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CAN DATE PALMS PLANTED FOR URBAN LANDSCAPING PURPOSES SERVE IN THE PRODUCTION OF EDIBLE FRUITS? AN EVALUATION OF TISSUE ELEMENT CONCENTRATIONS, FRUITS QUALITY AND HEALTH RISKS

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Khattab Omar Adam Al Nidawi

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Horticulture

Under the Supervision of Dr. Elke Neumann

June 2021

Declaration of Original Work

I, Khattab Omar Adam Al Nidawi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Can Date Palms Planted for Urban Landscaping Purposes Serve in the Production of Edible Fruits? An Evaluation of Tissue Element Concentrations, Fruits Quality and Health Risks*", hereby, solemnly declare that this is the original research work done by me under the supervision of Dr. Elke Neumann, in the College of Agriculture and Veterinary Medicine at UAEU. This work has not previously formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

More than 80.000 date palms are grown for ornamental purposes as part of public urban greenery in the city of Al Ain. The fruits that these palms produce, are often not valorized as food for humans, due to the fear that they might contain potentially hazardous pollutants, such as heavy metals. When palms are grown near roads or in urban environments, pollution might arise from the exhaust and dust produced by vehicles, industrial activities, as well as through urban waste material deposition, including irrigation with treated sewage effluent. On the other hand, many date palms grown for landscaping purposes might have a high potential to contribute to food production and security, should analyses reveal that their fruits are safe for consumption. The aim of the present study was thus to assess the overall quality of date fruits obtained from urban environments and roadside plantations in and around Al Ain. As part of this, possible heavy metal pollution of the fruits was investigated. In total, 34 date samples representing 11 date varieties were analyzed. All sampled palms were under long-term irrigation with treated sewage effluent. Element analysis of the potentially marketable dates revealed that their Fe, Zn, Cu, Mn, or Cr levels were too low to cause toxicity in humans, even at high daily consumption rates. In fact, concentrations of these trace metals, as well as other nutritional elements such as Ca, Mg, K and P in the sampled dates were in a rather low range compared with other plant-based food. This meant that the contribution of the date fruits to human supply with nutritional elements would be comparatively small at standard consumption rates. The concentrations of Pb, Co and Ni were in a safe range for human consumption, but Cd concentrations were slightly elevated across all analyzed samples. Ingestion of the sampled dates would exceed maximum permissible daily Cd intake at a rate of 50 – 70 g dry fruit pulp per day. This would correspond to 130 – 180 g fresh date fruits. Washing of the date fruits did not reduce their element concentrations. The latter were also in a similar range across all sampling locations and maturity groups.

The findings of the present study suggest that the use of date fruits produced in urban environments and along roads would be possible, given that Cd concentrations are closely monitored, and sources of Cd pollution identified. The elaboration and implementation of valorization strategies for fruits harvested from urban dates would

be facilitated by the ability of the site engineers, workers, and researchers to distinguish between the different date varieties. Experience with the date sampling pertaining to this study suggested that most workers and laboratory technicians are not able to do this. For this reason, a simple flowchart was developed as part of this thesis, based on which the most widely grown date cultivars in Abu Dhabi can be easily distinguished and classified. This decision matrix was accompanied by a reference photo repository, included into the literature review.

Keywords: Urban horticulture, date fruits, heavy metal contamination, treated sewage effluent, date fruit classification.

Title and Abstract (in Arabic)

هل يمكن استخدام ثمار التمر لأشجار النخيل المزروعة بالمدن والطرق الخارجية كمصدر غذائي؟ عن طريق تقييم العناصر الغذائية وجودة الثمار والمخاطر الصحية

الملخص

يزرع أكثر من 80,000 نخلة للزينة كجزء من المساحات الخضراء الحضرية العامة في مدينة العين وان الثمار التي تنتجها هذه الاشجار غالبا لا يتم استخدمها كمصدر غذاء للبشر وذلك بسبب الخوف من أنها قد تحتوي على ملوثات يحتمل أن تكون خطرة مثل المعادن الثقيلة. عندما تزرع اشجار النخيل بالقرب من الطرق أو في البيئات الحضرية، قد ينشأ التلوث من العادم والغبار الناتج عن المركبات والأنشطة الصناعية، وكذلك من خلال ترسب مواد النفايات الحضرية بما في ذلك الري بمياه الصرف الصحي المعالجة. من ناحية أخرى، قد يكون العديد من أشجار النخيل المزروعة لغرض استخدامها في تنسيق الحدائق ذات إمكانات عالية للمساهمة في تعزيز الامن الغذائي، إذا كشفت التحليلات أن ثمار هذه الاشجار آمنة للاستهلاك، ولذلك كان الهدف من هذه الدراسة تقييم الجودة الشاملة لثمار التمور التي تم الحصول عليها من البيئات الحضرية والمزارع المزروعة على جانب الطريق في مدينة العين والمناطق المجاورة لها. حيث تم التحقق من احتمالية تلوث الثمار بالمعادن الثقيلة حيث تم العمل على تحليل 34 عينة من التمور والتي تمثل 11 نوعا من اصناف اشجار النخيل وكانت جميع عينات اشجار النخيل التي تم أخذ العينات منها تحت الري طويل الأمد بمياه الصرف الصحي المعالجة. واظهر تحليل العناصر للتمور التي يُحتمل أن تكون قابلة للتسويق أن مستويات الحديد والزنك والنحاس والمنغنيز والكروم كانت منخفضة جدًا بحيث لا تسبب سمية لدى البشر حتى في معدلات الاستهلاك اليومي المرتفعة. في الواقع، كانت تركيزات المعادن الثقيلة بالإضافة إلى العناصر الغذائية الأخرى مثل الكالسيوم والمغنيسيوم والبوتاسيوم والفوسفور في عينات الثمار التي تم استخدمها كانت في نطاق منخفض إلى حد ما مقارنة بالأغذية النباتية الأخرى، وهذا يعني أن مساهمة ثمار التمر في إمداد الإنسان بالعناصر الغذائية ستكون صغيرة نسبيًا مقارنة بمعدلات الاستهلاك القياسية حيث كانت تركيزات الرصاص والكوبالت والنيكل في نطاق آمن للاستهلاك البشري، لكن تركيز عنصر الكادميوم كانت مرتفعة قليلاً في جميع العينات التي تم تحليلها، حيث إن تناول الثمار التي تم أخذ العينات منها تبين انها تجاوزت الحد الأقصى المسموح به لتناول الكادميوم يوميًا بمعدل 50-70 جم من لب ثمار التمر الجافة بينما كانت نسبة عنصر الكادميوم في العينة التي تم تحليلها تتراوح ما بين 130-180 جم من فواكه

التمر الطازجة، وان غسل الثمار لم يقلل من تركيز عنصر الكادميوم حيث كانت نسبته في نطاق متماثل في جميع العينات المستخدمة في هذه الدراسة. تشير نتائج الدراسة الحالية إلى أن استخدام ثمار التمر المنتجة في البيئات المدنية في الطرقات سيكون ممكنًا، على شرط ان يتم اخذ تركيز عنصر الكادميوم بعين الاعتبار ومراقبته بشكل دقيق وتحديد مصادر تلوث الكادميوم. من خلال هذه الرسالة تم وضع خطة تطويرية واستراتيجية لتصنيف التمور لتساعد المهندسين والعمال والباحثين العلميين لتصنيف انواع التمور من خلال التجربة تم اخذ عينات التمور المتعلقة بهذه الدراسة وعرضها على معظم العمال وفنيي المختبرات حيث تبين عدم قدرتهم على تصنيف التمور، ولهذا السبب تم عمل وتطوير مخطط انسيابي بسيط كجزء من هذه الرسالة ليساعد على إمكانية تمييز وتصنيف التمور بشكل سهل وسلس للأصناف الاكثر انتشار في امارة ابوظبي حيث يعتمد هذا المخطط على الصفات الخارجية للتمور وايضا على الصور الخاصة بالأصناف والتي تم وضعها في قسم الابحاث السابقة والتجارب العلمية.

الكلمات المفتاحية: البستنة الحضرية، ثمار التمر، التلوث بالمعادن الثقيلة، مياه الصرف الصحي التي تم معالجتها، تصنيف ثمار التمور.

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Dedication

To my Family Members, Omar Al Nidawi, Engineer Taha Al Jubouri

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List of Abbreviations

ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
ANOVA	Analysis of Variance
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
DW	Dry Weight
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Ni	Nickel
P	Phosphorous
Pb	Lead
Zn	Zinc

Chapter 1: Introduction and Literature Review

1.1 The Cultural and Nutritional Value of Date Fruits in the Arab World

In the Arab world the dates palms (*Phoenix dactylifera L.*) are highly valued as ‘blessed trees’ known since ancient times and essential part of cultural heritage, traditional books and poems. The cultivation of date palm for commercial date production has increased in the past 50 years across the United Arab Emirates (UAE), and the country produced 323,478 t of dates and related food products in 2019 (FAO STAT, 2021). The date palm is economically the most relevant cash crop of the UAE, with around 667,569.8 tons/year of dates sold on the world market annually (ICARDA, 2017). Dates are one of the most popular fruits consumed in the Middle East, containing considerable amounts of essential nutrients, vitamins, and minerals, required by humans for normal growth, development, and overall well-being. Date fruits are a nutritionally rich food and considered a source of carbohydrates, such as simple sugars and dietary fiber, vitamins such as ascorbic acid, thiamine, and riboflavin, and minerals such as iron, potassium, and phosphorus (Al-Shahib & Marshall, 2003). Fresh date pulp is easily digestible, providing simple sugars like fructose and dextrose. Dates are traditionally used to break fasts during the holy month of Ramadan across the Muslim world. It is said that dates have many benefits for human health, such as high potassium, iron, and sugar concentrations, which prevent anemia and protect against nervous disorders. They may also help the womb to contract during childbirth, and support secretion of hormones that stimulate lactation in breastfeeding women, because they contain glycine and threonine (Al-Kuran et al., 2011). Dates reduce the risk of heart disease and clogged arteries (Alhaider et al., 2017). They are among the foods that help treat and prevent increased blood cholesterol, as the soluble pectin in the fruits can reduce its absorption in the intestinal tract. Health benefits of date consumption might also arise from a wide variety of B-complex vitamins that these contain, along with nicotinic acid, and vitamin C (El-Sohaimy, 2010).

In recent years, research has also emphasized on studying antioxidative properties of date fruits, which might alleviate the symptoms of ageing and act anti-carcinogenic (Kchaou et al., 2014). The antioxidant concentrations in of date pulp can vary widely, depending on the cultivar type, ripening stage, growing conditions, storage periods, and quantity of sunlight received (Al-Farsi et al., 2007).

In the UAE, dates are traditionally consumed with meals and along with Arabic coffee. Dates and coffee are often offered to welcome guests in official and private settings. A high quality of the date fruits is of great relevance when these are consumed without prior processing. Dates of lower quality are often processed into date paste or syrup, used in many traditional dishes.

Dates ripen in four stages, known by their Arabic names:

- Kimri (unripe): 1 to 17 weeks after pollination. The fruits are green, hard, bitter and not yet fully grown.
- Khlal (full-size, crunchy but mostly not edible): 18 – 23 weeks after pollination. The fruits are yellow, orange, or red in color.
- Rutab (fresh fruit ready for consumption in most cultivars): weeks 24 to 27 after pollination. The fruits are mostly yellow, orange or red. As ripening progresses, the apex becomes soft and brown.

- Tamer (ripe, sun-dried) - weeks 28 and 29, hazel to dark brown, wrinkled, low respiration and cells disorganized. Most fruits are stored for consumption at this stage.

The most consumed date food groups are rutab and tamr, with rutab being more frequently consumed than tamr during the early summer season.

In the UAE, there is no major difference in average daily date consumption per capita between males and females. On average, daily consumption of dates per capita was 114.3 g, equivalent to approximately 10 date fruits (Ismail et al., 2006).

1.2 The Date Palm as a Component of Public Urban Greenery

Especially in desert environments, urban residents and tourists greatly benefit from urban greenery maintained by private and public entities. The visual perception of planted environments such as gardens or parks can have a positive psychological, cognitive, physiological and social impact on humans (Van den Berg et al., 2015). In addition, urban greenery can reduce air pollution (Przybysz et al., 2019), soil erosion (Sarma et al., 2013), and noise (Lacasta et al., 2016). Parks and gardens also provide a habitat for wildlife and can contribute to the conservation of endangered plant and animal species (Chong et al., 2014). More recently, urban greenery has also become a site through which waste materials, such as Treated Sewage Effluent (TSE), biosolids and urban composts can be recycled and valorised (Bizari & Cardoso, 2016).

Due to their high aesthetic and cultural value, date palms are very widely grown for ornamental purposes in urban environments of the Gulf Region. In public parks the plants provide diffuse shade and an attractive overstorey vegetation to bedding plants and turfgrass. Since date palms do not litter much, are evergreen and tolerate reflective heat and a range of soil conditions, they are also wiedely grown as roadside plantations

(Ahmed et al., 2022). Palm crowns break the wind and prevent sand from being deposited onto roads.

