Journal of Agricultural and Marine Sciences 2022, 27(1): 16–37
DOI: 10.53541/jams.vol27iss1pp16-37
Received 3 Jan 2021
Accepted 27 June 2021

REVIEW ARTICLE

Biotic and Abiotic Stresses of Major Fruit Crops in Oman: A Review

Rashid A. Al-Yahyai[1*], Latifa M. Al-Kharusi[2], Mumtaz M. Khan[1], Ali O. Al-Adawi[3], Ali M. Al-Subhi[1], Basim S. AL-Kalbani[1,3], Abdullah M. Al-Sadi[1]

الضغوط الحيوية واللاحيوية لمحاصيل الفاكهة الرئيسية في عمان: مراجعة

راشد اليحيائي، لطيفة الخروصي، ممتاز محمد خان، علي العدوي، علي الصبحي، باسم الكلباني، عبد الله السعدي

ABSTRACT: Oman is located in an arid region of the world that is characterized by adverse climatic conditions, including heat and drought. In recent years, it has also been affected by climate turbulence and the occurrence of severe weather, such as cyclones and heat/cold waves affecting large agricultural areas of the country. Fruit cultivation area represents 31% of the total cultivated area (97,239.58 ha) in the country. However, the production share is only 17% of the total crop production in the country (2.6 million tons). About 90% of the fruit cultivation area is dominated by date palm, banana, lime, and mango. In addition to the abiotic stresses, such as drought, heat, and salinity, major fruit crops have declined in recent years due to various biotic stressors, primarily insect pests, and diseases. For several decades, the date palm has suffered from the Dubas bug and in recent years from Red Palm Weevil. Lime has been infected with Witch's Broom Disease of Lime (WBDL) caused by '*Candidatus* Phytoplasma aurantifolia' that has led to the decline of production to 25% from its peak in the nineties. Banana is Oman`s second-largest fruit crop in production and export. It has also been the subject of studies due to losses incurred by farmers during pre-and post-harvest stages, in addition to several pests and diseases that affect bananas in Oman. Mango is another major fruit crop that is primarily cultivated in northern Oman. Severe infection with mango decline has led to the eradication of mango orchards from many regions of Oman, particularly in Batinah Coast, where increased salinity has led to a decline in mango yield. Research conducted in Oman has investigated several aspects of these challenges. This review paper summarizes the outcome from studies conducted in the country and proposes directions towards resolving current and future challenges to the fruit industry.

KEYWORDS: Date Palm, Lime, Mango, Banana, Fruit Trees, Climate Change, Abiotic Stress

الملخص:تقع سلطنة عمان في منطقة قاحلة من العالم تتميز بظروف مناخية قاسية تشمل شدة الحرارة والجفاف، وفي السنوات الأخيرة تأثرت أيضًا بالاضطرابات المناخية مثل الأعاصير وموجات الحرارة والبرودة التي أثرت على مناطق زراعية واسعة من البلاد، وتمثل مساحة زراعة الفاكهة ما نسبته ٣١٪ من إجمالي المساحة المزروعة (٩٧،٢٣٩,٥٨ هكتار) في السلطنة ومع ذلك ، فإن حصة الإنتاج لا تتجاوز ١٧٪ من إجمالي إنتاج المحاصيل الزراعية في السلطنة (٢,٦ مليون طن)، ويهيمن النخيل والموز والليمون العماني والمانجو على ٩٠٪ من مساحة زراعة الفاكهة، بالإضافة إلى الضغوط اللاأحيائية ، مثل الجفاف والحرارة والملوحة ، تراجعت محاصيل الفاكهة الرئيسية في السنوات الأخيرة بسبب الضغوطات الحيوية المختلفة وعلى رأسها الآفات والأمراض. ولعدة عقود، عانت نخيل التمر من حشرة الدوباس وفي السنوات الأخيرة من سوسة النخيل الحمراء. كما أصيب الليمون بمرض مكنسة الساحرة والناجمة عن (*Candidatus* Phytoplasma aurantifolia) مما أدى إلى انخفاض الإنتاج إلى ٢٥٪ من ذروة الانتاج في التسعينيات. ويعتبر الموز ثاني أكبر محصول فاكهة في سلطنة عمان انتاجا وتصديرا وبالإضافة الى الدراسات المختلفة عن الإنتاج، أقيمت دراسات عن الخسائر التي يتكبدها المزارعون خلال مرحلتي ما قبل وبعد الحصاد، بالإضافة إلى العديد من الآفات والأمراض التي تصيب الموز في عمان. وحيث أن المانجو هو محصول رئيسي آخر يزرع بشكل أساسي في شمال عمان فقد أدت الإصابة الشديدة بمرض تدهور المانجو إلى فقدان العديد من بساتين المانجو في السلطنة وخاصة في ساحل الباطنة، حيث ساهمت زيادة الملوحة كذلك إلى انخفاض انتاج محصول المانجو. وتلخص ورقة المراجعة هذه نتائج الدراسات التي أجريت في السلطنة والمتعلقة بإنتاج الفاكهة وتقترح حلول توجيهية للتحديات الحالية والمستقبلية.

الكلمات المفتاحية: نخيل التمر، الليمون العماني، المانجو ، الموز ، أشجار الفاكهة ، تغير المناخ ، الإجهاد اللاأحيائي.

Introduction

The Sultanate of Oman is situated on the south-eastern coast of the Arabian Peninsula, having a semi-arid to an arid climate. It's a unique country that lies within two geographic regions, the south-central part of the country is desert, having its resemblance with Africa (16-26° N and 51-59° E), while the northern part is mountainous which resembles continental Asia (20-40° N and 40-50° E), in its climatic conditions, while Dhofar Governorate in the South of Oman has tropical monsoon climate (Al-Khafaji et al., 2017). Oman receives less than 100 mm of annual average rainfall which is 10 times less than the average evapotranspiration rate. About 75% of its total area is desert while the remaining is highly diverse within its topographic and climatic conditions, which allowed the cultivation of various tropical to subtropical fruits (Al-Yahyai et al., 2014). Among the agricultural commodities,

Rashid A. Al-Yahyai[1*] alyahyai@squ.edu.om,Department of Plant Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khod, Sultanate of Oman.

CC BY ND

fruit crops are the main agricultural products that have been traditionally cultivated for thousands of years.

While this climatic and geographic diversity helped cultivate a variety of fruit crops in a subsistence manner, there have been many challenges that increased over time as the agricultural sector adopted more modern approaches to cultivation. These challenges include biotic, largely caused by the emergence of pests and diseases, while others are abiotic, including heat, drought, and salinity. Future challenges include the shift to the modernization of agriculture, climate change, and declining water and land resources. These challenges were the main research focus in Oman. This review article was aimed to present the status of research and major outcomes that can develop future research directions towards resolving some of these challenges.

Current Status of Fruit Production in Oman

A large percentage of the cultivated area in Oman is used to produce a variety of tropical, subtropical, and deciduous fruit crops. Fruit cultivation area represents 31% of the total cultivated area (97,239.58 ha) in the country. However, the production share is only 17% of the total crop production in the country (2.6 million tons) (Figure 1). This indicates that there are several challenges in fruit production at the pre-harvest and postharvest levels. However, despite the great potential of fruit crop production, the sector remains an unattractive alternative to fodder crops that use plenty of water resources.

The topographical and climatic variations in the country provided fruit growers. The high-altitude mountains in northern Oman, Al-Jabal Al-Akhdar at 2000 m above sea level, is characterized by low temperatures that are adequate to meet the chilling requirements of several deciduous fruit species, the most common being pomegranates, pome and stone fruits and nut crops such as walnuts (Figure 2). The southern plains of Salalah are characterized by summer rainfall due to annual drifts from the Indian Ocean monsoon, are characterized by the cultivation of several tropical fruit crops, most prominently coconut, bananas and papayas. Whereas, the rest of the country largely features hot summers, suitable for the cultivation of the most dominant fruit crop, the date palm. Other important fruit crops that are suitable for many of Oman's regional climatic zones include mango, lime, guavas and Annona.

According to the latest national agricultural census that was conducted in 2012/2013, the number of date palms declined slightly by 3.8% totaling 7,563,279 palms compared to 7,859,443 in the 2004/2005 census. This decline may be attributed to the continued loss of agricultural land to salinity and desertification, in addition to extreme weather events caused by climate change, in date palm cultivation areas. However, other fruit crops have increased in numbers by larger percentages, which may also indicate a replacement of date palms with a more profitable crop. Lime has increased by 11% (390,218 trees), mango by 8.5% (434788 trees), and coconut by 11.5% (159,527 palms) in 2012/2013 census, compared to 2004/2005 census (MAF, 2017). It is noteworthy, that Oman has initiated a project to plant one million date palms in 2009, of which 600, 000 palms have already been planted to date.

The major fruit crops in Oman are date palm, bananas, lime and mangoes, constituting 83%, 6%, 3%, 3% of fruit production areas in the country, respectively (Table 1). Over the past few years, there has been an increase in fruit production in Oman, despite a slight decline in the cultivated area (Figure 3), which may be attributed to improved cultural practices and the introduction of high-yielding cultivars, such as the case for mangoes. The increase in fruit production is driven by increasing

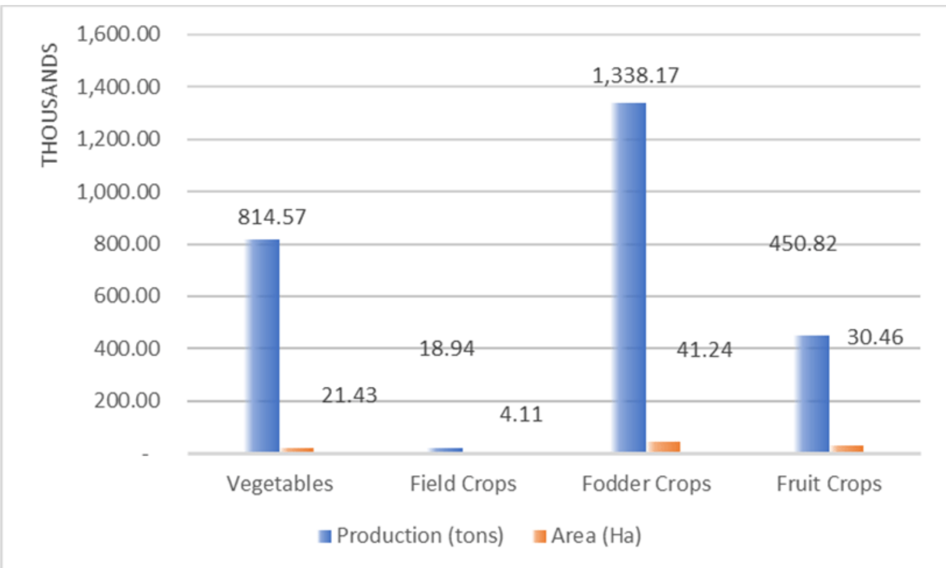

Figure 1. Production and cultivated area of crops in Oman in 2017 (MAF, 2017).

