 ± 1.86	0.9 ± 0.19
Doki	301 *	60 *	3.2 *	1.5 *	2.1 *	0.7 *	4.5 *	0.9 *
Halawi	300 ± 11.0	65 ± 10.0	3.5 ± 0.06	1.5 ± 0.10	2.2 ± 0.10	0.6 ± 0.04	5.5 ± 0.13	0.8 ± 0.05
Kalma	290 *	60 *	3.1 *	1.6 *	2.4 *	0.6 *	5.4 *	0.9 *
Ketchen	310 ± 18.0	54 ± 8.0	3.2 ± 0.28	2.2 ± 0.08	2.2 ± 0.00	0.7 ± 0.08	4.9 ± 1.02	1.1 ± 0.04
Khudrawi	280 ± 9.0	60 ± 3.0	3.6 ± 0.08	1.5 ± 0.05	1.9 ± 0.40	0.8 ± 0.01	7.0 ± 0.12	1.8 ± 0.06
Kobra	300 *	61 *	3.1 *	1.6 *	2.4 *	0.6 *	5.4 *	0.9 *
Meeri	295 *	57 *	3.2 *	1.6 *	2.2 *	0.7 *	5.3 *	0.6 *
Patal	295 *	57 *	3.2 *	1.6 *	2.2 *	0.7 *	5.3 *	0.6 *
Pathri	290 *	60 *	3.1 *	1.6 *	2.4 *	0.6 *	5.4 *	0.9 *
Sabzo	370 ± 10.0	52 ± 5.0	3.3 ± 0.10	1.9 ± 0.02	2.3 ± 0.08	0.6 ± 0.05	5.0 ± 0.06	0.7 ± 0.05
Shamran	280 ± 15.0	60 ± 9.0	3.1 ± 0.07	1.6 ± 0.03	2.3 ± 0.20	0.6 ± 0.09	4.5 ± 0.11	0.9 ± 0.06
Shershai	310 *	69 *	3.2 *	1.5 *	2.4 *	0.8 *	4.3 *	1.2 *
Sufaida	304 ± 24.0	47 ± 7.2	3.3 ± 0.26	1.6 ± 0.07	2.4 ± 0.19	0.4 ± 0.06	6.2 ± 0.12	0.9 ± 0.07
Sundri	305 ± 15.0	60 ± 7.4	3.2 ± 0.19	1.7 ± 0.04	2.4 ± 0.90	0.6 ± 0.04	3.0 ± 0.00	0.7 ± 0.05
Zaidi	225 ± 29.0	45 ± 9.6	3.1 ± 0.19	1.8 ± 0.08	2.3 ± 0.39	0.6 ± 0.03	5.4 ± 0.09	1.0 ± 0.08
Zeerin	300 *	68 *	3.2 *	1.5 *	2.4 *	0.8 *	4.3 *	1.2 *

*Cultivars with sample size n = 1

Table 12. Means (±SD) of different nutritional properties of 27 date palm cultivars (individual number per cultivar <6) grown in four provinces of Pakistan during 2012-2013.