Though date palms are widely cultivated for landscaping purposes, there are no ornamental varieties, and the plants grown in urban environments have the same potential to produce edible and marketable fruits as the ones that grow on commercial farms. Farmed date palms can produce around 100 kg of fruits per year, and even palms that grow under brackish water irrigation can yield 50 kg per plant annually, or more (Al-Muaini et al., 2019). The many date palms that grow along roadsides and in and other urban landscapes in the UAE thus have a high potential to contribute to food production and security. Their fruits are, however, usually not utilized as a food, due to the fear of their contamination with heavy metals and other harmful compounds in urban environments. Fruits harvested from palms near roads are fed to farm animals or composted.

With the provision of an improved infrastructure in urban environments, urbanization is a global trend, and is expected to progress over the coming years. The urbanization has affected the physiochemical properties of the soil such as its bulk density, pH, textures, and it has also led to the deposition of harmful heavy metals in the soils. Wide range of population and settlement activities including the use and misuse of resources has increased the amount of heavy metals in the atmosphere and in the soil. These harmful elements in the urban soils in turn are ingested by the humans and can pose threat to their health and safety (Ehsan et al., 2014).

1.3 Date Fruit Classification and Quality Parameters

More than 400 varieties of dates have been described all over the world. The cultivation of many of these varieties is restricted to certain geographic locations, where the fruits are an essential part of the local food culture. Date varieties differ mainly in the properties of their fruits, and taxonomic distinction of the varities is based on the observation of fruit traits rather than other physioloigcal or morphological features. Date fruits of different varieties differ in their shape, color, size and the time they take from pollination to harvest. The variety also determines the taste, culinary use and market value. Before dates can be processed and/or offered on the market, accurate classification of the varieties needs to be performed. Most consumers can not visually differentiate between all available date varieties, but wish to purchase batches of homogeneous and known sensory properties (Ismail et al., 2006).

In date processing factories, the fruit classification and sorting process is often done by hand, deploying workers who have been trained intensively to visually distinguish between a number of date varieties with adequate accuracy. Recently, artificial intelligence and machine learning systems have been developed and tested to take over this task (Nasiri et al., 2019), but such technologies are still in the development and testing stage (Kamal-Eldin & Ghnimi, 2018). Developed a classification system based on phenotypic, sensory as well as chemical fruit properties. The authors pointed out that accurate classification could help diabetic consumers to choose date fruits for consumption that have a low sucrose content and thus better suit their dietary requirements.

Apart from the culinary and dietary relevance, classification of date varieties might also be relevant for the scheduling of plant cultivation measures, such as fertilizer application, pollination, pruning and possibly sampling for fruit analysis. While workers on commercial date farms usually know which varieties are grown in which place, date classification in urban landscapes can be a far greater challenge.

Ornamental palms-stands may comprise of random mixtures of different varieties, while palm plantations on farms are more uniform. When landscape workers were asked to sample the date fruits for the present study, they were usually found unable to provide the name of the date variety they had sample or perform a fruit classification. The classification of the date fruits into different varieties was done later, based on literature research and the personal professional experience of the investigator. At the same time, the idea arose to use the collected information to provide horticultural workers with a simple flowchart that would allow them to distinguish fruits of the date varieties most widely cultivated in urban landscapes and roadside plantations of Abu Dhabi. Information on relevant distinctive fruit features obtained from the literature is provided in the following chapter, along with reference photographs of date fruits taken by the investigator. The developed flowchart is presented in the Results section.

1.4 Visual and Morphological Traits of The Fruits of Date Palm Varieties Most Widely Cultivated for Landscaping Purposes in the UAE

1.4.1 Negal

The variety Negal is cultivated in all parts of the UAE and considered one of the most widespread commercial varieties in urban landscaping. It flowers exceedingly early in the year, and fruits ripen early as well. Negal has yellow to orange fruits at khalal and rutab stage, and the shape of the fruits is long, oval, with a slight convexity. The inner side of the fruits has a light-yellow color (Figure 1). At tamr stage, the surface of the fruit and the color of the seed are light brown. The seed has a split that is narrow in the middle, and wider towards the ends. Near the apex, the seed has an irregular shape, and ratio of pulp to seed is slightly higher for Negal than for other varieties.

Figure 1: Photograph of Negal dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.2 Khanaizi

Similar with Negal, Khanaizi is an early flowering and fruiting variety that is widely grown for landscaping purposes in all parts of the UAE. At rutab stage, the fruits have a dark pink color. The fruit shape is an inverted oval with a bulge at the top (Figure 2). At tamr stage the fruits and seeds are brown. The seeds have a split notch that his shallow in the middle, and slighly wider and deeper towards the ends. The ratio of the fruit pulp to the seed weight is relatively high in this cultivar. The color of the micropyle is yellow and reddish towards the outer side.

Figure 2: Photograph of Khanaizi dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.3 Baql

Another early flowering and fruiting cultivar is Baql, which is cultivated in all parts of the UAE, and known for its relatively high salinity and heat tolerance. The color of the fruit is yellow at rutab stage, its shape is oval, elongated, thin or convex (Figure 3). The micropyle is yellow and lower than the level of the surface of the seed. The split is generally slanted, the seed is brown and the pod is in the center of the seed. The ventral part of the seed is of medium depth, and the average weight of the fruit is relatively small. The seed is relatively small compared with the pulp.

Figure 3: Photograph of Baql dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.4 Barhi

Barhi is cultivated in all regions of the UAE, except for coastal areas with high humidity. It flowers neither early nor late, and the fruits ripen in the mid season. The color of the Barhi fruits is light yellow, their shape is oval (Figure 4), the color of the micropyle position is orange, and the split cleft is of medium depth, open and wide on one side and narrow on the other side, and the ratio of the weight of the flesh part to the seed is medium. The fruit color a tamr stage is light brown.

Figure 4: Photograph of Barhi dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.5 Bu-Maan

This variety is grown in all parts of the UAE, but is particularly common in Al Ain, Umm Ghafa, Al Khazna, and Sweihan. It is considered a commercial variety that flowers in the mid-season. The color of the fruit is yellow at rutab stage, its shape is a short oval (Figure 5), the color of the micropyle position is yellow, large, and at the level of the surface of the fruit. The split is narrow in the middle and wide from the sides and the average weight of the fleshy part is very high compared with the seed.

Figure 5: Photograph of Bu-Maan dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.6 Saggee

This cultivar is common in the Emirate of Abu Dhabi, especially Al Ain, but is not widely grown in other parts of the UAE. Its flowering time is the mid-season. The color of the fruit is light yellow at rutab stage, and its shape is oval, conical, elongated (Figure 6). The color of the micropyle position of the fruit is yellow and lower than the level of the surface of the fruit, the split is medium in width and the weight of the fleshy part is high compared with that of the seed.

Figure 6: Photograph of Saggee dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.7 Farad

Farad is grown in all parts of the UAE, especially in the Emirate of Abu Dhabi and around Al Ain. Flowering and fruiting of the Farad variety occurs in the mid-season. The color of the fruit is bright red at rutab stage, its shape is elliptical (Figure 7), and the seed micropyle position is protruding from the surface of the fruit. The split is narrow in the midde, and the weight of the fleshy part in relation with that of the seed is in a medium range.

Figure 7: Photograph of Farad dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.8 Hilale

This variety is grown in all Emirates of the UAE. The flowering and ripening timee of this variety is the late season. The fruits are yellow at rutab stage, and their shape is an elongated, inverted oval (Figure 8). The color of the micropyle position is yellow-orange, and the weight of the fleshy part to the seed is very large.

Figure 8: Photograph of Hilale dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.9 Khasab

This variety is grown spread in all parts of the UAE. It flowers late in the season, and fruits ripen late as well. The fruits are bright red at rutab stage (Figure 9), the shape of the fruit is oval, and the micropyle position is yellow in color. The seed split cleft is shallow, and the fleshy part to the fruit is heavy compared with the weight of the seed.

Figure 9: Photograph of Khasab dates at rutab (top), and tamr (bottom) stage. The ruler shows a 1 cm scaling. The image was taken from http://basrahcity.net/pather/report/ammh/71.html#a23

1.4.10 Jabri

Jabri is grown in all parts of the UAE. The flowering date of this variety is the late-season. The color of the fruit is yellow at rutab stage, and its shape is an oval with the broader end facing downwards. The seeds are relatively large compared with the fruit flesh as shown in Figure 10.

Figure 10: Photograph of Jabri dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.4.11 Jash Ramli

Jash Ramli is a rather rare variety found in some farms and urban plantaitons in the Emirate of Abu Dhabi, especially around Al Ain, and in the Emirate of Ras Al Khaimah. The flowering time of this date is the late –season. The color of the fruit is light yellow at rutab stage, its shape is oval-conical. The fruits are of medium size, and the average weight of the flesh in relation with that of the seed is intermediate (Figure 11).

Figure 11: Photograph of Jash Ramli dates at tamr stage as a whole (left), cut into half (right), and seeds of this cultivar (middle). The background shows a 1 mm grid

1.5 Contamination and Health Risks Pertaining to the Cultivation of Date Fruits in Urban Environments or Near Busy Roads

Though dates are nutritious and generally considered a healthy alternative to industrial sweets, they can sometimes contain compounds that are harmful to human health, such as heavy metals, polycyclic aromatic hyrdocarbons, or other organic contaminants. Sources of such contamination can be polluted soils, irrigation water and air, as well as inappropriate post-harvest handling.

Risks of contamination may be particularly high when date palms are grown in urban environments where exhaust fumes from cars and industries can cause air pollution (Abass et al., 2015). In urban environments the use of treated sewage water for date palm irrigation is relatively common, especially in hyper-arid regions where irrigation water of high quality is scarce. Depending on the level of treatment, reclaimed water can be a source of soil contamination, similar with some solid urban waste materials that are sometimes applied to soils (D'itri, 1977). Heavy metals and metalloids in urban air, water and soil derive from industrial activities as well as road traffic. Vehicular combustion of gasoline and diesel emits a wide range of such elements, including lead (Pb), copper (Cu), zinc (Zn), nickel (Ni), iron (Fe), arsenic (As), cadmium (Cd), mercury (Hg), selenium (Se) and titanium (Ti) (Pulles et al., 2012). In addition, heavy metals are contained in tyre and brake dust that vehicles release (Adachi & Tainoshob, 2004). Heavy metals released into the atmosphere as part of dust may deposit on leaves of plants, and possibly also date fruits when these are grown near roads. The dust on leaves of date palms and other plants has been proposed as an indicator of the level of air pollution with heavy metals (Al-Khashman, 2007).

Dust containing heavy metals and possibly organic contaminants might also be produced when treated sewage water is used for sprinkler irrigation. Under warm, arid climatic conditions of the Gulf Region, the water droplets sprayed into the air partially evaporate, leaving small dust particles loaded with contaminants behind (Khalid et al., 2018).

Contamination in form of dust may be removed from the surface of leaves and fruits by washing these, but the removal may not always be complete, as metal cations can also be adsorbed to the cation exchange sites of the plant cell wall (Fritz, 2007).

The extent by which washing would alleviate heavy metal prevalence in or on date fruits has so far not been investigated. Amir et al. (2019) showed that washing could reduce heavy metal contamination in wastewater-irrigated spinach by between 6 and 54%, depending on the identity of the metal. Addition of citric acid to the washing water could increase the removal of heavy metals from the leaves. In fruit vegetables, heavy metal removal was increased with increasing frequency and intensity of washing

(Singh et al., 2004). Since ripe date fruits are relatively soft, intensive washing might not be possible without significantly compromising the fruit quality.

When heavy metals are brought into the soil, they can be taken up by plants and cause toxicity when tissue concentrations exceed tolerated limits. Heavy metals interfere with enzymatic processes, causing oxidative stress and cellular dysfunction (Puschenreiter, 2009) A decreased uptake of nutritional elements is also often observed in plants suffering from elevated levels of heavy metals (Yang et al., 2010).

The first symptom of heavy metal stress in plants is a decline in growth and yield, followed by chloroses and necroses of photosynthetic tissues (Das et al., 1997). However, heavy metals are not always harmful. At lower tissue concentrations, cobalt (Co), Cu, Fe, Mn, molybdenum (Mo), nickel (Ni) and Zn are essential nutritional elements for plants, animals and humans. Toxicity occurs only at concentrations exceeding the optimal range for a given genotype and developmental stage (Markert, 1993).

Heavy metals can accumulate in the food chain, with increasing trophic level. For this reason, threshold values for their concentrations in harvest products are often below those causing toxicity symptoms in plants. Some heavy metals are more toxic to humans and animals than others. Of particular concern are the heavy metals Cd, Co, Pb and Hg, due to their relatively high bioavailability (especially Cd) and toxicity in humans. These elements may not only hamper cell functioning, but are also carcinogens (Jaishankar et al., 2014).