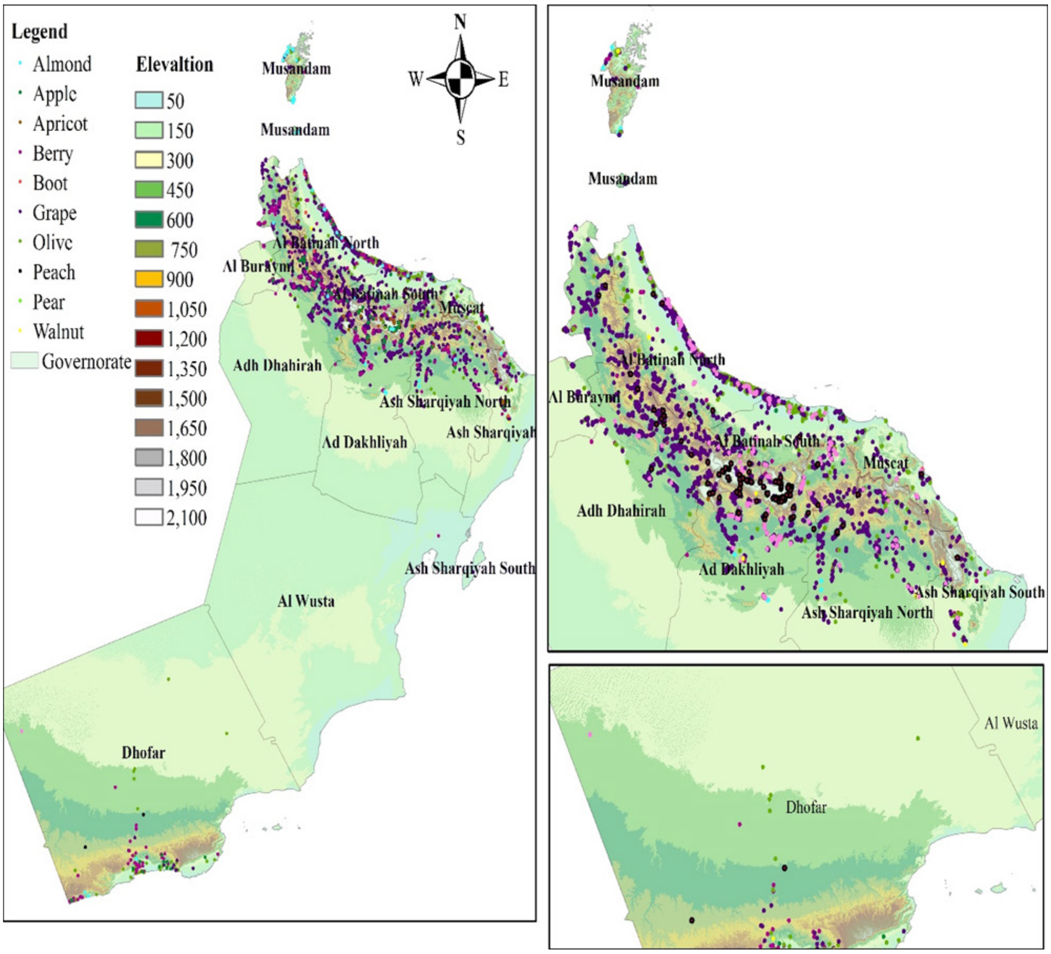

Figure 2. Distribution of deciduous fruit crops cultivated at various altitudes in Oman.
(Source: Basim Al-Kalbani, Unpublished).

demand, as the country's import of fruits continues to increase, driven by health consciousness and an increase in economic prosperity. Nonetheless, the increase in fruit production over the past few years varied from year to year, due to several factors, including climate anomalies, pests and diseases, and availability of resources, adverse abiotic conditions such as salinity and drought, and human factors related to labor, energy and the economy.

Challenges in Fruit Production

Cultural Practices

One of the major challenges to developing fruit production as an economic sector is the traditional means of cultivation and cultural practices followed by the less cost-effective resource and time-consuming methods. These traditional methods have been reported for various fruit crops, including date palm (Al-Yahyai and Khan, 2015), lime (Al-Yahyai et al., 2012), mangoes (Al-Jabri and Al-Yahyai, 2017; Al-Yahyai et al., 2013) and pomegranates and deciduous crops (Al-Yahyai et al., 2009; Al-Said et al., 2013; Al-Yahyai et al., 2014). This has resulted in decreased yield and selling price of locally produced fruits. Experiments have shown that several techniques can be followed to enhance the quality of fruit production, including management of irrigation water by utilizing deficit irrigation for date palm (Al-Yahyai and Khan, 2015) and bananas (Al-Harthi and Al-Yahyai, 2009), and improved storage (Al-Yahyai and Al-Kharusi, 2012) and marketing strategies (Al-Yahyai, 2007). Utilization of post-harvest technology can lead to enhanced marketability of major fruit crops, such as date palm (Al-Yahyai and Manickavasagan, 2012 a,b) and bananas (Opara et al., 2013, Opara et al., 2012).

Abiotic Stresses affecting Fruit Production in Oman

Drought, heat, salinity and climate change are major abiotic factors worldwide that limit fruit crop productivity and sustainability by disturbing their growth and productivity (Zörb et al., 2019). Generally, plants are highly susceptible to abiotic stresses due to their sessile nature, as these stresses limit their capability. It is reported that 90% of arable lands are suffering from one or more of the mentioned abiotic stresses and are causing about 70% yield losses (Reis et al., 2012; Mantri et al., 2012). Oman

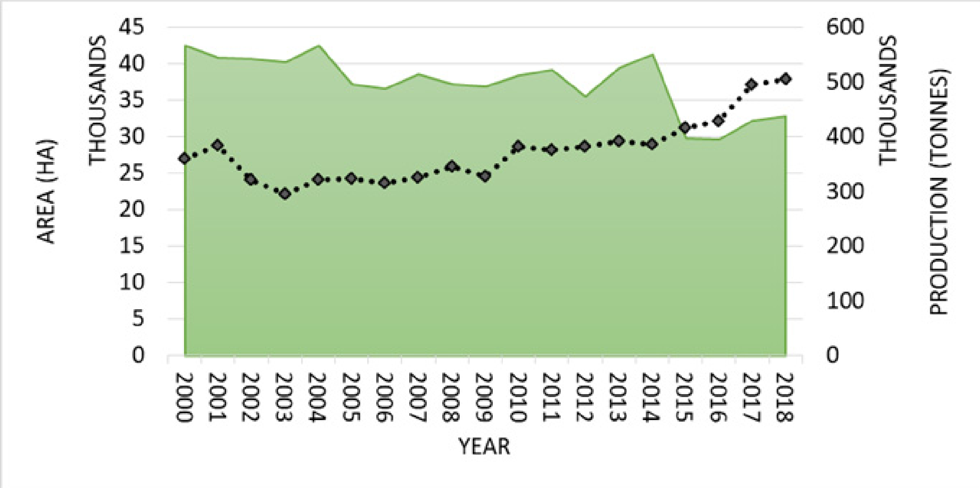

Figure 3. Fruit Area and Production in Oman (2000-2018) (Source: FAOSTAT, 2020).

fruit industry suffers from drought, aridity, salinity and water scarcity problems (Ahmed and Choudri, 2012). Also, more changes in environmental conditions may cause huge economic losses.

Due to climate change, the semi-arid regions are predominantly affected by abiotic stresses, resultant drought and soil salinization have been increased on agricultural lands. In arid and semi-arid regions, there is a natural phenomenon of high evapotranspiration and sea water entry in coastal areas, which causes salt accumulation around the plant rhizosphere (Sobhanian et al., 2020). Drought and salinity stresses have been increased due to global warming and anthropogenic activities such as improper irrigation and drainage. Besides, global warming, the changing rainfall pattern has also increased the evapotranspiration rate, which has ultimately increased the drought severity (Dai, 2011).

Drought

Due to environmental changes, the agriculture sector is greatly affected by drought stress, which seriously influences plant vegetative and reproductive stages (Chaves and Oliveira, 2004). Water is essential for all physiological functions occurring in plants. In drought, plants undergo complex anatomical mechanisms to regulate water in their body and inappropriate conditions stimulate fundamental changes in plant morphology, physiology and biochemistry of water-deficient organs (Anjum et al., 2011; Jarvis and Jarvis, 1963). To minimize water loss by transpiration, plants modify their anatomical characteristics like the closing of stomata, production of cuticle wax, reducing leaf area, besides it includes certain changes in plant physiological mechanism including a reduction in photosynthetic rate, changes in gene expression and increase in osmotic stress (Hadley and Smith, 2011; Munné-Bosch and Alegre, 2004; Chaves et al., 2003). In drought, the creation of drought-resistant varieties is a strategy to ensure proper food supply. The response of drought-tolerant species is different from the susceptible species. Plants adapt to drought stress in different ways, such as by changing their growth patterns, morphology and defense mechanism (Zandalinas et al., 2018). During drought, one of the most common mechanisms adopted by plants is the remobilization of prestored carbohydrates from stems to overcome drought (Schnyder, 1993). The other cellular and subcellular mechanism induced by plants during a drought include photosynthesis, antioxidative response, energy metabolism, osmotic adjustment, lipid metabolism, ion homeostasis and gene expression regulation (Sobhanian et al., 2020). Therefore, evaluation of drought-resistant cultivars, throughput analysis of plant genomics, proteomics and transcriptomics is required (Peng et al., 2009).

Effects of Drought on Fruits Trees

Horticultural crops are perishable and require a large amount of water for sustained growth and yield, whereas drought or water-deficient conditions adversely affect crop yields and quality. In fruit crops, the drought timing, duration, intensity, and species determine its hazardous effects. Date palm (*Phoenix dactylifera* L.) is the top fruit crop of Oman, which contributes about 80% to total fruit crops grown in the country (Al-Yahyai and Khan, 2015). It is considered tolerant to drought and salt stress and provides a significant contribution to the food security of the arid regions. However, recent threatened its productivity (Hazzouri et al., 2020). The date palm has various anatomical characteristics that enable it to tolerate drought stress, including thick pinnate compound leaves having waxy cuticles and spines on them. Besides, it has a deep root system, which enables it to maximize water uptake, while all other leaf traits help in minimizing evapotranspiration rate (Sané et al., 2005; Ramoliya and Pandey, 2003). Despite having drought-tolerant properties, it requires a lot of water for commercial productivity. Dates suffering from drought have reduced productivity and fruit quality (Hussain et al., 2012). Similar findings were observed by other researchers who stated that long-term drought negatively affects date palms by reducing their growth, productivity and quality (Elshibli et al., 2016; Alhammadi and Kurup, 2012). Arab et al. (2016) reported that 2-year-old date palm seedlings subjected to drought and heat showed a reduced concentration of antioxidants, e.g. ascorbate and glutathione in leaves. The fatty acid composition under drought was changed but it remained unchanged under heat environment, which shows that date palms may have independent metabolic systems to deal with drought and heat stresses. Proline accumulation occurs in plants due to multiple stresses; high proline contents were observed in date palms in response to drought and salinity, proline can be used as a possible marker in date palm to improve drought and salinity tolerance (Yaish, 2015).