Cultivar	TSS (g 100g^{-1})	Acidity (mg l^{-1})	Calcium (mg g^{-1})	Magnesium (mg g^{-1})	Firmness (g mm^{-1})
Ajwa	62 *	5.6 *	0.47 *	0.29 *	310 *
Akhrot	61 *	5.5 *	0.47 *	0.28 *	290 *
Amber	63 *	5.7 *	0.47 *	0.29 *	380 *
Angoor	61 *	5.4 *	0.47 *	0.28 *	760 *
Barni	63 *	2.9 *	0.43 *	0.36 *	330 *
Basra	60 ± 4.7	6.1 ± 0.10	0.19 ± 0.06	0.19 ± 0.01	310 ± 10
Begum Jhangi	64 *	5.7 *	0.47 *	0.29 *	90 *
Berehmi	48 *	6.2 *	0.23 *	0.14 *	290 *
Chohara	53 ± 5.7	5.8 ± 0.10	0.16 ± 0.03	0.29 ± 0.01	290 ± 120
Danda	67 ± 4.7	5.9 ± 1.09	0.32 ± 0.03	0.30 ± 0.01	480 ± 50
Dandari	65 ± 11.5	5.1 ± 0.41	0.35 ± 0.06	0.23 ± 0.03	250 ± 140
Doki	45 *	4.1 *	0.44 *	0.88 *	440 *
Halawi	68 ± 4.2	5.9 ± 0.03	0.31 ± 0.03	0.29 ± 0.01	310 ± 20
Kalma	49 *	6.2 *	0.23 *	0.14 *	540 *
Ketchen	65 ± 4.6	6.2 ± 0.29	0.29 ± 0.03	0.29 ± 0.04	440 ± 40
Khudrawi	72 ± 5.2	4.2 ± 0.01	0.43 ± 0.04	0.42 ± 0.03	410 ± 60
Kobra	53 *	5.9 *	0.33 *	0.29 *	290 *
Meeri	54 *	5.5 *	0.46 *	0.29 *	540 *
Patal	55 *	5.4 *	0.49 *	0.30 *	520 *
Pathri	53 *	5.9 *	0.33 *	0.29 *	560 *
Sabzo	64 ± 0.4	6.3 ± 0.01	0.16 ± 0.02	0.24 ± 0.01	310 ± 30
Shamran	47 ± 3.3	5.9 ± 0.04	0.31 ± 0.02	0.29 ± 0.02	330 ± 10
Shershai	57 *	5.6 *	0.46 *	0.29 *	440 *
Sufaida	52 ± 13.3	6.2 ± 0.05	0.34 ± 0.03	0.29 ± 0.03	610 ± 50
Sundri	61 ± 15.3	6.3 ± 0.31	0.34 ± 0.04	0.29 ± 0.03	590 ± 30
Zaidi	61 ± 23.4	6.2 ± 0.06	0.41 ± 0.01	0.24 ± 0.02	260 ± 60
Zeerin	55 *	5.6 *	0.46 *	0.29 *	520 *

*Cultivars with sample size n = 1

Chapter 5

General discussion, conclusions, and recommendations

5.1 General discussion

5.1.1 Date palm cultivation and marketing

Four decades ago it was proposed that date palm had a single origin around the Persian Gulf, followed by the dispersal of the cultivated date palms toward the east up to India and west up to Morocco (Munier, 1973). However, the presence of a clear genetic structure between the western and eastern pools (Zehdi-Azouzi *et al*., 2015) indicates that the Persian Gulf might not have been the only domestication center for date palm. Instead two cultivation origins of date palm are likely. North Africa could have been become a secondary domestication center after the introduction of early date palm genotypes from the Middle East and their crossing with local germplasm (Gros-Balthazard, 2012). Available data indicate that the date palm domestication started later in North Africa than in the Middle East (Chapter 2). As a species the domestication and cultivation history date palm is a good example of co-evolution with the onset of human culture, settlements and trade in hot arid environments of the Middle and Near East as well as the Mediterranean.

In Pakistan date palm cultivation plays a role in very different farming systems. In the southern Punjab where most of this study was conducted, scattered cultivation is more frequent than grove plantation (Ata, 2011), but in other areas scattered plantations, home gardens, and intercropping systems with other fruit trees (mostly in a triple-layer system) predominate (Chapter 3). Fruit trees frequently intercropped with date palm are fig, Christ's thorn, pomegranate, mango, papaya (*Carica papaya* L.), banana as well as various citrus hybrids such as lemon (*Citrus limon* (L.) Burm.f.), lime (*Citrus aurantifolia* (Christm.) Swingle), orange (*Citrus sinensis* L.), and grapevine. Crops grown as understory species in date palm groves include annuals harvested for direct human consumption (cereals, vegetables, oil plants, and pulses), fodder (cereals, legumes, clover, and grasses), and other purposes (medicinal and psychoactive plants; Tengberg, 2012). In our study date palm growers also cultivated industrial crops such as cotton (*Gossypium hirsutum* L.); however,

the majority of HHs used the understory plants for home consumption (Chapter 3).