Heavy metal concentrations in farmed date fruits are usually within safe limits, but the results of some previous studies suggest that dates harvested from urban or peri-urban areas should be closely monitored to make sure that metal intake levels do not exceed harmless levels. Sampled and analyzed date fruits from various urban areas in Saudi Arabia, and found that levels of Cd, As and Pb were elevated in some samples, imposing a potential health hazard at ingestion levels of 100 g fresh dates per day. In another study from Saudi Arabia, Aldjain et al. (2011) found that dust deposited on date fruits that had grown in various locations across the city of Riyadh, contained significant amounts of Cd and Pb, especially when fruits derived from areas exposed to heavy traffic. Though all samples remained within safe limits recommended by the World Health Organization (World Health Organization. Regional Office for Europe, 2000), the authors conclude that date fruits should be washed prior to consumption, in order to reduce heavy metal contamination.

Similar studies for date fruits harvested from urban areas of the UAE have not been conducted so far. Knowledge about possible contamination risks might help to decide about whether or not the fruits harvested from palms in urban areas could be valorized for food production, or not. Date fruits from roadside plantations that are not considered sufficiently safe for human consumption, are sometimes used to feed camels or goats. Especially Cd and Pb and can accumulate in animal tissues over time, which might cause toxicity symptoms in farm animals (Shen et al., 2019). Ultimately the toxic load might also return to the food supply chain via the animal products. Zinc, Cu, Mn, Co, and Fe are essential nutritional elements for plants. Since they are required in relatively small quantities, they are termed micronutrients. Zinc is required for the formation of chlorophyll, protein biosynthesis and the carbohydrate metabolism (Marschner, 2011). Copper and Iron play major roles in the photosynthetic and respiratory electron transport chains, cell wall biosynthesis and chloroplast functioning. Manganese is essential for the oxygen-evolving complex of the photosynthetic apparatus and supports protein functioning. Due to the high relevance of these nutritional elements for photosynthesis, deficiency of Zn, Cu, Mn and Fe causes chlorosis and poor growth (Kirkby, 1993) Micronutrients can be taken up by roots as well as shoot tissues. Uptake, however, requires that the elements be present in ionic form in a liquid medium around the cells. Toxicity of Zn, Cu, Mn, and Fe is not commonly observed in plants of the UAE, as the plant availability of these elements is rather low on the alkaline arenosols that dominate the Gulf Region. Plants suffering from heavy metal toxicity show a stunted growth, and older leaves often develop necrotic spots towards their tips and rims (Kirkby, 1993). Due to cation competition, excessive availability of one metal can induce deficiency of other, less available ones. For example, excessive Mn levels can induce Fe deficiency (Rengel, 2015). In humans, excessive ingestion of Zn can induce Cu deficiency. The recommended amount of daily Zn intake is 15 mg per day for adults, and to avoid a reduction in Cu uptake, daily Zn intake should not exceed 50 mg per day (World Health Organization. Regional Office for Europe, 2000). However, compared with other heavy metals, Zn is rather non-toxic, and symptoms of excessive Zn intake (up to 2000 mg per day), such as abdominal pain and anemia, are fully reversible. Worldwide, Zn deficiency is far more common than an excessive intake of Zn. Particularly in arid areas, Zn supply of crops as well as humans may be rather too low than too high (Sharma et al., 2013).

Similar with Zn, the toxicity of Cu is not as high as for some other heavy metals. The recommended daily intake rate for Cu is 0.9 mg per day for an adult person. A daily intake exceeding 10 mg per day can cause toxicity in form of abdominal pain, nausea, and vomiting (Ware, 2017). The adequate daily Mn intake for adults lies between 1.8 and 2.6 mg, depending on the gender and age (Trumbo et al., 2001). Excessive Mn intake is suspected to be neurotoxic and may impair brain development and learning at daily ingestion levels exceeding 11 mg for adults.

Adequate daily Fe intake for adults is in a range of 8 – 11 mg per day for men, and 8 – 27 mg per day for women (NIH, 2021a). Excessive Fe intake can cause nausea and abdominal bleeding at the short term. Intake rates exceeding 50 mg per kg of body weight can cause organ failures and death. Long-term intake exceeding 40 mg per day can cause liver cirrhosis and impaired pancreatic function.

Cobalt is a component of vitamin B12, and in this function essential to living organisms. It is assumed that coin the human body derives mainly from ingestion of Vitamin B12. The bioavailability of other Co sources is not yet completely understood, and thus no values for optimal and maximum oral daily intake values exist. Average daily oral intake rates seem to be 8 – 40 µg per day for adults (Kim et al., 2006). Excessive Co accumulates in the liver and kidney. Chromium functions in the human body are not yet completely understood, but the element may support the action of insulin, and play a role in the carbohydrate, lipid, and protein metabolism. Deficiency symptoms related to insufficient Cr supply have not yet been described, and for this reason the classification of Cr as an essential nutritional element for humans is a matter of debate. The recommended daily intake lies in the range of 25 – 45 µg for adults (NIH, 2021b). Though Cr toxicity is a matter of debate, maximum daily intake rates of 1 mg have been proposed for adults.

Different from Zn, Mn, Cu, Fe, Cr and Co, there are no known physiological functions of Ni, Pb and Cd in humans or higher animals. For this reason, no recommendations concerning optimal ingestion rates can be made. Exposure to Ni is of concern, as it may cause hypersensitivity and allergic reactions in humans exposed to it. Persons allergic to Ni can respond to Ni ingestions with dermatitis. In most parts of the world, the daily Ni intake is in the range of 200 – 400 µg per day for adults. Maximum recommended intake for adults is 1 mg per day (Ruppert et al., 1996).

Cadmium is one of the most toxic heavy metals released into the environment. It accumulates in kidneys when ingested and is known for its carcinogenic effect. It is also involved in lung damage and skeletal changes in exposed populations. Iron deficiency increases cadmium absorption. Daily ingestion of Cd should remain below 70 µg in adults. Since cereals, oilseeds and pulses have higher Cd concentrations than other food items, Cd uptake with a vegetarian diet can reach 56 µg per g. Recent research suggests that Pb is of greater toxicity to humans than previously thought. Especially in young children, Pb is neurotoxic, causing brain damage and impaired learning. In humans of all age, Pb accumulates in the liver and kidney, causing cancer and dysfunction. In many countries, maximum permissible intake levels for lead have been recently lowered. They are in the range of 90 µg per day for children, and 250 – 800 µg per day for adults (Wani et al., 2015).

1.6 The Aims of the Study

The aim of this study was to assess the overall quality and element concentrations of date fruits harvested from urban and rural roadside plantations, as well as urban parks. The sampled fruits represented eleven date varieties across all three ripening stages. All fruits were harvested in the tamr stage. The sampled date palms were all under long-term irrigation with treated sewage effluent. It was hypothesized that fruits of dates grown in public urban parks would be suitable for human consumption, whereas those grown near roads were expected to show elevated concentrations of heavy metals. Another aim of the current study was to find out whether date varieties of different ripening groups would differ in their contamination with heavy metals, and whether washing of the fruits might reduce heavy metal contamination in date fruits that had grown in urban environments and /or near roads. As the sampling of the date fruits for the purpose of this study was done, it was observed that the urban greenery workers were not well able to distinguish between the most grown date varieties in urban areas of Al Ain. For this reason, the development of a simple flowchart allowing for an easy visual distinction between fruits of the most grown date varieties in Al Ain was developed, based on literature information and personal experience.

Chapter 2: Material and Methods

2.1 Sampled Date Varieties

For the purpose of this study, fruits of eleven different varieties of date palm were sampled from 34 different locations within and around the city of Al Ain. The varieties from which samples were obtained are shown in Table 1. The sampled varieties belonged to either the early, intermediate, or late maturity group (also see Section 1.4). Between 0.3 and 1.9 kg of fresh fruits were sampled from each palm. The fruits were all in the tamr stage at the time of sampling. The fruit samples were brought to the laboratories of the UAEU Department of Integrative Agriculture, where they were assorted and classified.

Table 1: List of sampled date varieties and classification of their maturity groups

Early ripening	intermediate	Late-ripening
Negal (NG)	Barhi (BH)	Hilale (HE)
Khanaizi (KZ)	Bu-Maan (BM)	Khasab (KS)
Baql (BQ)	Saggee (SG)	Jabri (JB)
	Farad (FD)	Jash ramli (JR)

2.2 Sampling Locations

The 34 different date sampling locations were grouped into three categories. Dates that grew along a public road within the city of Al Ain were categorized as ‘Urban Roadside’ plantations. Palms growing within the city but as components of a public park or garden represented the ‘Urban Park’ category, and those that grew along roads outside of the city were categorized as 'Rural Roadside.' All roads along which dates were sampled represented main and heavily frequented traffic connections with at least four lanes. The dates were sampled in Summer 2020. The sampling locations are illustrated in Figure 12. Each sample was taken from one palm.

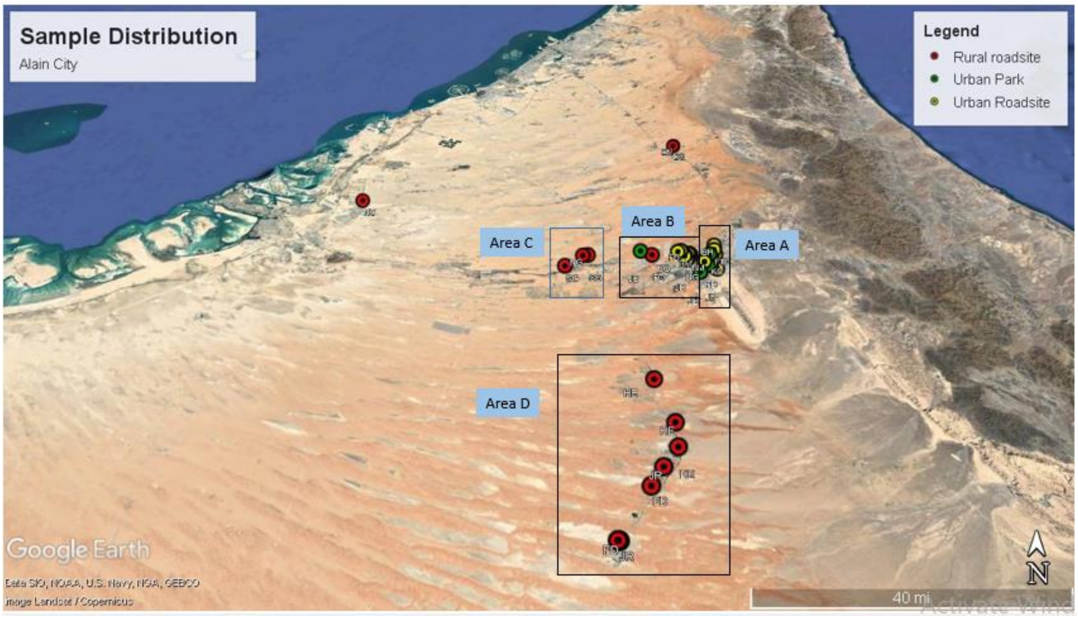


Figure 12: Overview over the date sampling locations

The red dots represent sampling locations classified as 'rural roadsides', while yellow dots stand for 'urban roadsides'. Locations of sampled date palms in urban parks or gardens are represented by a green dot. Close-ups of the different areas from which samples were obtained, are shown in Figures 13-16.

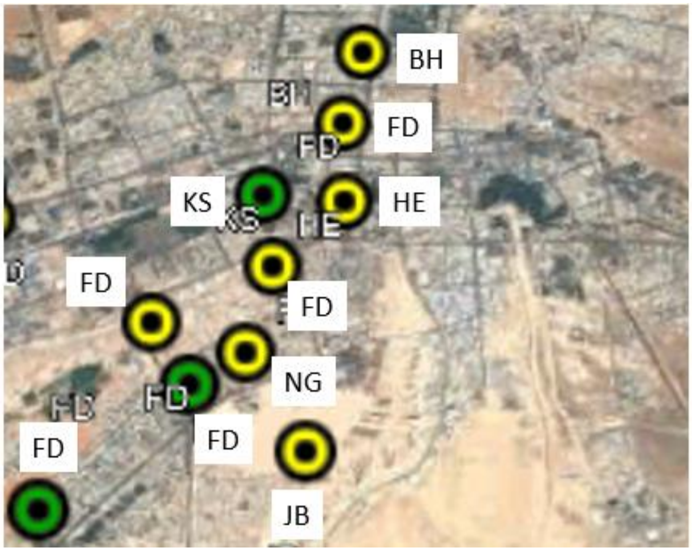


Figure 13: Close-up of area A shown in Figure 12. The abbreviations stand for the different date varieties that were sampled, as indicated in Table 1

Figure 14: Close-up of area B Shown in Figure 12. The abbreviations stand for the different date varieties that were sampled, as indicated in Table 1

Figure 15: Close-up of area C Shown in Figure 12. The abbreviations stand for the different date varieties that were sampled, as indicated in Table 1