The date palm (cv. Khalas) fruit chemical quality changes as a result of decreased water regimes, and overall the drought effects on fruit quality were significant (Al-Yahyai and Al-Kharusi, 2012). The Ministry of Agriculture and Fisheries reported that climate change and environmental constraints are major causes of date palm production instability in Oman. However, Kheiry (2017) used the stochastic model to analyze and identify the sustainable Date Palm Farming Systems in Oman. He argued that Al-Batinah is the most risk efficient region and recommended awarding economic incentives to growers for sustainable date palm varieties plantation and diversification which can minimize the sustainability risks of date palm production in Oman.

Al-Yahyai (2018) reported multifaceted challenges that growers are confronting in date palm production in Oman. He argued that farmer participation, training and extension agent's role can help in monitoring the crop limiting factors and mitigating such anomalies for the improvement of date palm cultivation and production of export-quality dates in Oman. It has been claimed that the date palm distribution in Oman will be changed due to ever-changing climate conditions. They used the basic CLIMEX software package to see the climate responses and later this was further integrated to demonstrate date palm possible distribution with two global climate models (GCMs) including CSIRO-Mk3.0 and MIROC-H. The earlier results showed that some regions may become unsuitable for date palm cultivation in Oman by 2100 (Shabani et al., 2015).

Historically, banana has been one of the most domesticated crops of the Arabian Peninsula and the gulf ports of Oman have played a major role in the exchange of banana genetic resources between Africa, China, the Indian subcontinent and the Arabian Peninsula, despite being arid and unfavorable climatic conditions for its cultivation (Al-Busaidi, 2013). Bananas are highly sensitive to drought, as they have large leaves with large air pockets inside; the annual evapotranspiration rate of bananas varies from 1200 to 2690 mm (Robinson and Alberts, 1986). *Musa* species show differences in stomatal conductance based on leaf age, climatic conditions and soil water relation (Ravi and Vaganan, 2016). In water stress, the flowering stage is highly affected as it is sensitive to drought, the lowest yield was observed in Banana genotype "Elakki" when drought was given at the flower differentiation stage (Murali et al., 2005). Similarly, the lowest yield was observed in genotype "Robusta" when water stress was applied after the flower set (Hegde and Srinivas, 1989). Ravi and Vaganan (2016) stated that the genotypes, "Rasthali", "Robusta" and "Karpuravalli" showed a reduction in bunch weights when stress was applied.

Mango (*Mangifera indica* L.) is the third-largest fruit crop of Oman after date palm and banana (Al-Yahyai et al., 2013). Due to the huge diversity of this crop, it has limited the outbreak of mango decline disease in Oman (Al-Adawi et al., 2006). In Oman drought conditions, mangoes showed a very little response in leaf visual parameters and leaf potential by adjusting their physiological functions according to drought. Mango growth comes in flushes, in drought, the mango vegetative flushes growth is reduced significantly, and it also lessens the leaf water contents, leaves in flush and flush length (Laxman and Bhatt, 2017). Water stress has a significant effect on mango reproductive growth, and it has been observed that drought stress for a longer time delayed flowering time (Tahir et al., 2003). However, drought for a lesser time enhanced flowering in mango (Scholefield et al., 1986). Similar findings were observed by Schaffer et al. (1994) who stated that drought has an inhibitory effect on vegetative flushes, but it promotes reproductive flushes. Drought can lead mangoes towards a decline in terms of yield and quality as well (Wei et al., 2017). Drought reduces fruit size by decreasing cell size and number and it also enhances fruit drop in mangoes (Singh, 2005). The variation in water requirement not only affects mango fruit size and yield but also affects fruit quality attributes like titratable acid, total soluble solids (TSS), starch and ascorbic acid contents (Wei et al., 2017).

Lime (*Citrus aurantifolia*) is one of the main citrus species cultivated in Oman, which represents about 3.44% of all fruit crops grown in Oman. However, in recent decades, the production of lime and its cultivated area is greatly reduced in Oman. This decline has been largely attributed to a combination of biotic and abiotic factors that negatively affected lime tree growth and yield (Al-Yahyai et al., 2012). In lime, abiotic stresses are of great concern as its key production countries such as India, Mexico and the Middle East are highly suffering from water scarcity and salinity (Donkersley et al., 2018). In citrus, irrigation and soil conditions are the important factors of its quality enhancement (Levy and Syvertsen, 2004). Well-managed and precision irrigation increases citrus economic production and profit (Ruiz-Sanchez et al., 2010). However, drought or water stress in citrus resulted in poor vegetative growth, yield and fruit quality, besides increasing pathogens susceptibility (Levy and Syvertsen, 2004). Similar findings were observed by other researchers who stated that water stress increased the incidence of disease development and has greatly influenced lime growth and yield (Syvertsen and Levy, 2005; Blodgett et al., 1997).

Grape (*Vitis vinifera* L.) is one of the most cultivated crops in the world. In 2005, drought severely affected grape yield and processing in South Africa, which resulted in an agricultural income loss of about 3.7 million dollars (Johnston, 2009). The family of Muscat grapes consists of more than 200 varieties; its name is associated with Muscat the governorate of Oman and these are planted at Jabal Akhdhar where the temperature is highly suitable for their production. Muscat grapes are known globally for their peculiar aroma (Ebuen, 2019). Grape is drought tolerant fruit as compared to other fruit crops and can endure stress conditions; however, it goes through certain morphological, anatomical and physiological changes during water stress conditions. Grapes have large xylem vessels as compared to other fruits, which enables them to tolerate water stress or drought (Serra et al., 2014). During adequate water supply its roots remain on the upper topsoil while during drought, roots move deep in the soil (Bauerle et al., 2008), leading to its increased root length but decreased shoot length (Hardie and Martin, 2000). A higher number of new roots were observed in grapes during drought for water uptake (Serra et al., 2014). Water stress causes stomata closure which limits photosynthesis and reduces dry mass production and yield (Berdeja et al., 2014). However, little drought stress at maturity increases sugar and phenolic contents in grapes (Van-Leeuwen et al., 2009).

Papaya (*Carica papaya* L.) is a drought-tolerant crop, however, to achieve its productive yield, sufficient water is required (Campostrini and Glenn, 2007). Drought drastically reduces papaya plant growth, nutrient uptake, transpiration, photosynthesis, chlorophyll contents and leaf abscission in papaya (Mahouachi et al., 2006; Slattery et al., 2017). Water stress conditions limit the physiological performance of papaya (Mahouachi et al., 2007), besides there is the highest accumulation of proline, abscisic acid and jasmonic acid during drought (Mahouachi et al., 2012). Masri et al. (1990) reported a 50% reduction in leaves, 86% in flowers and 58% in fruit, the growth and development of papaya fruit was highly reduced during drought.

Guava (*Psidium guajava* L.) is a dicotyledonous, evergreen plant that has tolerance against drought and saline conditions (Akram et al., 2017), however, various biotic and abiotic factors affect its growth. In guava, several morphological and physiological characteristics were affected by salinity (Bezerra, 2018). Salinity was also found to increase catalase, polyphenol oxidase, carotenoids, proline, but sodium chloride treatment decreased peroxidase and chlorophyll (a, b, and total) (Ghalati et al., 2020). Besides photosynthesis, drought severely affects certain biochemical and physiological functions (Estrada-Luna et al., 2000). Similarly, in coconut (*Cocos nucifera*) water deficit greatly affects the growth, productivity, and physiology of plants (Gomes and Prado, 2007; Passos et al., 2005).

Pomegranate (*Punica granatum* L.) is being grown in several parts of Oman, however, the green mountains (Al Jabal Al Akhdar) are the top areas where quality pomegranates are produced due to suitable climatic conditions, and is also a good source of income for growers (Al-Said et al., 2013; Al-Harthi, 2011). In Oman, harvesting of pomegranate local cultivars ('Hamedh', 'Malasi', 'Helow', 'Qusum') is done based on fruit size shape and color due to prevailing climatic conditions (Al-Yahyai et al., 2009). Pomegranate is popular due to the presence of antioxidants and phenolic compounds, while these contents vary with maturation, ripening and abiotic stresses (Labbé et al., 2016; Zarei et al., 2011). In pomegranate, Khattab et al. (2011) observed a decrease in chlorophyll contents with a decrease in irrigation. Similar findings were observed by Tavousi et al. (2015) who stated that it is highly susceptible to dehydration while it has resistance against salinity. Pourghayoumi et al. (2017) examined pomegranate cultivars under drought conditions and found increased proline contents in all cultivars except 'Ghojagh', while the cultivar 'Rabab' showed high contents reactive oxygen species (ROS) scavenging mechanism in drought conditions, besides these genotypes, showed good tolerance against drought as well.

Salinity

Salinity is one of the major problems in arid and semi-arid regions (Foster et al., 2018). More than 800 million hectares of land or over 6% of world soil surfaces are affected by this problem (Munns and Tester, 2008). Global annual losses in crops due to salinity are more than US $12 billion (Shabala, 2013). The first signs of salinity and its effects are osmotic effects, whereby the presence of high sodium chloride (NaCl) levels in soil inhibits water uptake leading to osmotic stress, which causes slow growth. Moreover, when the salt stress becomes severe, oxidative stress is induced and eventually causes death particularly in sensitive plants (Munns and Tester, 2008; Munns, 2002; Shabala, 2017). In the Sultanate of Oman, salinity has affected a large area of agricultural lands (Al-Yahyai, 2006). However, some fruit trees withstand harsh salinity conditions and thrive very well under salinity, such as date palms. In the Sultanate, date palm accounts for more than 200 cultivars (Al-Yahyai and Khan, 2015; Al-Yahyai, 2011). It is a dioeciously sustained fruit tree that can withstand salinity, drought, and temperature conditions (Hazzouri et al., 2020; Alhammadi and Kurup, 2012) it is a salinity tolerant fruit crop (Dowson, 1982; Yaish and Kumar, 2015; Sperling et al., 2014; Levy and Syvertsen, 2004; Furr and Armstrong, 1975). Date palm is a pivotal agriculture crop in Oman (Al-Yahyai and Khan, 2015; Al-Yahyai and Al-Khanjari, 2008), and the largest date palm yield is produced from the Al-Batinah region, the northern part of Oman (Al-Yahyai, 2011). According to FAO, the total date production in Oman is 8.5 Mt in 2018 (FAO, 2019).