The date palm growers' socio-economic characteristics across the six locations studied underlined how important date production is for the income of people in marginal areas of Pakistan (Chapter 3). Almost all the surveyed date palm growers used dates as an important food item for their families and in Punjab Province some also used low quality dates as a livestock feed. In addition to the fruit, practically all parts of the date palm (trunk, spadix, frond, inflorescence, and seed) can be used for agricultural and domestic purposes (Barreveld, 1993). In the study area, common date palm by-products were bread dishes, hand fans, sitting mats, and praying mats. Usage of date palm trunks as a construction material for huts and bridges was also popular (Chapter 3).

In Pakistan, farmers prefer to sell fresh dates because they bring more money as compared to dried dates and *chuhara*. Date palm growers do not have resources for drying and processing dates and proper transportation facilities for taking fruits to distant markets (Chapter 3). According to Ata (2011) date palm groves in Southern Punjab were located at a distance of 11-20 km from the nearest market and only <1% growers were able to market their dates at the farm gate. Under the current conditions most date palm farmers sold their dates to contractors, wholesalers or commission agents, mainly due to the unavailability of credit facilities, labour, time, and the large distance to the market (Chapter 3). Due to insufficient credit facilities provided by the government, date palm growers were taking loans from commission agents and were bound to sell their produce in their shops in big wholesale markets where growers were paying 7% of the total sale to commission agents (Ata, 2011). According to RUAF (2014) date palm growers in Gaza (Palestine) paid 6% of the value of their date sales to the wholesaler for allowing them to sell their produce. In fruit marketing sector of Pakistan, farmer's share in the consumer price is about one-fourth while the remaining share goes to commission agents (7%), contractors (39%), wholesalers (9%) and retailers (19%; Mahmood *et al*., 1989; Khushk and Smith, 1996).

Contractors play an important part in the marketing chain of dates in Pakistan (Chapter 3). They are known to assess with great accuracy the potential yield of a date palm grove and costs related to harvesting and marketing of dates (Khushk *et al*., 2009). Growers in the study area established contracts for the sale of dates from palm groves before the start of the harvesting season. It was also observed that value addition in dates through grading, sorting, and processing was not part of a well-established market chain (Chapter 3). A similar marketing structure of dates is has been reported for date palm growing areas of Iraq (Walsborn, 2008).

5.1.2 Nutritional properties of dates

Date palm has been closely linked with the survival of people living in hot desert climates (Ali *et al*., 2010). Dates are important in human nutrition due to their composition of carbohydrates, salts, minerals, vitamins, fatty acids, amino acids, dietary fibre, and protein (Al-Shahib and Marshall, 2003). In the current study, the Pakistani Muzawati, Haleni, Karbalaen, Karoch, and Aseel cultivars had particularly high concentrations in total soluble sugars, calcium, and magnesium (Chapter 4). During their ripening process dates undergo several morphological and nutritional changes: in particular sugar level increases, while moisture, fat, fiber, protein, tannins, ash, and pectin decrease (Vandercook *et al*., 1977; Al-Hooti *et al*., 1997). According to Ahmed *et al*. (1995), the moisture content of dates decreases with ripening from the *kimri* (green, hard and containing 80% moisture) to *tamar* (full ripe, dry flesh and contains less than 20% moisture) stage by about 60%. Most of the studied dates from different Pakistani cultivars showed nutritional properties similar to other commercial date cultivars in world (Chapter 4).