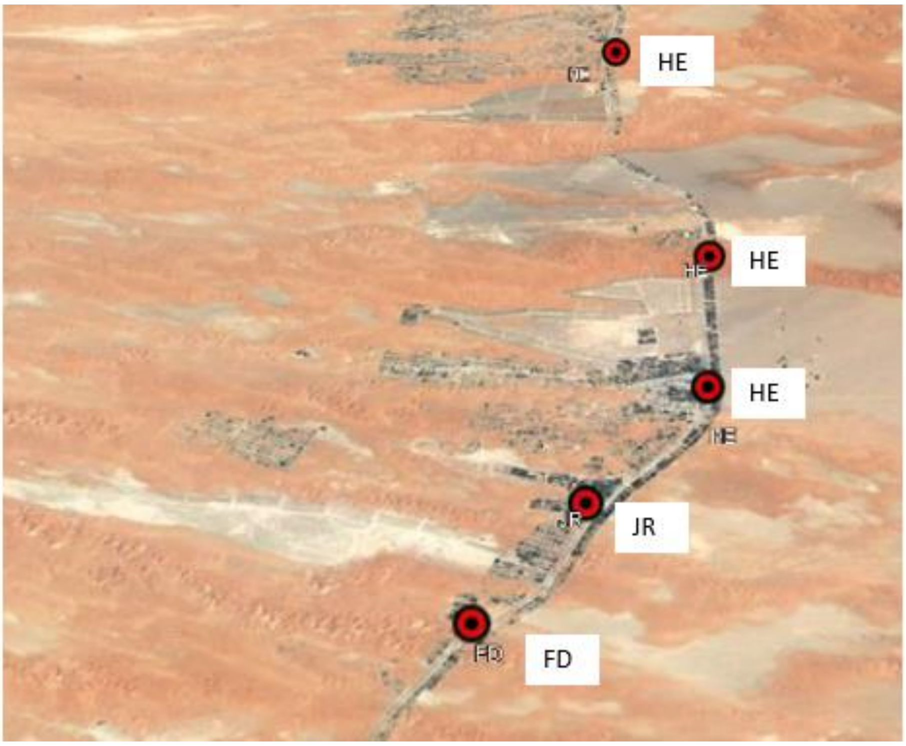


Figure 16: Close-up of area D Shown in Figure 12. The abbreviations stand for the different date varieties that were sampled, as indicated in Table 1

2.3 Date Fruit Classification, Photograph Repository, and Development of a Classification Scheme

The date fruit samples were classified into date varieties based on literature information and personal professional experience of the investigator (also see Section 1.4). as a reference, date fruits of known varieties were purchased from the Al-Zad date's factory in Al-Ain city. These date fruits were visually compared with the sampled ones. To establish Al Ain image repository for date fruit classification, representative date fruits of known variety were photographed on paper with a 1 mm grid. The fruits were photographed as a whole or cut into two halves with the seed taken out. A Nikon D5300 camera with a 70-300 mm lens was used for taking the photos. The camera was placed on a 90-degree tripod and set up on an F22 aperture. The shutter speed was 1 second at ISO 100. The images were sharpened using the Photoshop program. They are shown in Section 1.4 of this thesis.

2.4 Storage and Physical Characteristics of Sampled Date Fruits

The date samples were stored in plastic bags in a deep freezer at -20ºC until they were further processed. After thawing, they were sorted into two categories, potentially marketable/edible and non-marketable/non-edible fruits. The non-edible fruits represented wasted fruits that had changed their color (usually much darker) and firmness (much softer) compared with the standard fruits. It was assumed that the grand majority of non-marketable fruits were wasted, possibly due to microbial decay. The marketable and non-marketable fruit portions were weighed, and the number of fruits in each portion was counted. The average fruit weights were then calculated by dividing the portion weight by the corresponding number of fruits. Four randomly chosen fruits of the marketable portion were then washed with deionized water for approximately half a minute, while another subsample of four fruits remained unwashed. The fruits of the washed and unwashed subsamples were cut open, and the date pit was removed. The samples were weighed to estimate the fresh weight of the fruit pulp, and then they were placed into a drying oven at 65ºC for two weeks. The fruit and pit samples were then weighed again to estimate their dry weight. It needs to be noted here that the fruit pulp samples did apparently not completely dry, and remained to some extent flexible, suggesting that some water had remained in the fruits, even after two weeks in the oven. The dried fruit pulp was ground into a paste using a ceramic pestle and mortar.

2.5 Element Analysis of Date Pulp

Subsamples of approximately 0.3 g of the ground, dry fruit pulp weighed into a Teflon tube and microwave digested in presence of 10 ml nitric acid (HNO3 69%) and 2 ml hydrochloric acid (HCl 37%), for 35 minutes at 200ºC. After cooling, the digested solution was brought to a volume of to 50 ml with doubled distilled water. Concentrations of P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Co, Cd, Ni, Pb and Cr in the liquid samples were then measured using Iinductively Coupled Plasma Mass Spectroscopy (ICPMS).

2.6 Statistical Analyses

The results were presented as mean values and standard deviations. Data were tested using statistical analysis in IBM SPSS statistics 26 software. Means were compared using One Way ANOVAs at significance level of $P<0.05$. Differences between means of the treatments were compared by the Turkey's Multiple Comparison. A Two-Way ANOVA was performed on element concentrations obtained for date fruits sampled from the rural roadsides to test whether the maturity group or the washing of the fruits had a significant ($P<0.05$) effect on the obtained results. Element concentrations obtained for all washed or unwashed fruits of the experiment were also analyzed using

Two Way ANOVAS, to test whether the maturity group or the sampling location had a significant ($P<0.05$) effect on the results.

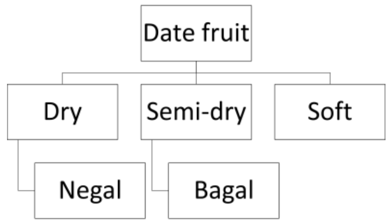
Chapter 3: Results

3.1 A Classification Flowchart for Date Varieties Commonly Grown for Urban Landscaping Purposes in Abu Dhabi

Based on the literature review, photographs and years of personal work experience, a flowchart allowing for the classification of date fruits among the eleven cultivars described in Section 1.4 was developed (Figure 17).

This flowchart requires first that fruits are classified as either dry, semi-dry or soft at the tamr stage (Figure 17a). Dry fruits are characterized by a very firm fruit pulp, while soft fruits have a moist and sticky pulp. Semi-dry fruits are inbetween. Among the date varieties commonly grown in urban landscapes, only Negal classifies as dry, and Baqal classifies as semi-dry. All other fruits are soft and require to be classified next according to their size class, shape and fruit color. The color refers to the rutab stage, not the tamr stage. Fruits that classify as soft need to be further classified according to Figure 17b.

a



b

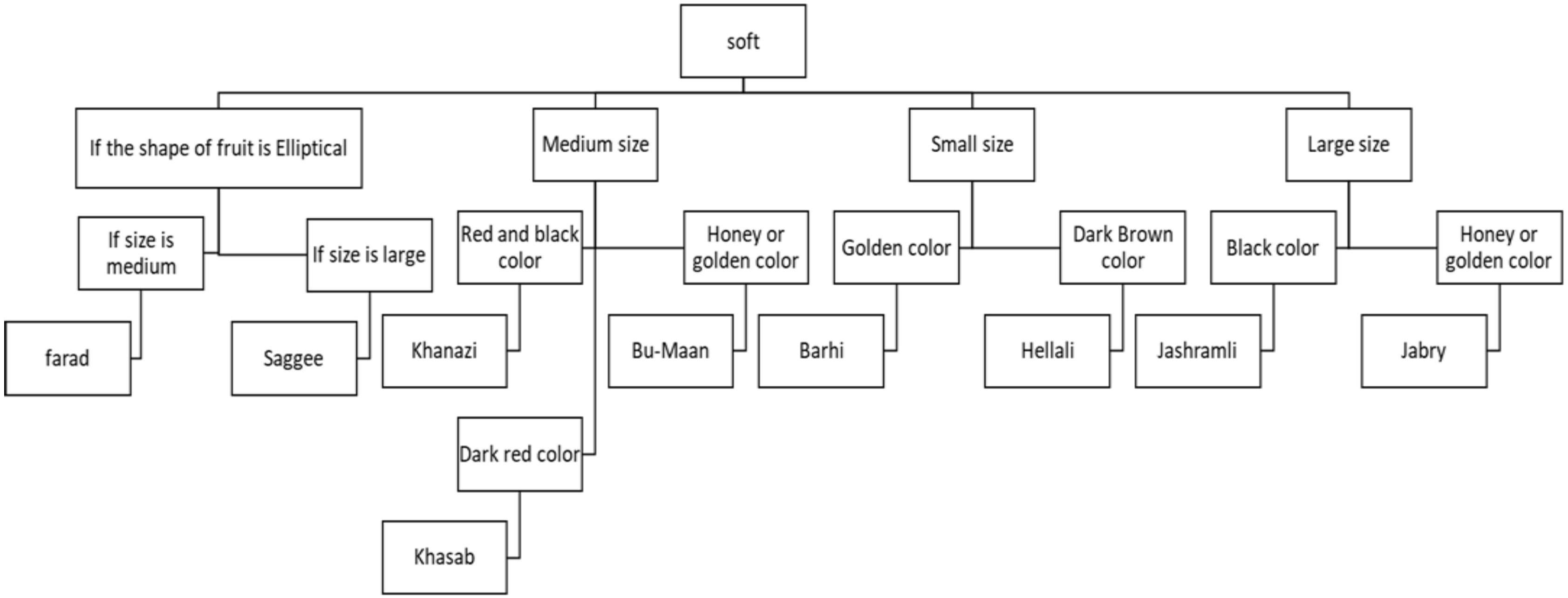


Figure 17: Classification scheme for date fruits belonging to varieties commonly grown for landscaping purposes in urban environments and along roads (a), (b) classification scheme for soft date fruits belonging to varieties commonly grown for landscaping purposes in urban environments and along roads

3.2 Physical Properties of Date Fruits Harvested from Roadside Plantations and Public Urban Parks

The average fresh weight of marketable date fruits was between 5 and 18 g (Figure 18). For some cultivars, such as Farad, Bu-Maan, Hilale and Jabri, the fruit fresh weight did not differ much depending on where the fruits had been sampled. In Negal, Baql and Jash Ramli the fruit weights differed considerably between the different sampling locations.

Across all cultivars and sampling locations, a portion of between 20 and 85% of total fruit weight was classified as non-marketable (Figure 19). On an average, the individual non-marketable fruits were slightly lighter compared with the marketable ones (Figure 20), but there was no difference in marketable/non-marketable fruit weight ratio depending on the sampling location or the maturity group. Most non-marketable dates were too soft, dark and of unpleasant smell.

The date pit accounted for 3 to 18% of the fresh fruit weight (Figure 21, bottom). Except for the varieties Baql and Jash Ramli, the weight of the date pit in percent of the total fruit weight remained in a similar range for each variety, irrespective of the sampling location. Averaged across the different date varieties, the date pits accounted for approximately 10% of the fresh fruit weight, irrespective of the sampling location and maturity group (Figure 21, top).

Drying of the date pulp reduced its weight by 60 – 70% (Figure 22), suggesting that the water content of the fresh fruit pulp was in this range. However, the date pulp remained slightly elastic and sticky even after two weeks of drying, suggesting that the fruits had not dried entirely, but retained some residual moisture. Washing of the fruits had no impact on the percentage of weight lost from the fruit pulp during the drying.

The dates were either sampled from palms that grew along main roads outside of the city of Al Ain (‘rural roadside’), along roads within the city (‘urban roadside’), or in public parks within the city (‘urban park’). process. There was also no difference in removable moisture percentage between the different maturity groups or sampling locations.