Date palm growth and development decrease under environmental stress conditions. Reduction in date palm under salinity is well documented in different countries (Tripler et al., 2007; Tripler et al., 2012; Chao and Krueger 2007; Serret et al., 2020; Al-Qurainy et al., 2020; Al Mansoori et al., 2006) and in Oman (Jana et al., 2019; Yaish et al., 2015; Al-Yahyai, 2006; Al-Harrasi et al., 2020; Alrasbi et al., 2010; Haplogypsids et al., 2006; Erskine et al., 2004; Al-Yahyai and Manickavasagan, 2012a,b; Al Kharusi et al., 2017); however, the degree of reduction varies within the cultivars. Recently, several researchers in the country reported that salinity has affected the growth of some susceptible cultivars of date palm (Al Kharusi et al., 2017; Patankar et al., 2019, Al-Rahbi, Al-Mulla and Jayasuriya, 2020; Al-Harrasi et al., 2020). These cultivars can withstand low-moderate salinity, however, more energy is required to perform normal metabolism. Additionally, in date palm, there are some inappropriate irrigation practices such as using saline water, which is pumped from wells (Yaish et al., 2017) and has changed the groundwater recharge rates resulting in sea-water intrusion into the groundwater leading to soil salinization (Yaish et al., 2015) . Therefore, a significant cause of soil salinity may be owing to the use of poor-quality water for crop irrigation (Munns and Tester, 2008). Besides, other factors may have contributed to the reduction of date yields such as high evapotranspiration rates and low rainfall amount. On the other hand, some tolerant cultivars, when exposed to high salinity metabolize normally without showing any damage symptoms (Al Kharusi et al., 2017b). In general, salt stress can reduce date palm growth and development through different aspects such as osmotic effects, ion toxicity, inadequate nutrients (Al-Qurainy et al., 2020; Hazzouri et al., 2020). Aljuburi (1992) studied the effects of salt stress on the growth of four date palm cultivars, Lulu, Khalas, Boman and Barhee. He found that the cultivar Lulu was more susceptible to salinity than other cultivars.

Salinity tolerance, which involves several complex mechanisms, protects plants against the harmful effects of salinity. Date palm cultivars differ in their salinity tolerance capacities (Marashi et al., 2017; Al-Khateeb et al., 2019; Abdulwahid 2017; Djibril et al., 2005; Ibraheem et al., 2011; El-Khawaga, 2013; Yaish et al., 2015).

In the Sultanate of Oman, some date palm cultivars (i.e., Manoma, Umsila, Fard Nagal and Barni) can thrive in saline conditions (Al Kharusi et al., 2017; Alrasbi et al., 2010). Despite some of these cultivars are considered not good quality and used as animal feed (Al-Yahyai and Khan 2015; Al-Yahyai, 2006), are capable to adapt and mitigating the environmental impacts in their growing zones such as salinity stress. These cultivars possess various mechanisms that allow their roots, leaves and trunk tissues to cope with high salt availability where they are grown (Satisha et al., 2020; Patankar et al., 2019; Hazzouri et al., 2020; Al Kharusi et al., 2019; Youssef and Awad 2008; Kurup et al., 2009; Al Mansoori et al., 2006).

Salinity Adaptation Mechanisms in Omani Date Palm

Osmotic Adjustment Mechanism

The osmotic adjustment mechanism is a pivotal adaptation in date palm surviving under salinity because it helps to maintain turgor and cell volume amide salinity soil (Shabala and Shabala, 2011; Munns and Tester, 2008). Recently, an osmotic adjustment mechanism was reported in some Omani date palm cultivars (Al Kharusi et al., 2017) via an efficient photosynthetic system as indicated by the higher quantum yield, stomatal conductance, membrane stability and the excessive photochemical energy diverted to various pathways. Also, an osmotic adjustment mechanism was reported in another Omani cultivar (Al-Harrasi et al., 2020), where salt ions are then regulated and transported across the cell membrane via the proton motive force (pmf) (Wegner and Shabala, 2020) and pumped by the date palm gene (Pd6NHX) into the vacuole of transgenic Arabidopsis plants (Al-Harrasi et al., 2020), followed by electrochemical gradients. Then the gradients are balanced by the synthesis of high hydration organic metabolites and compatibles. These metabolites were indicated in recent research in Omani date palm cultivar as an adaptation mechanism under salt stress (Al Kharusi et al., 2019b), including sugars, nitrogenous compounds (proline and glycine-betaine) in the cytoplasm. These solutes are capable to stabilize the cytoplasmic enzymes on the cellular membranes, thereby protecting them against inactivation by salt ions (Smirnoff and Stewart, 1985), where they play a pivotal role in mitigating NaCl-induced potassium K^+ efflux (Shabala et al., 2012), and these have a direct protective role for membrane integrity as osmoprotectants under salt stress and other environmental stresses (Zhang et al., 2010; He et al. 2010; Yaish, 2015). They also have an indirect protective role through participating in signal transduction pathways (Kumar et al., 2018). Similarly, effects of high salinity irrigation on growth, gas exchange, and photoprotection on young date palms (cv. Medjool) were reported by Sperling et al. (2014), where photosynthetic efficiency and potentially were preserved through osmotically driven stomatal closure. Furthermore, another Omani date palm (cv. Umsila) was reported as a saline tolerant cultivar and can adapt to salinity by better maintenance of plant-water relations (Al Kharusi et al., 2019). However, the synthesis of sufficient osmoprotectant is metabolically expensive and energy exhaustive in plant tissues (Chen and Jiang, 2010). However, date palms have proven to accumulate high energy primary and secondary metabolites such as antioxidants, vitamins, growth regulators, sugars and nitrogenous compounds (Al-Kharusi et al., 2009; Abdulwahid, 2012; Al Kharusi, Al Yahyai and Yaish, 2019a, Jana et al., 2019, Daoud et al., 2019).

Ion Homeostasis Mechanism

Salt Inclusion vs. Exclusion

Some of the physiological and molecular basis of salt tolerance in Omani date palm cultivars were reported (Al Kharusi et al., 2019b; Al-Harrasi et al., 2020; Alrasbi, Hussain and Schmeisky, 2010; Jana et al., 2019; Yaish et al., 2015; Al-Yahyai and Manickavasagan 2012a,b; Patankar et al., 2016). Besides the production of organic Osmo-regulators, date palm tissues also possess an alternative mechanism to accumulate high levels of ions, such as K+ and calcium Ca^{2+} and more other ions from the external soil medium (Al Kharusi et al., 2019b). Date palms can take up low amounts of Na^+ in the leaves tissues and accumulate high amounts of K^+ (Al-Rahbi et al., 2020; Al Kharusi et al., 2017a,b; Patankar et al., 2019a,b), with low energy demand. In a recent study on the salinity tolerance mechanism on Omani date palm (cv. Khalas), it was proven that overexpression of one of the date palm aquaporin genes (PdPIP1;2) confer salinity tolerance and implicated in Na^+ and K^+ transportation (Patankar et al., 2019a). In addition, it was found that accumulation of this gene in the date palm leaves under different stress conditions (e.g. drought) could also have a role in photosynthesis efficiency (Patankar et al., 2019a). Another study on Omani established young date palm seedlings (cv. Umsila) reported that significant accumulation of enzymatic and non-enzymatic antioxidants are pivotal and have caused a significant increase in the xylem loading of K^+, which then is translocated to the leaves (Assaha et al., 2017) as a result of higher K^+/Na^+ ratio balance. Additionally, this study revealed that both leaves and roots tissues maintained higher chlorophyll content indicating better photosynthesis capacity and high proline content and subsequently decreased reactive oxygen species (ROS), which confer salinity tolerance (Al Kharusi et al., 2019). Another recent study on Omani date palm revealed that a cloned date palm gene (PdMT2A) improved drought and salinity stress tolerance in transgenic Arabidopsis plants and showed a higher K^+/Na^+ ratio (Patankar et al., 2019b).

Salt tolerance in date palm is associated with lignin accumulation (Al Kharusi et al., 2019b) and the formation of Casparian strips (Jana et al., 2019). Increased deposition of lignin in the steel was reported in Omani date palm salt-tolerant cultivar (Al Kharusi et al., 2019), as lignification was observed in the root endodermal vascular tissues in response to salinity. On the other hand, increased deposition of Casparian band was reported in two Omani date palm cultivars (Al Kharusi et al., 2019b; Jana et al., 2019). Casparian strip enhances selective ion and water movements across the root cell membranes and maintains a balanced Na^+/K^+ ratio and antioxidant defense as well (García-Caparrós et al., 2018). Also, Casparian strips enhance the apoplastic barriers and regulate hydraulic conductivity in roots and therefore, prevent the non-selective apoplastic bypass of Na^+ into the stele tissues, which helps increase salinity tolerance (Zimmermann et al., 2000; Karahara et al., 2004). It was also proposed that maize, cotton and beans tend to accelerate the growth of the exo- and endoderm cells in response to salinity (Karahara et al., 2004; Reinhardt and Rost, 1995; Schreiber et al., 2005). Also, the effects of high salinity irrigation on the growth of young date palms (cv. Medjool) was reported by Sperling et al. (2014), where toxic sodium ions were excluded from the leaves of the young seedlings through the exclusion method.

Accumulation of Global Metabolomics and Differential Metabolites Mechanism

Salt tolerance mechanisms are yet to be puzzled out in date palm, since specific metabolites may be associated with salinity tolerance. A study aimed to decipher the salinity tolerance mechanism in date palm based on the information encoded by the metabolomics profiles of the Omani date palm salt-tolerant cultivar revealed the presence of natural metabolites, potent antioxidants, growth regulators and essential vitamins under salt conditions. These metabolites may help to improve the membrane capacities to control water and ion flow, as well as modification of the lignin and Casparian strip constituents, which may assist in better salt exclusion. In addition, the enhancement of the accumulation of various antioxidants, which act as reactive oxygen species (ROS) scavengers, may help to reduce the oxidative damage caused by salinity. Therefore, these metabolites could represent a key mechanism for salt tolerance in date palms. Also, this study showed another adaptation mechanism through the accumulation of some membrane and cell-wall constituents that were altered in response to salinity in date palms such as phospholipids, antioxidants, and vitamins. The phosphatidylethanolamine (LysoPE), a plant growth regulator, is among the phospholipid metabolites and was found exclusively accumulated in the leaves of the salt-tolerant cultivar (cv. Umsila) when exposed to salinity. This metabolite is involved in the growth-promoting activity (Cowan, 2009). Another accumulation of glycolipids was noted from this study; monogalactosyldiacylglycerol (MGDG) increased by 5.8-fold and digalactosyldiacylglycerol (DGDG) were exclusively detected in the leaf tissues of 'Umsila' when exposed to salinity. The abundance of these two glycolipids in the membrane determines the stability and physical properties of the thylakoid membrane of the chloroplast, which may influence salinity tolerance (Quartacci et al., 2000). This study also reported various antioxidants, which were identified using the LC-MS technology and were mapped to the flavonoid synthesis pathways that usually result in the production of antioxidants metabolites and potential free radical scavengers (Figure 4). These metabolites included catechin, epicatechin, and eriodictyol. Epicatechin and catechin, which are flavonoids that perform antioxidant and iron-chelating functions (Morel et al., 1993, Koch et al., 2017). These compounds accumulated in salinity-treated 'Umsila' seedlings. This study also revealed the importance of vitamin B9 in date palm under salinity stress, as it was found that metabolites such as 5, 10-methenyltetrahydrofolic acid, L-glutamic acid, methionine, cysteine, and other antioxidants were involved in vitamin B9 synthesis. These metabolites were differentially accumulated in cv. 'Umsila' upon exposure to salinity. Previous studies have also shown that vitamin B9 is involved in abiotic stress tolerance in plants, with susceptible plants unable to maintain a reasonable level of this vitamin under abiotic stresses (Hanson et al., 2016).