5.1.3 Role of date palm for rural development

In Pakistan date palm groves play a pivotal role for rural development by their contribution to the economic, cultural, and social well-being of poor households (Safwat, 2007). Cultivation of date palms in marginal areas can be highly remunerative and provides up to seven times

higher revenue per unit area to growers as compared with many other perennial crops (Rajmohan, 2011). Typically date palm cultivation starts to be profitable after the fourth year of cultivation which continues for about 70 years. Farmers can make additional income through the sale of palm by-products and by intercropping with other fruits and crops (Rajmohan, 2011). In our study, 24% of the HHs interviewed were getting 91-100% of their total cash income through the sale of dates and palm by-products (Chapter 3). The establishment of palm groves can offer many employment opportunities for rural and urban community members, both in the groves and in fruit processing units. Rural fruit processing, the establishment of domestic retail markets in palm cultivation areas and the development of international markets of dates demand manpower for transportation, promotion of diversified products, sales, and business development (Rajmohan, 2011). In the current study, most of the date palm groves were of small scale, where all family members were working as cheap labourers (Chapter 3).

Financial insecurity, unstable employment opportunities, gender discrimination, and food and nutritional insecurity are serious concerns of rural women in developing countries. In this context date palm cultivation provides year- round employment potential for rural women, in the sector of weeding, cleanising (separating dates from bunches), sorting, grading, and packing of dates, making many by-products (praying mats, sleeping mats, bread dishes and hand fans) from date palm fronds, and in processing of dates (Rajmohan, 2011). Processed dates are more demanded than unprocessed ones. Tunisia accounts for only 2% of world date production but its share of global exports is 21% (Rajmohan, 2011).

In the surveyed areas of Pakistan, processing and export were not part of a regular market chain, thus there was low value addition in the date value chain (Chapter 3).