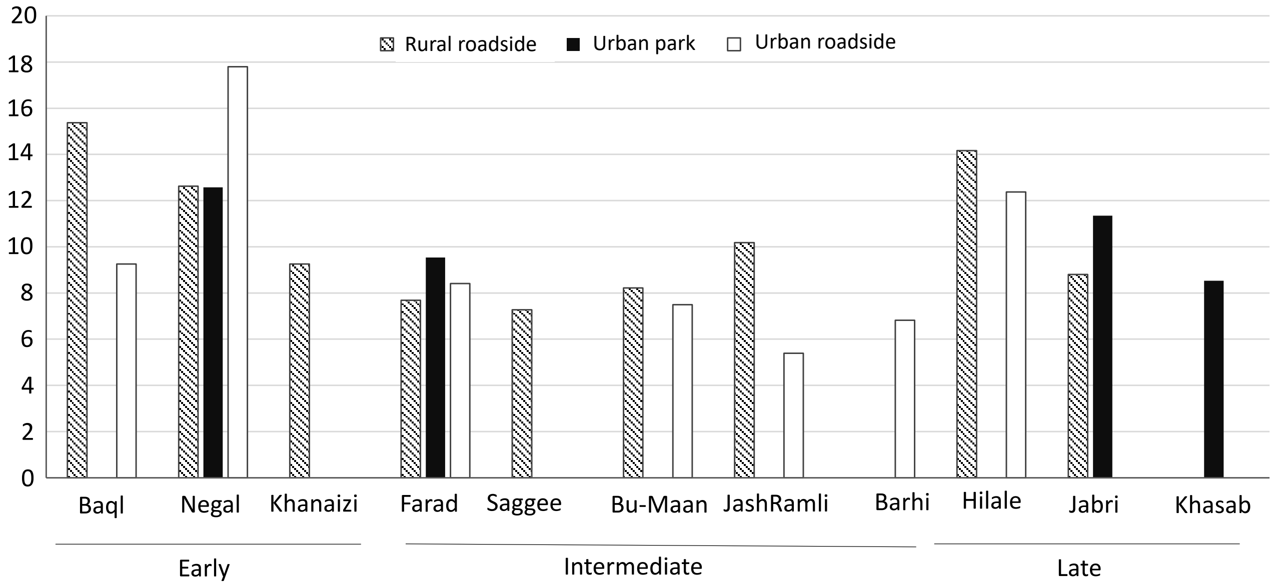


Figure 18: Average fresh weight of individual date fruits obtained from different cultivars and for different sampling locations in g per fruit (including the pit)

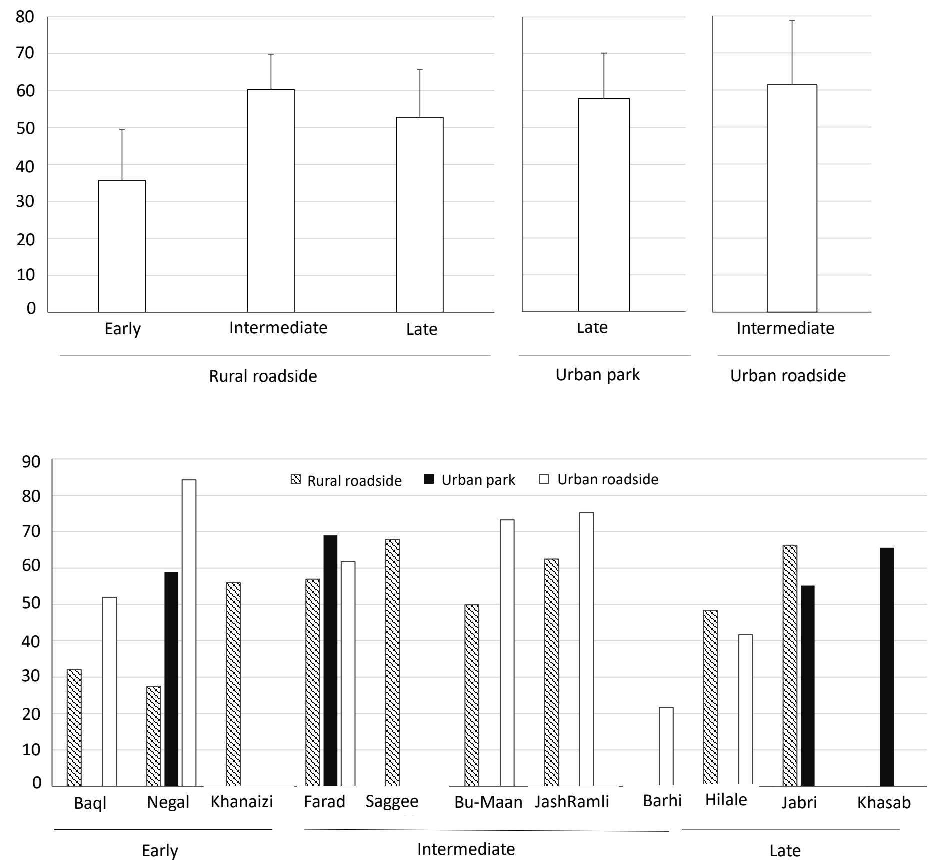


Figure 19: The total fresh weight of non-marketable date fruits in percent of the total sampled fruit weight (including pits). Shown are mean values for individual date varieties (bottom), and mean values ± standard deviation for dates of the different maturity groups (early, intermediate and late) and sampling locations (top). The mean values shown in the figure on the top did not differ significantly (Tukey's multiple comparison, P<0.05). For a description of the sampling locations see Figure 18

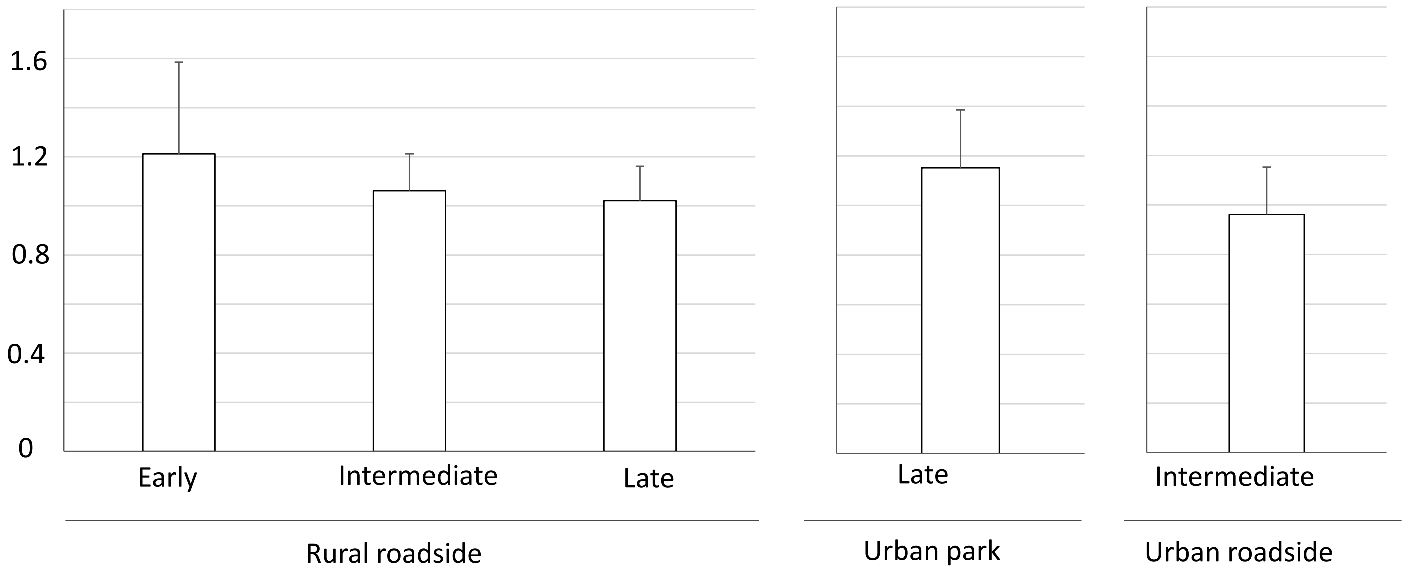


Figure 20: The average weight of individual marketable fruits divided by the average fruit weight of non-marketable fruits (including pits). Shown are the mean values for samples obtained from date varieties belonging to the early, intermediate or late maturity group, and from different sampling locations. For a description of the sampling locations see Figure 18

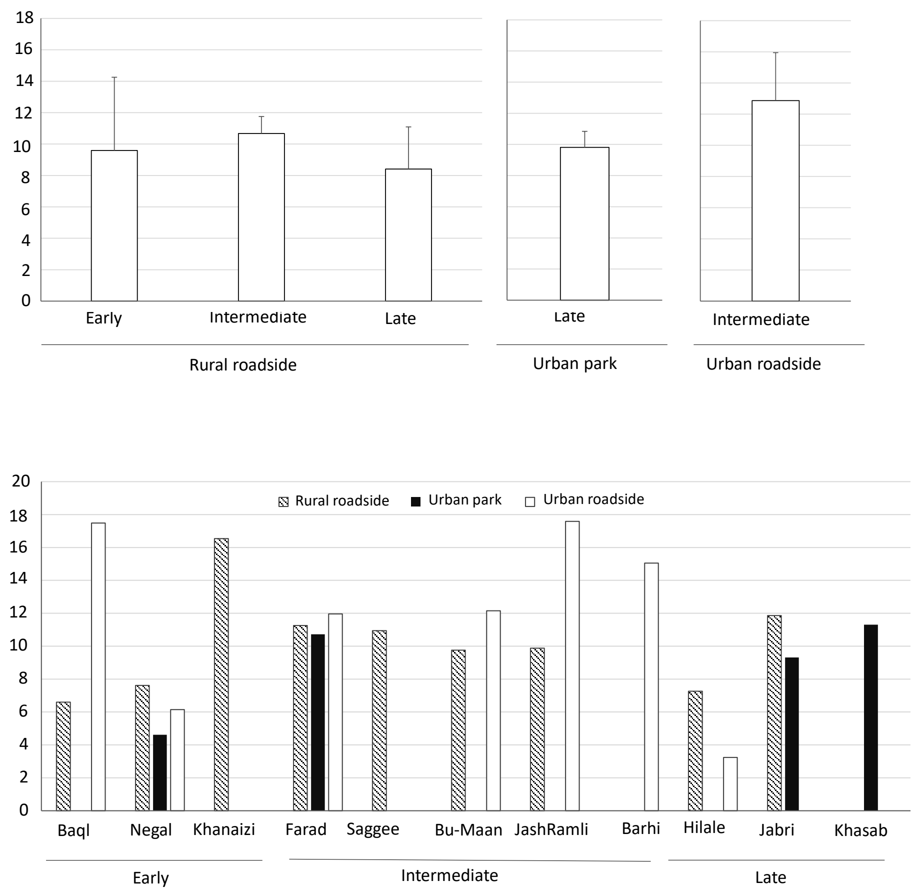
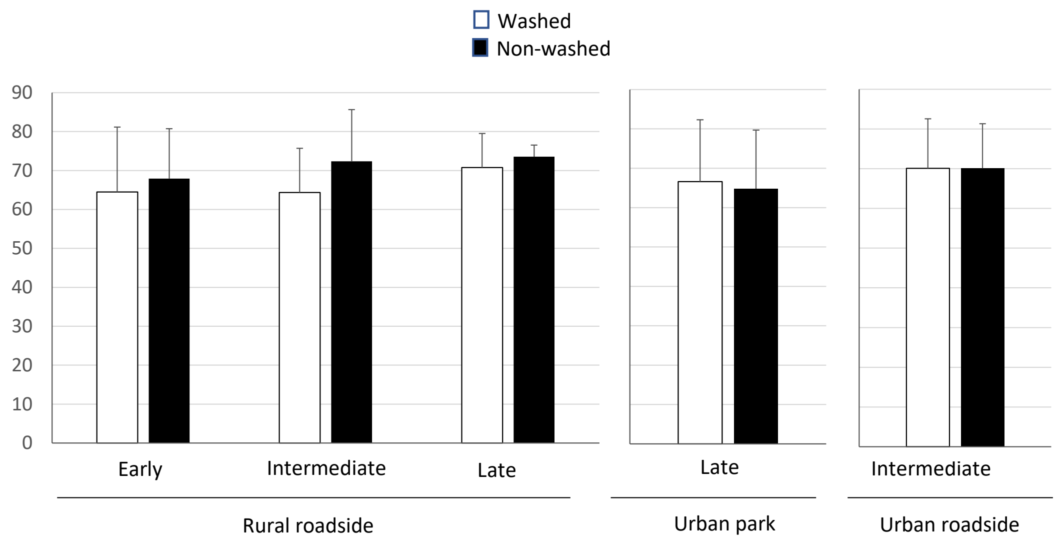


Figure 21: The weight of the fresh date pit in percent of the total fresh fruit weight. Shown are mean values for individual date varieties (bottom), and mean values ± standard deviation for dates of the different maturity groups (early, intermediate and late) and sampling locations (top). The mean values shown in the figure on the top did not differ significantly (Tukey's multiple comparison, $P<0.05$). For a description of the sampling locations see Figure 18



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.674	0.404
Factor 2 Fruit washing (W)	0.384	0.802
Interaction (R x W)	0.903	0.103

Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.721	0.334
Factor 2 Ripening group (R)	0.783	0.247

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

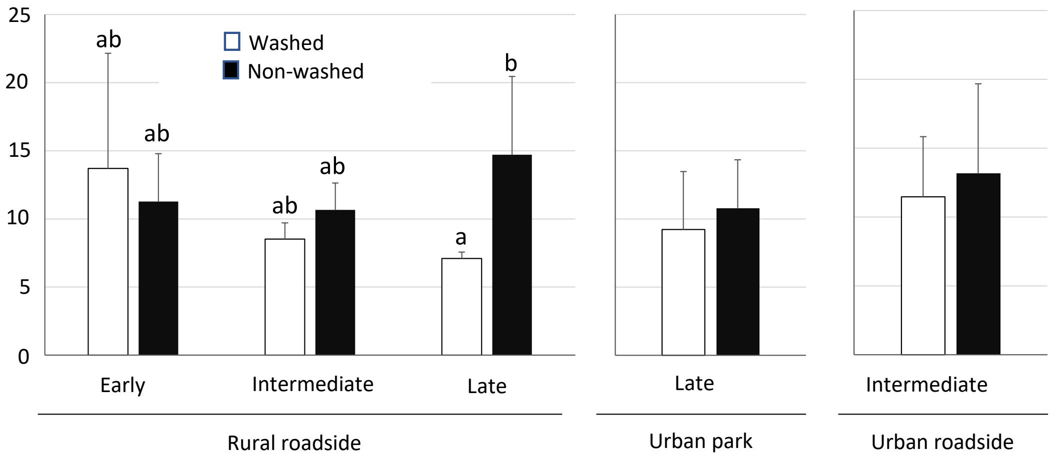
	P value	F value
Factor 1 Location (L)	0.557	0.604
Factor 2 Ripening group (R)	0.918	0.086

Figure 22: Weight loss from fresh fruit pulp (without pit) during two weeks of drying in a ventilated oven at 65ºC in percent. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. The tables below the figure show the results of the Two Way ANOVA performed on data obtained for fruits from the rural roadside locations (middle). Two Way ANOVAS were also performed on results obtained for all washed (bottom left) or non-washed fruits (bottom right). P values indicating a significant ($P<0.05$) effect of the ripening group, fruit washing or the sampling location are printed in bold. Factor interactions were only analyzed for the data obtained from rural roadside locations, as the data sets from the other sampling locations did not equally represent all maturity groups

3.3 Micronutrient Concentrations in Date Fruits Sampled from Roadside Plantations and Public Urban Parks

Among the five micronutrients analyzed as part of this study (Fe, Zn, Mn, Cu and Cr, (Figures 23-27)), the Fe concentrations in date fruits were highest, followed by Zn, Cu, Mn and Cr. There were no major differences in micronutrient concentrations, depending on whether the fruit samples had been obtained from a rural roadside, urban roadside or urban park. There was no effect of fruit washing on the micronutrient concentrations in date fruits. The Zn and Cu concentrations were higher in early compared with intermediate and late ripening dates sampled from rural roadsides (Figures 24 and 26). Dates of the intermediate ripening group sampled from rural roadside plantations also had slightly higher Mn concentrations compared with the early and late varieties, but no impact of the ripening group on Fe and Cr concentrations was observed.