Biotic Stresses affecting Fruit Production in Oman

Several biological challenges affect fruit production in Oman. Biotic stresses are important due to the economic losses that cause to fruit growers. Several studies have identified, major issues with fruit crops, most notably Dubas bug on date palm, phytoplasma in lime, viral & fungal diseases in citrus, and mango sudden wealth in mangoes, are the most common causing major challenge to the main fruit crops in the country.

Dubas bug (*Ommatissus lybicus* de Bergevin) is a major pest that causes major damage to date palm and reduces its growth and productivity (Al-Kindi et al., 2018) and requires large chemical input to control this pest. Studies have been conducted to investigate the potential of natural enemies such as *Pseudoligosita babylonica* Viggiani, *Aprostocetusnr beatus*, and *Bocchus hyalinus* to control the Dubas bug (Al-Kindi et al., 2018). Further research on the impact of Dubas bug distribution throughout Oman and the environmental and climatic factors that affect the distribution of Dubas. Studies have predicted that the north of Oman is presently at great risk of Dubas bug invasions and will remain high in 2050 and 2070 (Shabani et al., 2018).

Mango Wilt Disease in Oman

Mango is an important fruit crop in Oman with a cultivation area of 1,269 ha, representing 3.39% of the total

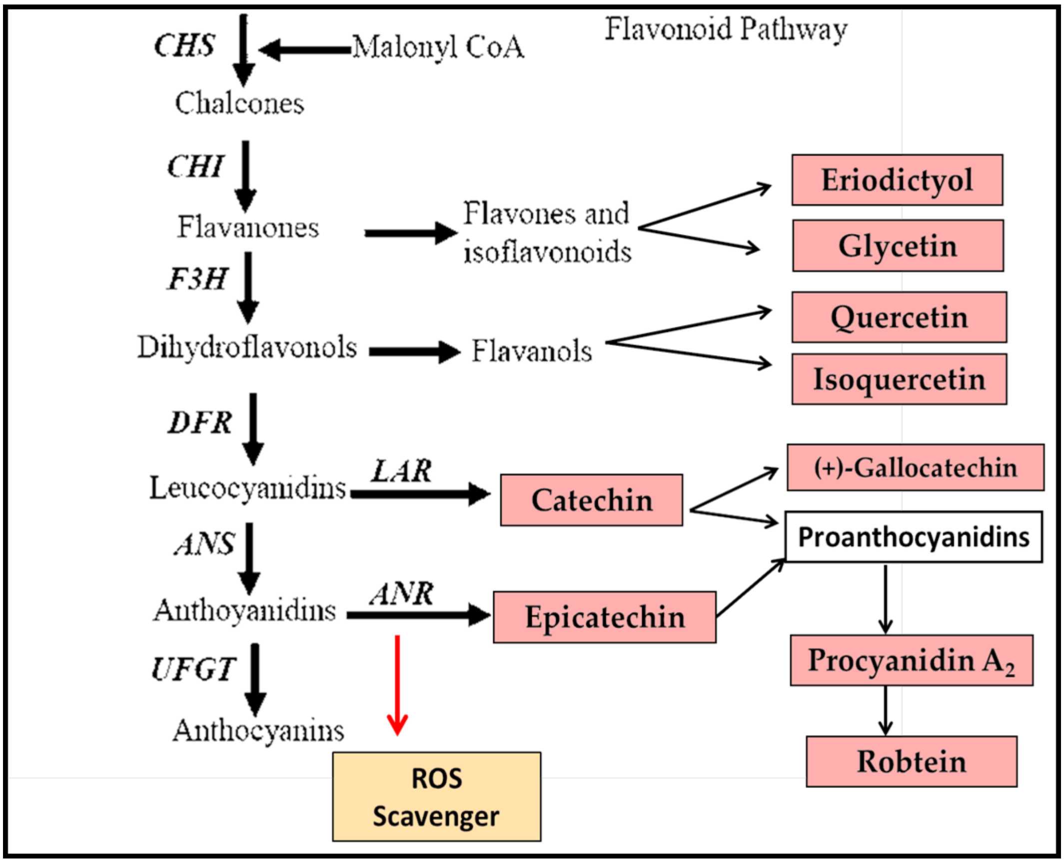

Figure 4. The involvement of differentially accumulated metabolites in response to salinity in the flavonoid pathway and the production of antioxidants. The pink boxes indicate the differentially accumulated metabolites in date palm as a result of salinity.

fruit cultivated area with a production of 10.9 thousand tons (Table 1). Mango wilts disease, caused by *Ceratocystis manginecans* (Al Adawi et al., 2006; Van Wyk et al., 2007), is the most serious threat to the production of mango in the country. The disease killed thousands of mango trees in Oman since its first report in 1998 (Al Adawi et al., 2006). The bark beetle *Hypocryphalus mangiferae* vectors the pathogen from diseased to healthy hosts, which helps spread the disease (Al Adawi et al., 2013a).

Data from the agriculture census in 2004/2005 estimated the death of over 210,000 mango trees during 2000–2005 in the Al Batinah region alone (MAF, 2002; 2003; 2004; 2006). The disease is more severe in trees propagated from local seed sources and on exotic cultivars grafted on the rootstock of Omani cultivars (Al Adawi et al., 2006).

Mango wilt disease management includes chemical treatments that are expensive and effective only for short periods of time. The selection of resistant cultivars is a long-term effective control of this disease. *C. manginecans* inoculation trials in Oman showed that the cultivar 'Pairi' and local mango cultivars were highly susceptible. On the other hand, the cultivars 'Hindi Besennara', 'Sherokerzam', 'Mulgoa', 'Baneshan', 'Rose', and 'Alumpur Baneshan' were relatively resistant (Al Adawi et al., 2013b).

Witches' Broom Disease of Lime (WBDL)

Acid lime has been a major commercial crop in Oman for decades. However, acid lime production has been seriously hampered over the last forty years due to Witches' Broom Disease of Lime (WBDL). In Oman, lime production has declined by 75% due to WBDL and now it stands at an average 6.68 thousand tons representing 1.79% of fruit production in the country (Table 1). About 80% of the mature acid lime crops are infected with WBDL and most of them either have been killed or removed from the orchards (Khan, 2000; Al-Yahyai et al., 2012). Affected acid lime trees show witches' broom, small leaves, production of several branches and reduction in flower and fruit production from symptomatic branches of infected trees (Al-Yahyai et al., 2015). WBDL has been worsened by biotic stresses that include *Citrus tristeza virus* and citrus viroids (Al-Sadi et al., 2017) and abiotic conditions caused by drought and salinity. The disease is caused by '*Candidatus* Phytoplasma aurantifolia' (16SrII-B) (Zreik et al., 1995; Al-Subhi, 2018). WBDL has also been reported in the UAE, Iran, Saudi Arabia, India and Brazil (Bove et al., 2000; Alhudaib et al., 2009, Queiroz et al., 2016; Ghosh et al., 1999). Infected acid lime trees from southern Oman, Saudi Arabia and Brazil do not show typical witches' broom symptoms (Al-Subhi, 2018). Environmental conditions may influence symptom expression (Al-Ghaithi, 2017). Other citrus species like citron, lemon, *C. macrophylla* and rough lemon have been reported as hosts of the '*Ca.* P. aurantifolia' in Oman (Al-Subhi, 2018, Al-Subhi et al., 2019, Al-Yahyai et al., 2012).

WBDL phytoplasmas can be transmitted by different means including insect vectors, grafting and seeds. There is evidence that WBDL phytoplasma can be transmitted via seeds (Al-Shanfari, 2000; Al-Amri, 2006). The main means of spread of phytoplasma diseases in the fields is by phloem-feeding insect vectors in the families Cicadellidae (leafhoppers), Fulgoridea (planthoppers) and Psylloidae (psyllids). Two hemipteran species, leafhoppers and psyllids were recorded as vectors of WBDL phytoplasma in Oman (Queiroz et al., 2016).

Citrus Tristeza Virus (CTV)

Citrus tristeza virus (CTV) resulted in extreme losses in citrus in different parts of the world. The first report of CTV epidemics was in the early 20th century in South Africa where millions of citrus trees grafted on sour orange rootstocks collapsed (EPPO, 2004). Subsequently, millions of citrus trees were lost in Argentina and Brazil in the 1930s (Bar-Joseph et al., 1989). Also, over 40 million trees declined progressively in Spain in 1957 (Cambra et al., 2000).

CTV causes different symptoms, the most severe of which are rapid decline (tristeza) and stem pitting. The first causes the decline of trees grafted on sour orange, where grafted trees start collapsing in a few weeks. Trees affected with CTV stem pitting strain can show variously sized pits or grooves on twigs or trunks (Brlansky, 2002). Stem pitting symptoms are common in lime, pummelo, grapefruit and sweet orange (Lee and Bar-Joseph, 2000). Other symptoms include leaf chlorosis, stunting and a reduced root system. CTV dispersal can be either by the propagation of virus-infected buds that can cause an introduction of CTV to a new area (Bar-Joseph and Lee, 1989) or by vector transmission.

In Oman, the first detection of CTV was reported in 1986 in grapefruit, mandarin and lemon seedlings shipped from India (Bove, 1995). *Aphis gossypii*, which is one of the important vectors of CTV, was reported in Oman in 1984 (Moneem, 2005). The Ministry of Agriculture (MA) surveyed the Sultanate in 2007 and 2008. They found that CTV is associated with acid lime and is distributed in Muscat, Dhofar and Al Batinah regions (MA, 2009). A subsequent study by Al-Sadi et al. (2012) in 2009 and 2010 showed that CTV is present in acid lime farms in Barka, Alrustaq, Shinas, Sohar, Alsuwaiq, Boushar, Alseeb, Quarayat, Dhank, Yanqul, Ibri, Mahadha, Bahla, Nizwa, Samael, Dibba, Madha, Ibra, Almudhaibi, and Salalah. The incidence ranged from 3 to 63%. In addition, CTV was detected in citrus seedlings/budlings imported from different countries.