5.1.4 Problems of the date palm sector in Pakistan

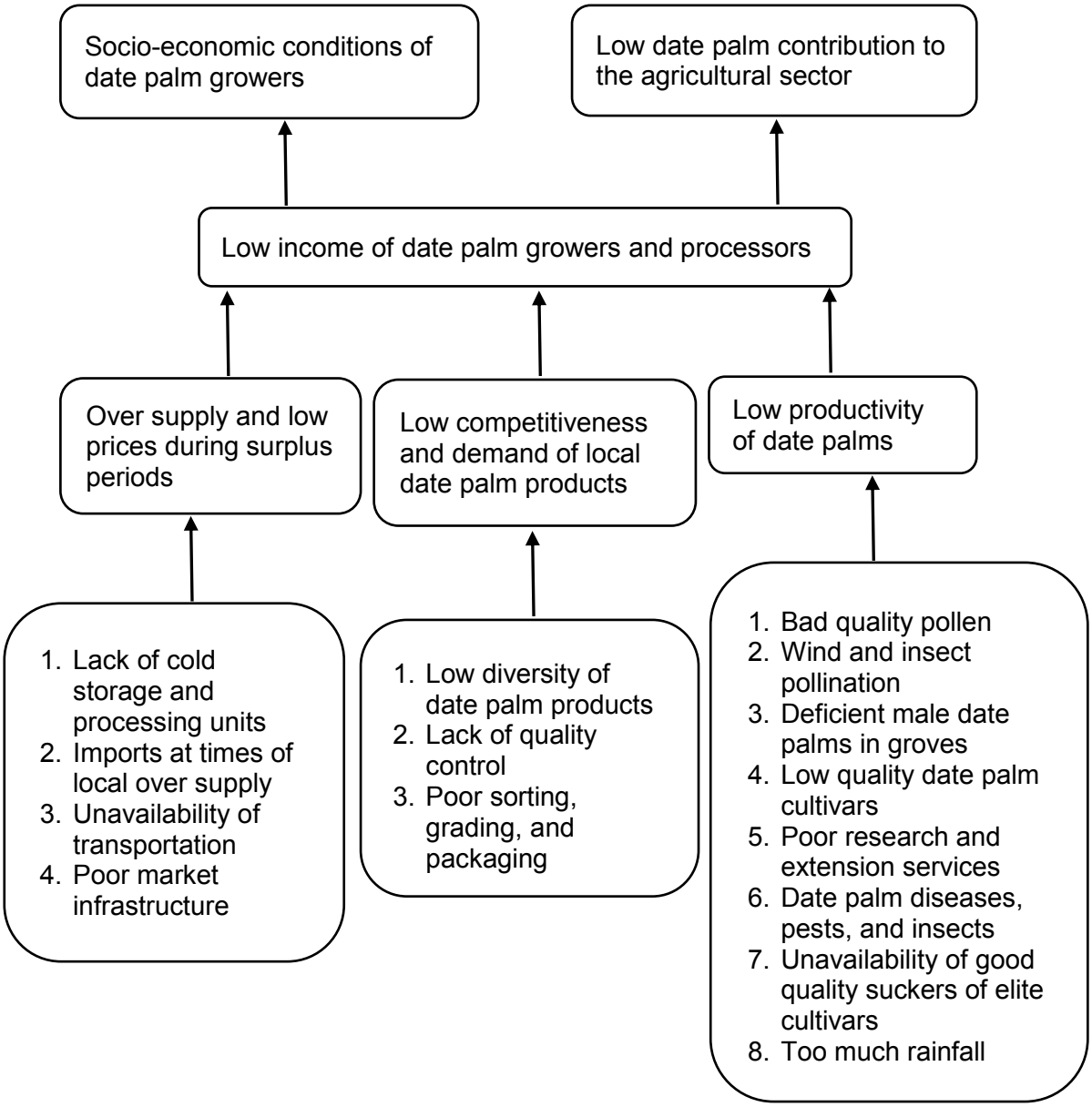

Figure 1. Schematic diagram of constraints faced by the date palm sector in Pakistan.

5.2 Conclusions

In the study area, wealthy farmers had substantially more date palm cultivars in their groves than others. The data cultivars Aseel, Karoch, and Muzawati had superior nutritional properties and hence may have good potential for marketing. Across sites soil BD, CEC, $CaCO_3$, and available P affected the nutritional properties of dates, as well as fruit and seed length and weight. Further detailed studies are needed in order to better understand the effect of soil properties on nutritional contents of dates. In view of increasing opportunities for (inter-) national marketing of dates, farmers may be well advised on growing commercial date palm cultivars which contain smaller seeds and desirable nutritional traits. This seems particularly important for groves especially in Punjab where Desi date palm cultivars produced very big seeds and had low flesh of poor nutritional properties.

Low literacy rate and age of the HH heads may hinder the adoption of farm innovations. Lack of suckers from high yielding date palm varieties was one of the major problems faced by the date palm growers interviewed. They were mostly using vegetative offshoots of the date palm varieties they already had in their groves. Most local farmers did not have access to the offshoots of elite cultivars because of absence of nurseries in the date growing areas and many were not hand-pollinating date palm because of reportedly being unaware of the advantages of pollination. Lack of technical training, credit availability, processing facilities, and marketing infrastructure are reasons for low popularity of date palm in Pakistan. In Khairpur (Sindh) and Dera Ismail Khan (KPK) farmers give sales rights to contractors due to the lack of sufficient credit and marketing facilities. At present the government of Pakistan is not effectively regulating the role of intermediaries in the marketing chain between producers and consumers and date value chains are not sufficiently exploited.

5.3 Recommendations

- The establishment of basic agricultural education facilities at the village level would help to empower marginal date palm growers and to enhance their knowledge about the role of varieties and pollination on date quality.

- Nurseries with selected germplasm at the regional level would help to enhance the quality of marketable dates and thus income generated by growers.

- There is great scope for post-harvest technologies in dates, particularly in sorting, grading, cleaning, drying and packing. A chilling chain would help to protect high value fresh dates on their way to the high end markets thereby meeting international hygienic standards.

- The increasing trend of cultivating only a few date palm cultivars whose fruits can be more easily marketed may pose a threat to date palm diversity and could result in the extinction of local germplasm. This requires policy attention and merits special marketing efforts of rare cultivars.

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Affidavit

I herewith assure that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either words-for-word or in paraphrase have been clearly identified as such. Third parties were not involved in the drafting of the materials contents, of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.

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Witzenhausen, den 17.06.2015 Ghayoor Fatima