When fruits were sampled from rural roadsides, the iron concentrations in fruits of late cultivars were higher for non-washed compared with washed samples (Figure 23), but no such difference could be observed for other ripening classes or sampling locations.



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.725	0.327
Factor 2 Fruit washing (W)	0.401	0.732
Interaction (R x W)	**0.033**	4.001

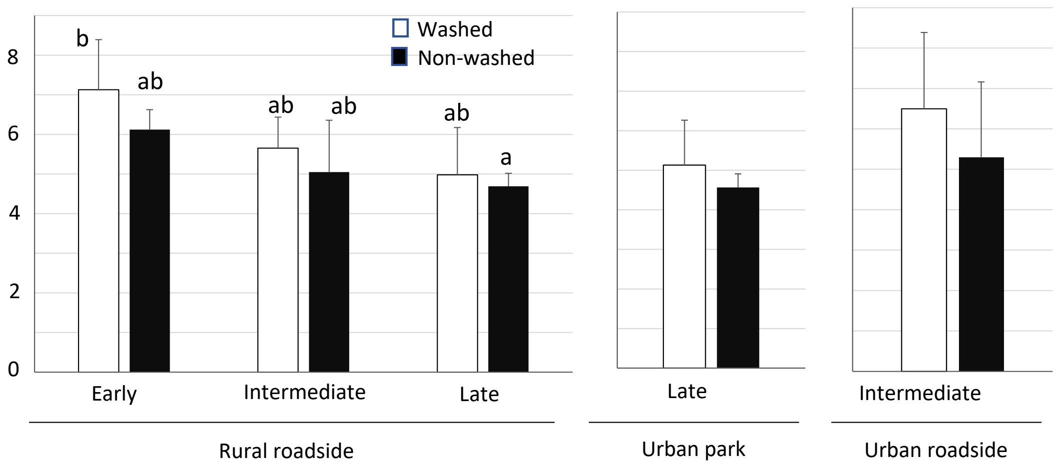
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.355	1.083
Factor 2 Ripening group (R)	0.098	2.568

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.364	1.057
Factor 2 Ripening group (R)	0.455	0.816

Figure 23: Iron concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. Mean vlues obtaine for the dates sampled from rural roadsides followed by the same letter are not significantly different ($P<0.05$, Tukey's multiple comparison). The tables below the figure show the results of the Two Way ANOVA performed on data obtained for fruits from the rural roadside locations (middle). Two Way ANOVAS were also performed on results obtained for all washed (bottom left) or non-washed fruits (bottom right). P values indicating a significant ($P<0.05$) effect of the ripening group, fruit washing or the sampling location are printed in bold. Factor interactions were only analyzed for the data obtained from rural roadside locations, as the data sets from the other sampling locations did not equally represent all maturity groups. For an explanation of the sampling locations see Figure 18



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.005**	6.961
Factor 2 Fruit washing (W)	0.113	2.720
Interaction (R x W)	0.772	0.262

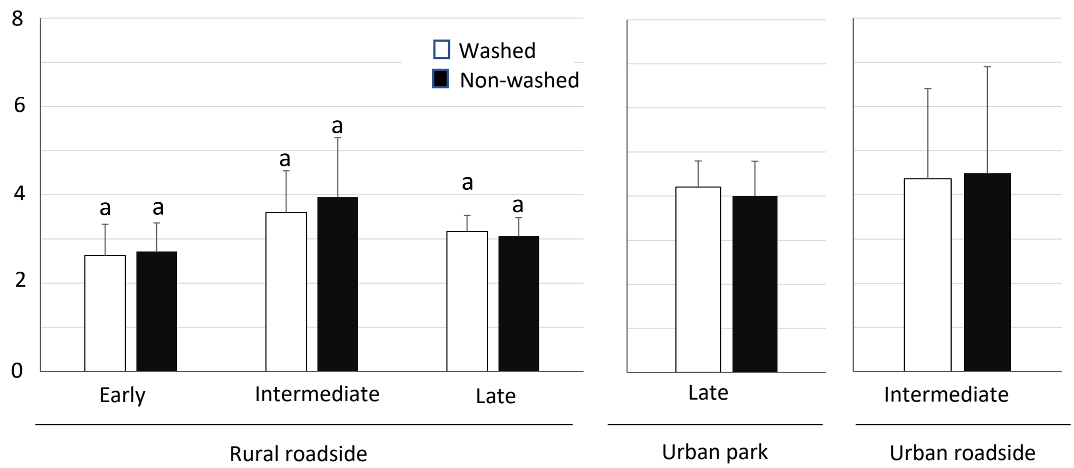
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.531	2.341
Factor 2 Ripening group (R)	0.119	0.119

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.928	0.075
Factor 2 Ripening group (R)	0.301	1.265

Figure 24: Zinc concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.035**	3.924
Factor 2 Fruit washing (W)	0.744	0.109
Interaction (R x W)	0.845	0.170

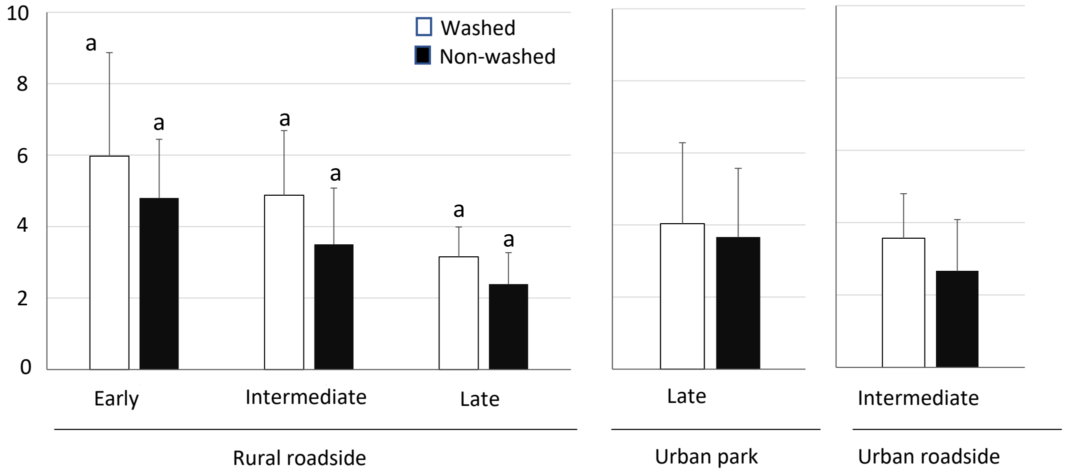
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.348	1.106
Factor 2 Ripening group (R)	0.567	0.582

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.613	0.499
Factor 2 Ripening group (R)	0.496	0.722

Figure 25: Manganese concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.022**	4.548
Factor 2 Fruit washing (W)	0.113	2.723
Interaction (R x W)	0.929	0.074

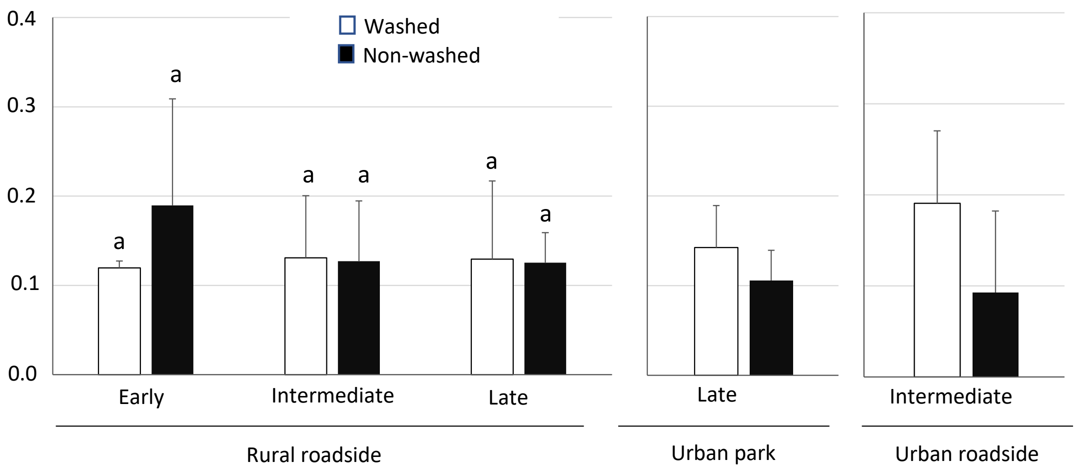
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.301	1.265
Factor 2 Ripening group (R)	0.097	2.581

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.288	1.313
Factor 2 Ripening group (R)	0.098	2.579

Figure 26: Copper concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.939	0.064
Factor 2 Fruit washing (W)	0.306	1.100
Interaction (R x W)	0.284	1.334

Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.310	1.232
Factor 2 Ripening group (R)	0.672	0.404

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.542	0.628
Factor 2 Ripening group (R)	0.417	0.910

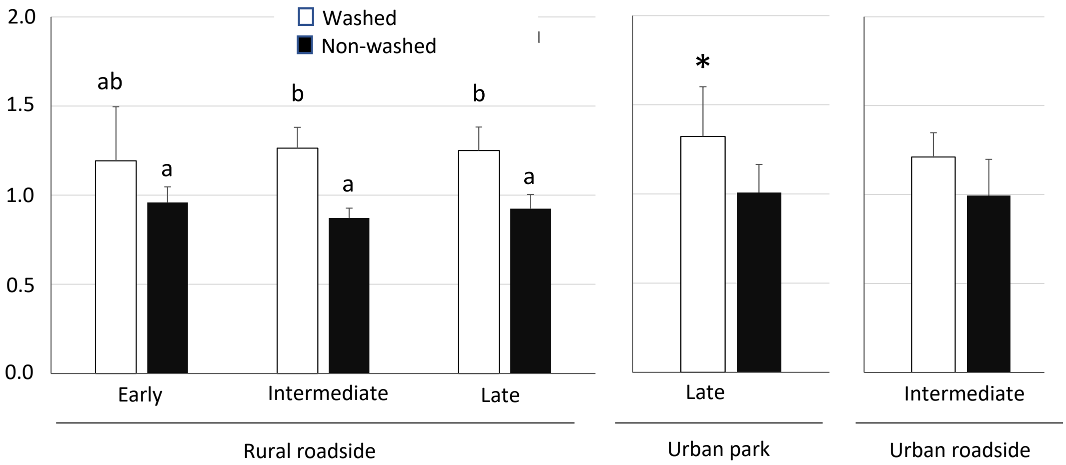
Figure 27: Chromium concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23

3.4 Non-Nutritional Heavy Metal Concentrations in Date Fruits Sampled From Roadside Plantations and Pubic Urban Parks

The concentrations of Co and Pb in date fruit samples obtained as part of this study were below detection limit of the analytical machinery used across all analyzed samples. Mean Cd concentrations in date fruits were in the range of 1 to 1.5 µg per g dry weight (Figure 28). Across all sampling locations, the Cd concentrations were higher for washed compared with non-washed samples, but there were no differences in fruit Cd concentrations depending on the sampling location. The ripening group also had no impact on the Cd concentrations in date fruits. The concentrations of Ni in date fruits were in the range of 0.4 to 0.8 µg per g dry weight, with no difference depending on where the samples had been taken (Figure 29). There was also not difference in Ni concentrations between washed and non-washed fruits, or between dates of different ripening gropus. The standard deviations were relatively high around mean values obtained for Ni concentrations, suggesting a high variability between individual replicates.