Management options of the disease should include strict quarantine measures and eradication programs (Navarro et al., 1984; Frison and Taher, 1991). All citrus-growing counties should have certification programs to ensure that CTV is not spread with budwood

Table 1. Area and production of major fruit crops in Oman (2000-2018) (Source: FAOSTAT, 2020).

	Area (ha)					Production (tons)				
Year	All Fruits	Dates	Bananas	Limes	Mangoes	All Fruits	Dates	Bananas	Limes	Mangoes
2000	42,485.00	35,508.00	2,633.00	1,678.00	1,507.00	359,353.00	280,030.00	32,150.00	8,210.00	10,874.00
2001	40,758.00	33,919.00	2,716.00	1,620.00	1,510.00	383,465.00	298,006.00	33,680.00	8,560.00	10,945.00
2002	40,672.00	33,869.00	2,610.00	1,690.00	1,510.00	320,298.00	238,611.00	32,915.00	8,385.00	10,910.00
2003	40,198.00	33,848.00	2,520.00	1,440.00	1,500.00	295,395.00	219,770.00	28,750.00	6,830.00	10,910.00
2004	42,463.00	35,532.00	2,856.00	1,210.00	1,470.00	320,275.00	231,000.00	34,000.00	5,875.00	8,700.00
2005	37,173.00	31,353.00	2,225.00	1,242.00	1,070.00	324,012.00	247,331.00	26,720.00	6,159.00	7,743.00
2006	36,580.00	31,353.00	2,225.00	1,242.00	1,071.00	315,090.00	258,738.00	25,955.00	5,916.00	6,882.00
2007	38,521.00	32,746.00	2,435.00	1,231.00	1,071.00	325,544.00	255,871.00	28,892.00	5,983.00	6,373.00
2008	37,239.00	31,353.00	2,435.00	1,231.00	1,071.00	345,560.00	267,000.00	29,000.00	7,440.00	10,000.00
2009	36,947.00	31,353.00	2,436.00	1,233.00	1,071.00	327,379.00	258,572.00	28,890.00	6,354.00	10,199.00
2010	38,468.00	31,353.00	3,720.00	1,233.00	1,071.00	382,421.00	276,405.00	56,686.00	6,354.00	10,199.00
2011	39,136.00	31,348.00	4,374.00	1,236.00	1,071.00	376,587.00	268,011.00	61,584.00	6,503.00	8,949.00
2012	35,526.00	30,615.00	2,500.00	710.00	610.00	382,491.00	281,000.00	56,790.00	6,340.00	8,600.00
2013	39,434.00	34,195.00	1,400.00	1,200.00	1,490.00	391,497.00	308,400.00	19,970.00	6,250.00	12,969.00
2014	41,218.00	36,255.00	1,421.00	1,208.00	1,019.00	386,583.00	317,400.00	18,184.00	5,943.00	9,496.00
2015	29,832.00	24,120.00	1,421.00	1,208.00	1,496.00	416,832.00	344,690.00	16,578.00	6,199.00	15,673.00
2016	29,576.00	24,120.00	1,421.00	1,207.00	1,496.00	427,567.00	355,332.00	16,578.00	6,199.00	15,673.00
2017	32,126.00	24,617.00	1,564.00	1,302.00	1,505.00	495,765.00	360,917.00	18,397.00	6,340.00	15,924.00
2018	32,805.00	25,125.00	1,560.00	1,399.00	1,506.00	505,114.00	368,808.00	18,265.00	7,112.00	15,847.00
Average	37,429.32	31,188.53	2,340.63	1,290.53	1,269.21	372,696.21	286,099.58	30,736.00	6,681.68	10,887.68
% of total		83.32	6.25	3.44	3.39		76.76	8.25	1.79	2.92

or seedlings (Navarro et al., 1988). It is also important to avoid grafting trees on sour orange rootstocks as they make trees more vulnerable to the decline disease.

Fusarium Wilt Disease of Banana

Banana is the second most important fruit crop Oman. Over 2.3 thousand hectares of agricultural land in the Sultanate are grown with the banana crop of various varieties producing an annual average of 30.74 tons, which represents 8.25% of all fruits produced in Oman (Table 1). The North and South Al Batinah governorates come first in terms of cultivated area, with an area of 4,197 faddan (1762.74 ha), followed by Dhofar Governorate with 960 faddan (403.2 ha), then Sharqyia governates with an area of 81 faddan (34.02 ha) (MAF, 2014). Banana varieties grown in Oman include dwarf cavendish (local known as Malindi bananas), Al-Barshi, Somali, Al-Fard, and Williams (Viswanath, et al., 2000, de Langhe, 2002, Al-Hosni et al., 2010; Al-Saady et al., 2010). Many diseases limit banana production in the world like Fusarium wilt (Panama disease), Moco disease, black segatoka, bunchy top virus disease (Ploetz, et al., 2003).

Banana Fusarium wilt disease caused by *Fusarium oxysporium* f.sp *cubense* (FOC) is a soil borne disease and pathogen persist in the infected area for decades. The pathogen initially infects banana plants through roots then moves through the plant into the vascular system within the pseudo-stem and blocks vascular tissue and causes plant death. Infected banana plants exhibit yellowing of older leaves and discoloration of vascular tissues. The disease became most destructive in many banana-growing countries. The disease was firstly reported during 1874 in Australia and later race1 of the pathogen FOC was reported in Central American countries (Ecuador and Panama) wiping Gross Michel banana cultivar from these areas and South America. Consequently, the Gross Michel cultivar was replaced with the cultivation of Cavendish cultivars which was resistant to FOC race 1, and Cavendish cultivars dominated the market (Ploetz, 2005).

During the early 1990s, a new race of FOC called Tropical race 4 (TR4) was reported Southeast Asia causing a serious problem for Cavendish cultivars plantations in this region (Ploetz, 2006a &b). The new race TR4 spread around the world and reported threatening banana cultivation in many countries in Asia, Africa and recently in South America (Damodaran et al., 2019, O'Neill et al., 2016, Ordóñez et al., 2016, Ploetz, 2015, Ploetz, et al., 2015). In Oman, symptoms resembling that of Fusarium wilt disease of banana were first observed in northern governates. Samples from diseased banana plants were collected from infected farms and isolated pathogen identified as FOC race TR4 using molecular diagnostic marker (Dita et al., 2010). Integrated disease management options of Fusarium wilt of banana should be considered as until now there is no known effective chemical or biological control measures for this serious disease. Strict quarantine measures are important to prevent the spread of the disease from infected area to new healthy banana plantations and Oman has established strict quarantine measures in banana production regions to prevent the spread of diseases. Furthermore, tissue culture banana plant materials should be the sole source for planting banana in an area free of FOC TR4 and avoid using sucker planting material as it could be a source of new inoculum of the pathogen to an area free of the disease. Several banana cultivars were found to be moderately resistant to FOC TR4 including Giant Cavendish Tissue Culture Variants (GCTCV), which was developed in Taiwan and two of these variants including GCTCV 218 & GCTCV 219 were used in several countries to reduce the impact of the disease in the infected area. Furthermore, several hybrids developed through a breeding program at Fundacion Hondurena de Investigacion Agricola (FHIA) in Honduras such as FHIA 1, FHIA 2, FHIA 3, FHIA 18 and FHIA 25 were found slightly susceptible to FOC TR4. However, all the above-mentioned bananas were not acceptable in the market, compared with world-known Cavendish cultivars such as William and Grand Nain (Ploetz, 2015a &b). Many of these developed cultivars of banana are being evaluated in the banana gene banks at research centers of Al Batinah and Dhofar in Oman.

Climate Change

Globally, climate change is of major concern (Thomas et al., 2004). Due to this climate change, Oman has been ranked at 40th position by German Watch, based on data available at Global Climate Risk Index (Harmeling, 2010). According to IPCC (Intergovernmental Panel on Climate Change) findings, Oman has been declared at higher risk due to climate change and the increasing temperature, sea level, erratic rainfall pattern and their combination is leading Oman towards desertification by affecting its coastal regions and ecosystem (IPCC, 2007). The climate of a particular area affects its various environmental aspects and climate change greatly reduces agricultural productivity and stability, by changing cropping patterns and loss of agricultural land (Waqas et al., 2019).

Climate change is one of the major concerns of 21st century, anthropogenic activities have increased the carbon dioxide level in the atmosphere which has resulted in very high or low temperatures and irregular rainfall patterns. Due to these climatic changes, stresses occur in plants which severely affect agriculture production and are key constraints to the food supply, as climate change disturbed the cropping season, pattern, duration, and production intensity (Harmeling, 2010). Oman is at high risk of these vulnerable climate changes, for example, there is an increase in average temperature, sea level, desertification, and irregular rainfalls. Besides in 2007 and 2010, Oman suffered from two cyclonic storms that caused adverse effects on agriculture production and plant genetic resources (Al-Khafaji et al., 2017). It is also speculated that recent harmful algal bloom outbreaks along the Oman coast are due to climate change (Al-Azri et al., 2010).

Cold stress and heat stress, both are related to temperature, any of these stresses during plant development stages severely affect crop production (Zhou et al., 2018). The temperature stress in plants reduces their biochemical and physiological functions by tempering their molecular mechanism (Takahashi and Shinozaki, 2019). High-temperature stress increases plant growth and reduces crop duration (Lobell et al., 2011). It greatly affects plant reproductive growth by reducing pollen viability, pollen fertility, flower abortion, and pistil tissues (Djanaguiraman et al., 2018; Talwar et al., 1999). It has also been reported that heat stress or high temperature causes premature another development, restricted cell proliferation and induces male sterility in plants (Oshino et al., 2007; Abiko et al., 2005). Likewise, cold temperature stress affects the cropping season and yield as well, according to geographical distribution one-degree drop on average can reduce the yield of summer field crop up to 40% (Larcher, 2003). Cold temperature affects plants at various stages including the early stage, acclimatization phase, developmental stage, and fruit maturity stage. Cold stress at any stage of plants highly disturbs its biochemical and physiological functions.

Potential Impact of Climate Change

Climatic factors such as temperature and precipitation affect the quality and production of fruits (Akram et al., 2020). In Oman, high temperature is of great concern as it disrupts various plant physiological processes. During the photosynthesis process, high temperature causes carbon fixation in dry matter, disturbs plant parts during its various stages of development (Laxman and Bhatt, 2017). Generally, in fruit plants, it causes sunburn of various plant parts like leaves, branches, twigs and stems. Besides, it retards shoot and root growth, leaf senescence and fruit discoloration (Wahid et al., 2007). It also disrupts plant normal cell functioning and reproductive stages.