3.5 Phosphorus Concentrations in Date Fruits Samples from Roadside Plantations and Public Urban Parks

The P concentrations in sampled date fruits were in the range of 0.6 to 1 mg per g dry weight (Figure 30). There was no difference in fruit P concentrations, depending on whether these had been washed prior to analysis, or not. There was also no impact of the location or the ripening group on the fruit P concentrations.



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.956	0.045
Factor 2 Fruit washing (W)	**<0.001**	32.853
Interaction (R x W)	0.494	0.728

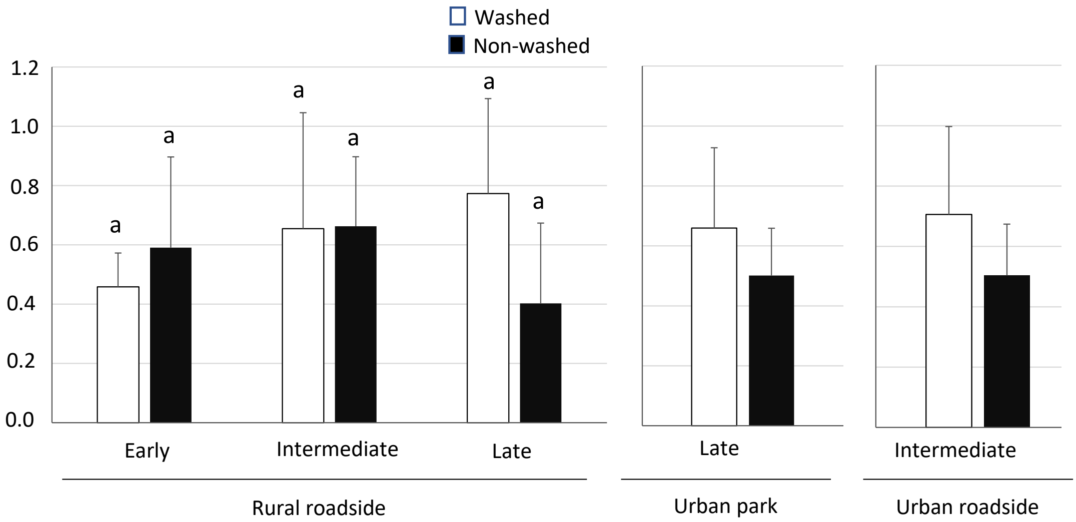
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.747	0.296
Factor 2 Ripening group (R)	0.836	0.180

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.222	1.610
Factor 2 Ripening group (R)	0.647	0.444

Figure 28: Cadmium concentrations in dried date fruit pulp in µg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.401	0.953
Factor 2 Fruit washing (W)	0.745	0.109
Interaction (R x W)	0.145	2.113

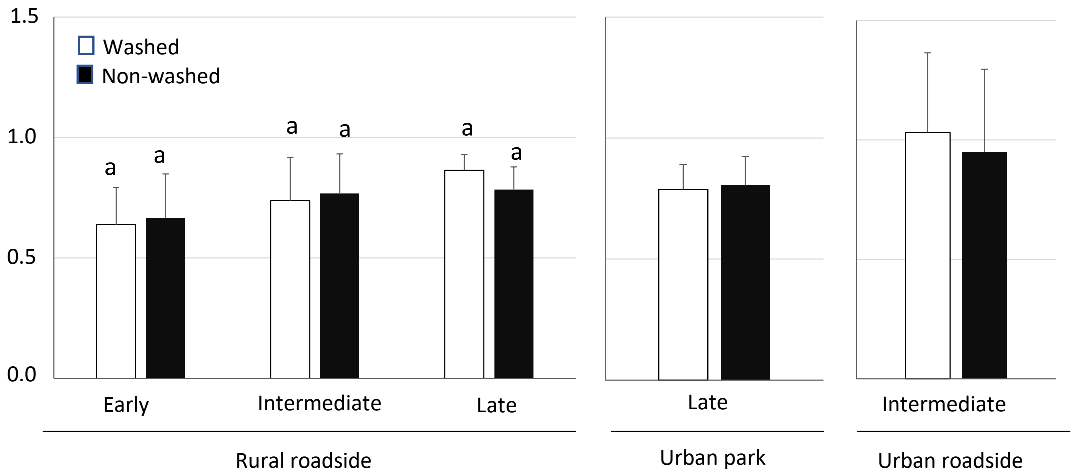
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.478	0.762
Factor 2 Ripening group (R)	0.180	1.849

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.219	1.622
Factor 2 Ripening group (R)	0.254	1.456

Figure 29: Nickel concentrations in dried date fruit pulp in µg per g.Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.098	2.584
Factor 2 Fruit washing (W)	0.903	0.015
Interaction (R x W)	0.695	0.370

Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.069	3.008
Factor 2 Ripening group (R)	0.412	0.921

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.377	1.019
Factor 2 Ripening group (R)	0.758	0.280

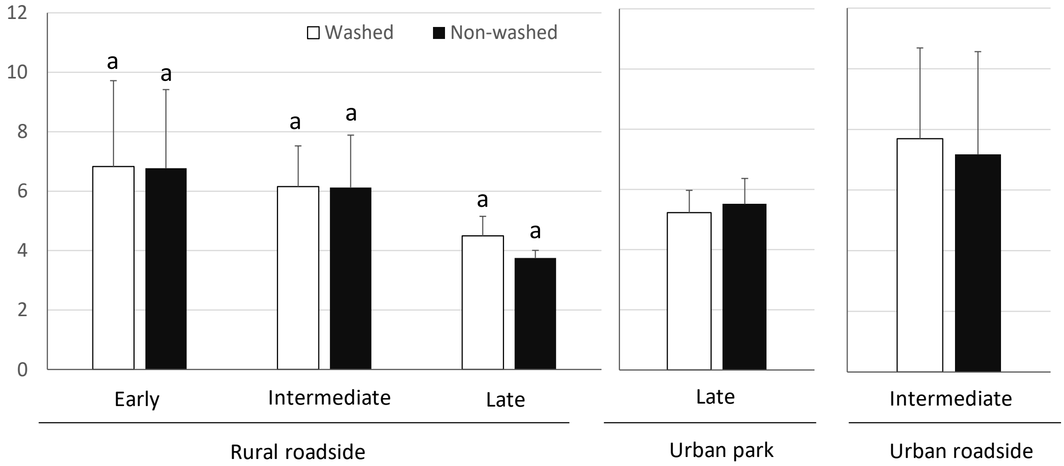
Figure 30: Phosphorus concentrations in dried date fruit pulp in mg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23

3.6 Cation Concentrations in Date Fruits Sampled from Roadside Plantations and Public Urban Parks

The K concentrations in date fruits were in the range of 4 to 8 mg per g dry weight (Figure 31). For the fruits sampled from rural roadsides, late ripening varieties had lower K concentrations compared with those ripening early or intermediately. There were no differences in fruit K concentrations depending on the sampling location, and also washing had no impact on the K concentrations in the fruits.

Similar with the K concentrations, the Na levels in date fruits were higher for early compared with late ripening fruits (Figure 32). Across all samples analyzed, the Na levels were in the range of 0.1 to 0.3 mg per go dry weight, with K/Na ratios between 23 and 35 (data not shown). The sampling location had no effect on the fruit Na concentrations or the K/Na ratio. Concentrations of Na in date fruits also remained unaffected by washing.

The concentrations of divalent cations in date fruits were at a similar level for Ca (Figure 33) and Mg (Figure 34), ranging from 0.5 to 1.2 mg per g dry weight. Calcium concentrations in fruits of early and intermediate ripening varieties were in a higher range compared with those of late ripening ones, but there was no such difference in the Mg levels. Neither the sampling location nor washing of the fruits had an impact on the Ca or Mg levels in date fruits.



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.018**	4.828
Factor 2 Fruit washing (W)	0.694	0.159
Interaction (R x W)	0.899	0.107

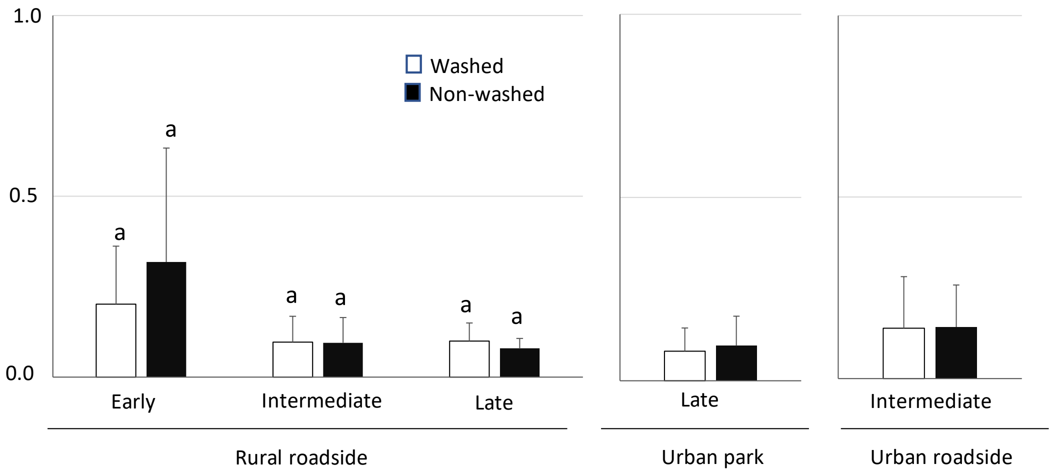
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.394	0.971
Factor 2 Ripening group (R)	0.336	1.143

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.448	0.832
Factor 2 Ripening group (R)	0.209	1.674

Figure 31: Potassium concentrations in dried date fruit pulp in mg per g.Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.032**	0.566
Factor 2 Fruit washing (W)	4.032	0.340
Interaction (R x W)	0.568	0.580

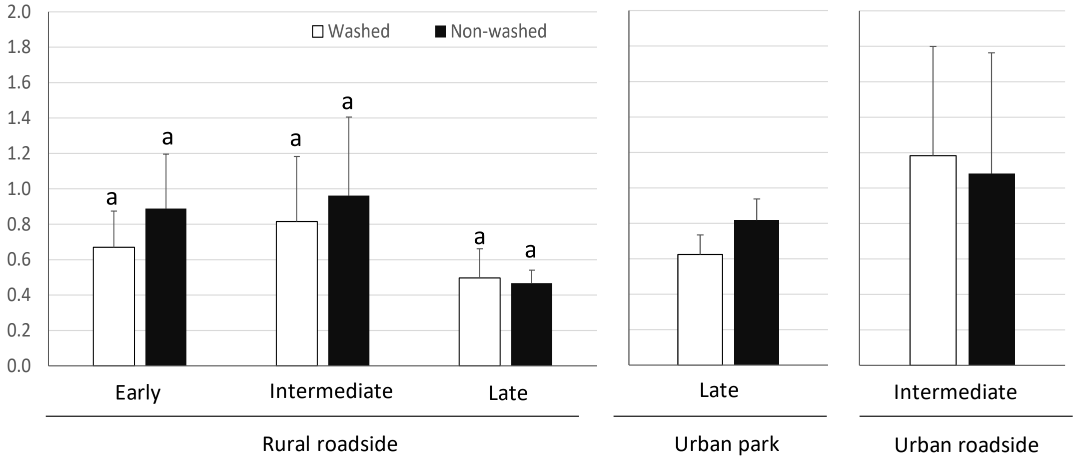
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.760	0.328
Factor 2 Ripening group (R)	0.278	1.169

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.801	0.224
Factor 2 Ripening group (R)	**0.039**	3.751

Figure 32: Sodium concentrations in dried date fruit pulp in mg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	**0.030**	4.127
Factor 2 Fruit washing (W)	0.365	0.857
Interaction (R x W)	0.719	0.335

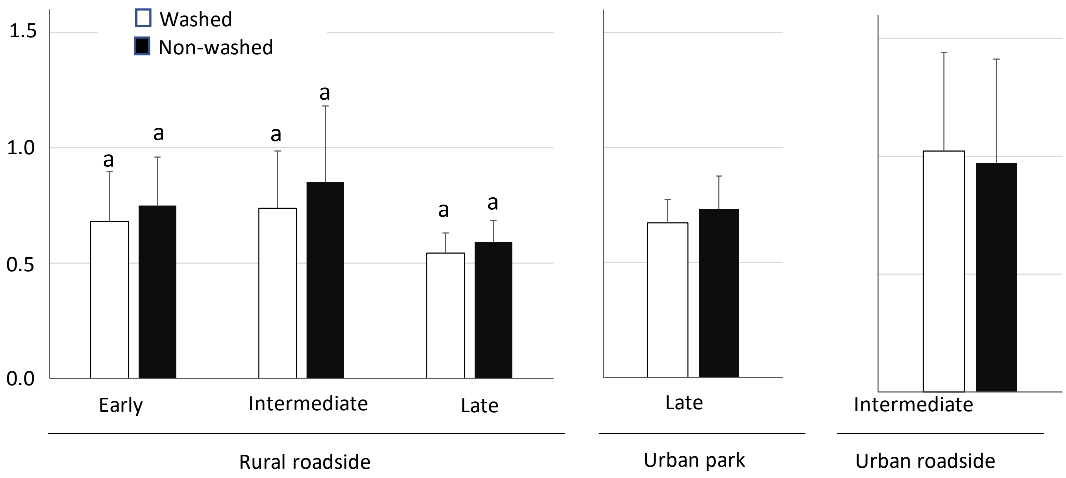
Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.260	1.429
Factor 2 Ripening group (R)	0.530	0.652

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.543	0.628
Factor 2 Ripening group (R)	0.286	1.321

Figure 33: Calcium concentrations in dried date fruit pulp in mg per g.Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23



Results of the Two Way ANOVA performed on data obtained for the fruits from the rural roadside.

	P value	F value
Factor 1 Ripening group (R)	0.121	2.329
Factor 2 Fruit washing (W)	0.393	0.760
Interaction (R x W)	0.949	0.052

Results of the Two Way ANOVA performed on data obtained for washed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.179	1.857
Factor 2 Ripening group (R)	0.608	0.509

Results of the Two Way ANOVA performed on data obtained for unwashed fruits from all locations

	P value	F value
Factor 1 Location (L)	0.665	0.491
Factor 2 Ripening group (R)	0.415	0.734

Figure 34: Magnesium concentrations in dried date fruit pulp in mg per g. Shown are the mean values for date fruits that were either or not washed before drying ± standard deviation. For statistics and explanation of treatments see Figure 23

Chapter 4: Discussion

Date palms are indigenous to the Arabian peninsula and one of the best adapted and highest yielding crops under the climatic and soil conditions of the Gulf Region. The palms are also grown widely as attractive components of urban greenery in form of roadside plantations and public parks and gardens. More than 80.000 date palms are grown for landscaping purposes in the city of Al Ain, and along the main roads radiating from the city into peri-urban and rural areas (Al Ain Municipality, personal communication). Date palms grown for landscaping purposes belong to the same varieties as those grown on farms, and have a similar fruit production potental of up to 100 kg fresh fruits per palm and year. The fruits produced by date palms grown along roads or in public urban areas are rarely used as food for humans, due to fears that they might be contaminated with heavy metals or other pollutants potentially hazardous to human health. Contamination might arise from the exaust of cars and industries, dust (e.g. vehicular tire and brake dust evolving near roads) and possibly treated sewage effluent used for plant irrigation. However, element concentrations in date fruits obtained from urban environments and roadsides in or near Al Ain have previously not been comprehensively analyzed.

In the present study, date fruit samples from 34 different locations in and around Al Ain were collected and analyzed. The date fruits belonged to 11 different date varieties and were all under irrigation with treated sewage effluent. All date fruits had been harvested in the tamr stage. Since the moisture content was relatively high in the harvested date samples, it is likely that their harvest occurred relatively early, possibly shortly after the fruits had entered the final ripening stage. According to (Tapia-Paniagua et al, 2014) moisture levels in date fruits at the tamr stage are in the range of

25% rather than 60 – 70% observed in the fruits of the present study. The high moisture content at sampling might have been the reason for a relatively high spoilage of the fruits. The fruits identified as non-marketable in the present study accounted for between 35 and 60% of total fruit weight and were characterized by a darker color, soft, puffy appearance and at times unpleasant odor. This might have been caused by enzymatic reactions taking place in the relatively moist date fruits before or shortly after harvest (Tapia-Paniagua et al, 2014), as well as spoilage with yeasts, *Acetobacter spp*., *Aspergillus spp*. or Alternaria spp., all of which have been shown to proliferate on dates that have a high moisture content (Yahia, 2011).

Dates are valued not only for their culinary features, but also various health benefits. Most of these have been related to their dietary fiber and secondary metabolite contents. However, some authors have also suggested that date fruits are rich in mineral nutritional elements and contribute significantly to human supply with Fe (Irandegani et al., 2019), Cu, K, Mg, and Ca. The results of our study suggest that nutritional element concentrations in date fruits are in a rather low to intermediate range. Consumption of 100 g fresh fruits analyzed as part of the present study would contribute to daily Ca, Mg, K and P requirements of an adult person by around 2, 7, 6 and 3%, respectively (Melse-Boonstra, 2020). Due to their high sugar content, dates are relatively rich in energy, and 100 g fresh dates would cover 10 – 15% of the energy requirements of an adult person.

Iron concentrations in date fruits analyzed as part of the present study were in the range of 7 to 15 µg per g dried fruit weight. This is in a similar range as values reported by Al-Farsi et al. (2007), but around ten times lower compared with Fe concentrations in dates. According to the findings of our study, the ingestion of 35 g dry date fruits, corresponding to around 100 g fresh fruits, would cover only 2 – 5% of the total daily recommended Fe intake for adults. Similarly, the consumption of 35 g dry date fruits analyzed as part of the present study would contribute around 1.2 – 1.6% to the recommended daily Zn intake, and 5 – 8% to total daily Mn needs of an adult person. The Zn and Mn concentrations in date pulp reported in the present study agree with values stated and slightly higher than those reported by Al-Farsi et al. (2007). Concentrations of Fe, Mn, and Zn in green plant parts, such as leafy greens, are commonly around ten times higher compared with those reported in date fruits (Oehler et al., 1994). Based on these findings it is very unlikely that ingestion of date fruits obtained from roadsides or parks could be contaminated with Fe, Zn or Mn. Concentrations of Cu and Cr in the analyzed date fruits were in a rage similar to those reported for leaves of crops. Daily ingestion of 35 g dried fruit pulp would contribute 10 – 20% to the daily Cu and Cr demand of an adult. Based on these findings there is no risk of elevated Cu or Cr intake via consumption of date fruits from urban or roadside palms.

The concentrations of Ni in date fruits sampled as part of the present study were in the range of 0.4 – 0.8 µg per g dried date pulp. To exceed the daily permissible Ni intake of 1 mg, an adult person would need to eat 400 – 800 g dry date pulp, corresponding to more than one kg of fresh dates. It can thus be concluded that an excessive ingestion of Ni via date fruits harvested from urban or roadside plantations is very unlikely to occur. Concentrations of Co and Pb in all analyzed date fruits were below detection limit, indicating that contaminations of date fruits with these two heavy metals is uncommon in urban and peri-urban areas of Al Ain.

Cadmium is one of the most toxic heavy metals known to occur in the food supply chain, and for this reason it is recommended that daily ingestion remains below 70 µg in adults. Cadmium concentrations are in the range of 0.001 – 0.05 µg per g in fresh meat and fish, and up to 0.3 µg per g in cereals. The FAO-WHO recommended that Cd concentrations in fruits should not exceed 0.3 µg per g dry weight. The concentrations in dried date pulp analyzed in this study were above these values, ranging between 1.0 and 1.3 µg per g. The Cd concentrations in date fruits observed in this study were also higher than those reported by Aldjain et al. (2011) for dates obtained from urban palms of Riyadh, and by Salama et al. (2019) for dates from other urban sites in Saudi Arabia. Based on our analyses, an adult would reach the daily permissible Cd intake through consumption of 130 – 180 g fresh date fruits from Al Ain roadsides or urban parks, corresponding to 50 – 70 g dried date pulp. Though most people are likely to consume less, Cd contamination might limit the opportunities for valorization of date fruits from urban parks and roadsides to some extent. Different from results obtained by Aldjain et al. (2011) washing of the date fruits could not reduce heavy metal concentrations in date samples analyzed in the present study, suggesting that contamination might not be in form of dust deposition on the fruit surface, but possibly rather plant uptake from the soil.

Sources of Cd in urban soils can be dust arising from oil combustion, waste incineration, cement manufacturing and other industries. Natural sources of Cd are also possible, such as dust from Cd rich sediments. It can also not be excluded that Cd is brought in with the TSE irrigation water. Cadmium is of greater mobility and plant availability in soils compared with other heavy metals, even on alkaline soils (Prokop et al., 2003).

Based on the results of the present study it can be recommended that the Cd levels in urban soils of Al Ain are assessed, especially near roadsides. Paths through which Cd might enter the date fruits require further investigation. The palms might take up the element either via their roots, leaves or the fruits as they collect dust from the nearby road.

Date fruits obtained from other urban plantations, such as urban farms, should be analyzed for Cd to make sure that levels are not elevated. Future analysis of date fruits from urban environments will also need to take differences between the date varieties into account. It is possible that contamination profiles differ significantly between individual varieties, even though no major effect of the maturity groups on element concentrations were detected in the present study. For this purpose, it will be important that site engineers, farm workers and laboratory specialist are able to classify fruits of the most widely grown date varieties in urban environments. It is believed that the classification flowchart and reference photographs produced as part of the present study can greatly contribute to this. Future experiments should compare the performance of different date varieties under irrigation with fresh water or TSE under farming conditions and in urban landscapes.

Chapter 5: Conclusion

In conclusion, date fruits harvested from urban or rural roadsides and urban parks did not differ much in their element concentrations depending on the sampling location or the maturity group. Concentrations of analyzed elements were in a safe range for consumption, except for Cd, where maximum permissible concentrations exceeded recommended values. Fruit washing could not remove Cd and had no impact on concentrations of other elements. It is recommended that sources of Cd in dates are identified, and if possible, eliminated. This might pave the way for a valorization of date fruits from ornamental and roadside plantations into the food supply chain. Differences in element concentrations between dates varieties should be identified in future studies. A classification flowchart for date fruits developed as part of this study.

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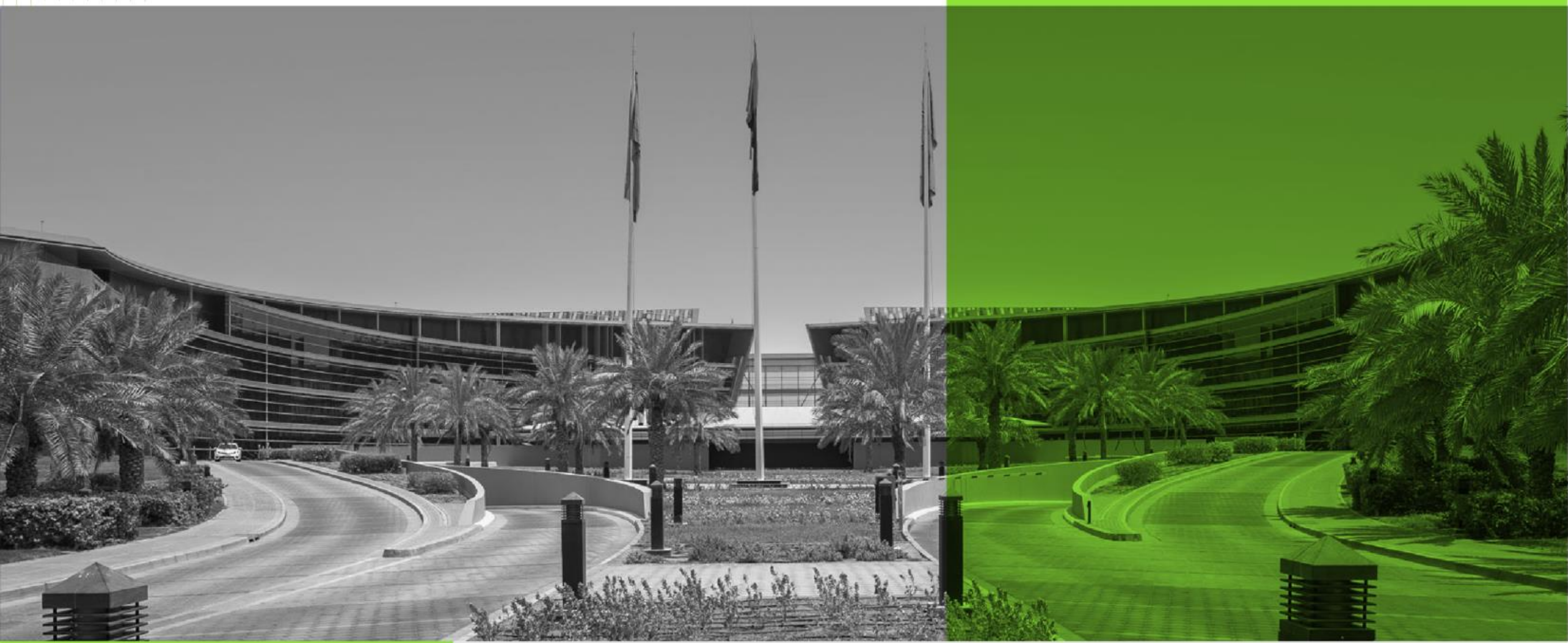

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Date fruits harvested from urban or rural roadsides and urban parks did not differ much in their element concentrations depending on the sampling location or the maturity group. Concentrations of analyzed elements were in a safe range for consumption, except for Cd, where maximum permissible concentrations exceeded recommended values. Fruit washing could not remove Cd and had no impact on concentrations of other elements. It is recommended that sources of Cd in dates are identified, and if possible, eliminated. This might pave the way for a valorization of date fruits from ornamental and roadside plantations into the food supply chain.

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