The date palm can tolerate a wide range of climatic conditions, it can tolerate frost and is well adapted to heat as well. Temperature widely affects date growth, flowering, fruit setting and fruit production. Due to high temperatures, early bloom in dates was also noticed (Darfaoui and Assiri, 2009). Dates require prolonged summer to mature fruit, however, rainfall and humidity at fruit maturity cause fruit cracking and attract fungal diseases (Burt, 2005). Date palm can tolerate temperature up to 50°C under irrigation and as low as 0°C, however, growth is restricted below 7°C and above 40°C and it also affects the quality of date production (Al-Yahyai, 2018).

The date palm biodiversity is on a steady decline in Oman due to certain biotic and abiotic factors. However, realizing the vulnerability of *in-situ* gene banks of date palm, newer approaches for preserving local varieties are being investigated. Detailed studies on date palm in Oman are under way at the Date Palm Horticulture Research Laboratory, Jimmah (MAF, 2006). It has been argued that Oman is prone to climate change effects and farming and precious plant genetic resources are under threat due to ever-changing climate, population influx, urbanization, and other factors along with environment are playing substantial roles in agricultural activities and Plant Genetic Resources (Hameed et al., 2017).

In mango, temperature determines vegetative and flowering flushes. High temperature induces vegetative flushes (Laxman and Bhatt, 2017), temperature below 16 °C induces floral induction (Schaffer et al., 1994). Panicles that emerged below low temperature have more male flowers (Singh et al., 1974). The sudden variability in climate change may influence the vegetative and reproductive growth of mango by affecting its production. Recently extreme weather scenarios such as Gonu in 2007 and Phet in 2010, and torrential rains-caused flooding have damaged the date plantation. Events related to climate change may be the next challenge to date palm sustainable cultivation in Oman. The government helped in replacing date palms destroyed by climatic catastrophes like cyclones and storms (Al-Yahyai and Khan, 2015).

Each grape cultivar performs well in a suitable range of temperatures and changes in temperature of climate its physical and biochemical parameters (Akram et al., 2020). In grapes, the adaptability of genotypes of a particular region enables it to produce fruit efficiently (Akram et al., 2019). High-temperature effects sugars, acids and antioxidant compounds in grapes, besides it may affect the aroma and color of grape vines (De-Orduna, 2010). In grapes, high temperatures lead plants towards prematurity due to which berry size does not develop properly.

Due to climate change, frost and storms have changed the citrus phenology which has increased the risk factor (Fitchett et al., 2014). The global increase in temperature has increased the distribution and behavior of citrus insects. For example, the incidence of pathogens *Candidatus* and *Diaphorina citri* is highly increased with an increase in temperature (López-Arroyo et al., 2009). Likewise, rainfall distribution highly affected the natural distribution of citrus black spot disease (Martı´nez-Minaya et al., 2015). In coconut, the high temperature reduces the pollen production and promotes male flowers induction (Burke et al. 2004), besides high temperature and excessive rainfall cause flower and fruit abortions (Nainanayake et al. 2008). Likewise, in banana, growth is also affected by high temperature and it was observed that leaf emergence and fruit production was highly reduced beyond 33.5°C and 35°C, respectively (Thornton and Cramer, 2012). In pomegranate, the ideal temperature for fruit growth is from 17 and 26°C, the high temperature at the fruit maturity increases oxidative stress by increasing peroxidase activity (Fischer et al., 2013). High temperature also varies antioxidant, anthocyanin, and the chemical composition of pomegranate fruits (Fernandes et al., 2015).

Conclusion

The potential for expanding fruit crop production in Oman is great, especially since the country has the requirements, including diverse climatic conditions, educated labor force, market chains, industrial infrastructure, and logistical needs. Knowledge and cumulative experience that is based on research is also growing and aims to address fruit crop cultivation challenges. This review paper has highlighted the latest research on major challenges to fruit production in Oman, which include abiotic and biotic stress factors. In recent years, Oman witnessed a drastic change in climatic patterns and severe weather attributed to climate change, and existing adverse conditions, such as heat, salinity, and drought. Fruit production constitutes a large percentage of the total agricultural cultivated area in Oman, and almost 90% consists of date palm, banana, lime, and mango. In addition to the abiotic stress, major fruit crops have declined in recent years due to various biotic stressors, primarily pests and diseases including Dubas bug and Red Palm Weevil. Furthermore, lime has been infected with Witch's Broom Disease of Lime (WBDL) caused by '*Ca*. Phytoplasma aurantifolia', and large areas of mangoes have been lost to Sudden Wilt. Several solutions have been proposed to address these challenges, however, further research is still needed as the challenges will continue to grow. Furthermore, applied research is still lacking in the areas of fruit production best management practices and postharvest processing.

References

Abdulwahid AH. (2012). Investigation of the effect of salt stress on the antioxidant enzyme activities on leaves of date palm (*Phoenix dactylifera*) seedling. Advances in Agriculture & Botanics 4(3): 94-102.

Abdulwahid AH. (2017). Mechanisms of date palm *Phoenix dactylifera* salt tolerance, effect of water salinity on some cell wall enzymes activity during development of Sayer date palm fruit. Advances in Agriculture & Botanics 9(3): 154-160.

Abiko M, Akibayashi K, Sakata T, Kimura M, Kihara M, Itoh K, Asamizu K, Sato S, Takahashi H, Higashitani A. (2005). High- temperature induction of male sterility during barley (*Hordeum vulgare* L.) anther development is mediated by transcriptional inhibition. Sexual Plant Reproduction 18(2): 91-100.

Abu-Sharkh B, Hamid H. (2004). Degradation study of date palm fibre/polypropylene composites in natural and artificial weathering: mechanical and thermal analysis. Polymer Degradation and Stability 85(3): 967-973.

Agrios GN. (2005). Plant Pathology 5th Edition Academic Press. San Diego, CA.

Ahmed M, Choudri BS. (2012). Climate change in Oman: Current knowledge and way forward. Education, Business and Society: Contemporary Middle

Eastern Issues 5: 228-236.

Akram MT, Qadri RWK, Khan I, Bashir M, Jahangir MM, Nisar N, Khan MM. 2017. Clonal multiplication of guava (*Psidium guajava* L.) through soft wood cuttings using IBA under low-plastic tunnel. *International Journal of Agriculture & Biology, 19*(3): 417-422.

Akram MT, Qadri RWK, Jaskani MJ, Awan FS. (2019). Ampelographic and genetic characterization of grapes genotypes collected from Potohar region of Pakistan. Pakistan Journal of Agricultural Sciences 56(3): 595-605.

Akram MT, Qadri RWK, Jaskani MJ, Awan FS (2020). Phenological and physicochemical evaluation of table grapes germplasm growing under arid subtropical climate of Pakistan. Pakistan Journal of Botany 52(3): 1011-1018.

Al Adawi AO, Al Jabri RM, Deadman ML, Barnes I, Wingfield B, Wingfield MJ. (2013a). The mango sudden decline pathogen, *Ceratocystis manginecans*, is vectored by *Hypocryphalus mangiferae* (Coleoptera: Scolytinae) in Oman. European Journal of Plant Pathology 135(2): 243-251.

Al Adawi AO, Al Sadi BA, Deadman ML, Barnes I, Al Jabri MH, Wingfield BD, Wingfield MJ. (2013b). Evaluation of mango cultivars for resistance to infection by *Ceratocystis manginecans*. Acta Horticulturae 992: 393-406.

Al Adawi AO, Deadman ML, Al Rawahi AK, Al Maqbali YM, Al Jahwari AA, Al Saadi BA, Al Amri IS, Wingfield MJ. (2006). Aetiology and causal agents of mango sudden decline disease in the Sultanate of Oman. European Journal of Plant Pathology 116(4): 247-254.

Al Kharusi L, Assaha D, Al-Yahyai R, Yaish M. (2017). Screening of date palm (*Phoenix dactylifera* L.) cultivars for salinity tolerance. Forests 8(4): 1-15 (Article 136).

Al Kharusi L, Al Yahyai R, Yaish MW. (2019a). Antioxidant response to salinity in salt-tolerant and salt-susceptible cultivars of date palm. Agriculture 9(1): 1-17.

Al Kharusi L, Sunkar R, Al-Yahyai R, Yaish MW. (2019b). Comparative Water Relations of Two Contrasting Date Palm Genotypes under Salinity. International Journal of Agronomy 2019: 1-16 (Article ID 4262013).

Al Mansoori TA, Alaa El-Deen M, Caligari PD. (2006). Editors. Evaluation of in vitro screening techniques for salt tolerance in date palm. III International Date Palm Conference 736; 2006.

Al Said FA, Al-Yahyai RA, Opara UL. (2013). Traditional Cultivation Of Pomegranate In Oman. In II All Africa Horticulture Congress 1007, p. 549-555.

Al-Amri HA, 2006. *Detection of Phytoplasma DNA in Seeds and In-vitro Cultured Seedlings of Lime*. College of Agricultural and Marine Sciences: Sultan Qaboos University, BSc Plant Science Special Problem.

Al-Azri AR, Piontkovski SA, Ai-Hasmi KA, Goes JI, Gomes HR. (2010). Recent outbreaks of harmful algal blooms along the coast of Oman: possible response to climate change? In: Yassine C, editor. Indian Ocean Tropical Cyclones and Climate Change, (pp. 349-357). Springer, Dordrecht.

Al-Busaidi KTS. (2013). Banana domestication on the Arabian Peninsula: A review of their domestication history. Journal of Horticulture and Forestry 5(11): 194-203.

Al-Ghaithi AGS. (2017). *Genetic diversity and interaction of Candidatus Phytoplasma aurantifolia with acid lime in Oman*. Muscat: (Doctoral dissertation, Sultan Qaboos University).

Alhammadi MS, Kurup SS. (2012). Impact of salinity stress on date palm (*Phoenix dactylifera* L.)–a review. In: Crop Production Technologies, InTechOpen, pp. 169-173.

Al-Harrasi I, Jana, GA, Patankar, HV, Al-Yahyai, R, Rajappa, S, Kumar PP. (2020). A novel tonoplast Na^+/H^+ antiporter gene from date palm (PdNHX6) confers enhanced salt tolerance response in *Arabidopsis*. Plant Cell Reports 39: 1079–1093.

Al-Harrasi I, Patankar HV, Al-Yahyai R, Sunkar R, Krishnamurthy P, Kumar PP, Yaish MW. Molecular characterization of a date palm vascular highway 1-interacting kinase (PdVIK) under abiotic stresses. Genes. 2020 May;11(5):568.

Al-Harthi AN. (2011). Oman in the era of Bani Nabhan (1154-1624 D.C.): Political and economic situation and the cultural life, a historical study. Sultan Qaboos University, Oman. p.105.

Al-Harthi K, Al-Yahyai R. (2009). Effect of NPK fertilizer on growth and yield of banana in Northern Oman. Journal of Horticulture and Forestry 1(8): 160-167.

Alhudaib K, Arocha Y, Wilson M, Jones P. (2009). Molecular identification, potential vectors and alternative hosts of the phytoplasma associated with a lime decline disease in Saudi Arabia. Crop Protection 28(1): 13-18.

Al Jabri SA, Al Yahyai RA. (2017). Plant-soil approach for irrigation scheduling of mango trees in the Sultanate of Oman. Acta Horticulturae 1150: 153-158.

Aljuburi, H.J. (1992). Response of date palm (*Phoenix dactylifera* i.) seedlings to sodium chloride in irrigation water. HortScience 27(6): 599-599.

Al-Khafaji HCA, Al-Saady NA, Al-Lawati AH, Nadaf SK. (2017). The effect of climate change on plant genetic resources and agriculture in Oman. International Journal of Agriculture Innovations and Research 5: 663-670.

Al-Kharusi LM, Elmardi MO, Ali A, Al-Said FAJ, Abdelbasit KM, Al-Rawahi S. (2009). Effect of mineral and organic fertilizers on the chemical characteristics and quality of date fruits. International Journal of Agricultural Biology 11: 290-296.

Al-Khateeb SA, Al-Khateeb AA, Sattar MN, Mohmand AS, El-Beltagi HS. (2019). Assessment of somaclonal variation in salt-adapted and non-adapted regenerated date palm (*phoenix dactylifera* l.). Fresenius Environmental Bulletin 28: 3686-3695.

Al-Kindi KM, Al Wahaibi AK, Kwan P, Andrew NR, Welch M, Al-Oufi M, Al-Hinai Z. (2018). Predicting the potential geographical distribution of parasitic natural enemies of the Dubas bug (*Ommatissus lybicus* de Bergevin) using geographic information systems. International Journal of Business Innovation and Research 17(3): 8297-8310.

Al-Qurainy F, Khan, S, Tarroum M, Nadeem M, Alansi S, Alshameri A. (2020). Comparison of salt tolerance between two potential cultivars of *Phoenix dactylifera* L. growing in Saudi Arabia. Pakistan Journal of Botany 52(3): 753-761.

Al-Rahbi SH, Al-Mulla YA, Jayasuriya H. (2020). Evaluation of Salinity Intrusion in Arable Lands of Al-Batinah Coastal Belt Using Unmanned Aerial Vehicle (UAV) Color Imagery. Journal of Agricultural and Marine Sciences 24: 44-50.

Alrasbi SAR, Hussain N, Schmeisky H. (2010). Evaluation of the growth of date palm seedlings irrigated with saline water in the Sultanate of Oman. *IV International Date Palm Conference 882*.

Al-Sadi A, Queiroz RB, Donkersley P, Nasehi A, Elliot SL. (2017). Plant Protection: Lime Diseases and Insect Pests. *The Lime: Botany, Production and Uses,* 149.

Al-Sadi AM, Al-Hilali SA, Al-Yahyai RA, Al-Said FA, Deadman ML, Al-Mahmooli IH, Nolasco G. (2012). Molecular characterization and potential sources of *Citrus tristeza virus* in Oman. Plant Pathology 61: 632-640.

Al-Said FA, Al-Yahyai RA, Opara UL. (2013). Traditional cultivation of pomegranate in Oman. Acta Horticulturae 1007: 549-556.

Al-Shanfari AB. (2000). *Molecular approach towards the study of witches'-broom disease on lime in the Sultanate of Oman*. Oman.: Sultan Qaboos University, MS Thesis.

Al-Subhi A (2018). *Molecular Characterization and Genetic Diversity of Phytoplasma in Oman Using Multiple Genes Analyses and Functional Genomics of SAP11*: Sultan Qaboos University, PhD.

Al-Subhi AM, Al-Yahyai RA, Al-Sadi AM, (2019). First report of a 'Candidatus Phytoplasma aurantifolia'-related strain in Citrus macrophylla in Oman. Phytopathogenic Mollicutes 9(1): 7-8.

Al-Yahyai R, Al-Kharusi L. (2012). Sub-optimal irrigation affects chemical quality attributes of dates during fruit development. African Journal of Agricultural Research 7(10): 1498-1503.

Al-Yahyai R, Al-Said F, Opara L. (2009). Fruit growth characteristics of four pomegranate cultivars from northern Oman. Fruits 64(6): 335-341.

Al-Yahyai RA, Al-Subhi AM, Al-Khanjari S, Al-Farei Z. (2013). Phenotypic diversity of cultivated mangoes in Oman. Acta Horticulturae 1007: 267-278.

Al-Yahyai R, Al-Said F, Opara L. (2014). Deciduous Fruit Crops of Oman. Acta Horticulturae 1095: 185-188.

Al-Yahyai R. (2006). Improvement of date palm production in the Sultanate of Oman. Acta Horticulturae 736: 337-343.

Al-Yahyai R, Khan I, Al-Said F, Al-Sadi A, Al-Wahaibi A, Deadman M. (2012). Status of Citrus aurantifolia Infected with Witches' Broom Disease of Lime in Oman. Acta Horticulturae 928: 375-381.

Al-Yahyai R, Khan MM. (2015). Date Palm Status and Perspective in Oman. In: Al-Khayri JM, Jain SM, Johnson DV, editors. Date Palm genetic resources and utilization. Netherland: Springer. p. 207-240.

Al-Yahyai R, Manickavasagan A. (2012a). Quality of dates: Influencing factors and assessment methods. Acta Horticulturae 1012: 1241-1246

Al-Yahyai R, Manickavasagan A. (2012b). An overview of date palm production. Dates: production, processing, food, and medicinal values. CRC Press, Boca Raton, Florida, USA, p. 3-12.

Al-Yahyai R. (2018). Strategies to Improve date palm production and hence Dates Quality in the Sultanate of Oman. UNCTAD-CAMS Joint Workshop for Dates Farmers and Stakeholders (Processors and Exporters) March 19 to 21, 2018 SQU, Oman.

Al-Yahyai RA, Al-Sadi AM, Al-Said FAJ, Alkalbani ZH, Carvalho CM, Elliot SL, Bertaccini A. (2015). Development and morphological changes in leaves and branches of acid lime (Citrus aurantifolia) affected by witches' broom. Phytopathologia Mediterranea 54(1): 133-139.

Al-Yahyai R. (2011). Fruit production in the Sultanate of Oman. Proceedings of Integrated Approaches to Fruit Production and Postharvest Management in Arid Climates, Sultan Qaboos University, Oman.

Al-Yahyai R, Al-Kharusi L. (2012). Physical and chemical quality attributes of freeze-stored dates. International Journal of Agriculture and Biology 14(1): 97-100.

Anjum SA, Xie XY, Wang LC, Saleem MF, Man C, Lei W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. African Journal of Agricultural Research 6: 2026-2032.

Arab L, Kreuzwieser J, Kruse J, Zimmer I, Ache P, Alfarraj S. (2016). Acclimation to heat and drought- lessons to learn from the date palm (*Phoenix dactylifera*). Environmental and Experimental Botany 125: 20-30.

Assaha DV, Ueda A, Saneoka H, Al-Yahyai R, Yaish, MW. (2017). The role of Na^+ and K^+ transporters in salt stress adaptation in glycophytes. Frontiers in

Physiology 8: 1-19 (Article 509).

Bar-Joseph M, Lee RF. (1989). Citrus tristeza virus. In: Description of Plant Viruses, No.353. Commonwealth Mycological Institute/Association of Applied Biology, Kew, Surrey, UK.

Bar-Joseph M, Marcus R, Lee RF. (1989). The continuous challenge of citrus tristeza virus control. Annual Review of Phytopathology 27: 291–316.

Bauerle TL, Smart DR, Bauerle W, Stockert CM, Eissenstat DM. (2008). Root foraging in response to heterogenous soil moisture in two grapevines that differ in potential growth rate. New Phytologist 179(3): 857-866.

Berdeja M, Hilbert G, Lafontaine M, Stoll M, Gomes E, Renaud C, Delrot S. (2014). Effects of drought stress and rootstock genotype on grape berry quality. In: Braun P, editor. Proc. VIIth IS on Irrigation of Horticultural Crops. Acta Horticulturae. p. 375-378.

Bezerra IL, Nobre RG, Gheyi HR, Souza, LP, Pinheiro FWA, Lima, GS. (2018). Morphophysiology of guava under saline water irrigation and nitrogen fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental 22(1): 32-37.

Blodgett J, Kruger E, Stanosz G. (1997). Effects of moderate water stress on disease development by *Sphaeropsis sapinea* on Red Pine. Phytopathology 87(4): 422-428.

Bove JM, Danet JL, Bananej K. (2000). Witches' Broom Disease of Lime (WBDL) in Iran. In. Proceedings of the fourteenth Conference of IOCV. 207-12.

Bove JM. (1995). Virus and virus-like disease of citrus in the Near East region. Chapter 16, FAO, Rome.

Brlansky RH, Howd DS, Broadbent P, Damsteegt VD. (2002). Histology of sweet orange stem pitting caused by an Australian isolate of Citrus tristeza virus. Plant Disease 86: 1169-1174.

Burke JJ, Velten J, Oliver MJ. (2004). In vitro analysis of cotton pollen germination. Agronomy Journal 96(2): 359-368.

Burt J. (2005). Growing date palms in Western Australia. http://www.agric.wa.gov.au

Cambra M, Gorris MT, Marroquin C, Roman MP, Olmos A, Martinez MC, Hermoso de Mendoza A, Lopez A, Navarro L. (2000). Incidence and epidemiology of *Citrus tristeza virus* in the Valencian Community of Spain. Virus Research 71: 85-95.

Campostrini E, Glenn DM. (2007). Ecophysiology of papaya: A review. Brazilian Journal of Plant Physiology 19(4): 413-424.

Chao CT, Krueger, RR. (2007). The date palm (*Phoenix dactylifera* L.): overview of biology, uses, and cultivation. HortScience 42(5): 1077-1082.

Chaves MM, Maroco JP, Pereira JS. (2003). Understanding plant responses to drought-from genes to the whole plant. Functional Plant Biology 30(3): 239-264.

Chaves MM, Oliveira MM. (2004). Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. Journal of Experimental Botany 55(407): 2365-2384.

Chen H, Jiang, JG. (2010). Osmotic adjustment and plant adaptation to environmental changes related to drought and salinity. Environmental Reviews 18(NA): 309-319.

Cowan AK. (2009). Plant growth promotion by 18: 0-lyso-phosphatidylethanolamine involves senescence delay. Plant Signaling and Behavior 4(4): 324-327.

Dai A. (2011). Drought under global warming: A review. Wiley Interdisciplinary Reviews: Climate Change 2: 45-65.

Daoud A, Malika, D, Bakari, S, Hfaiedh N, Mnafgui, K, Kadri, A. (2019). Assessment of polyphenol composition, antioxidant and antimicrobial properties of various extracts of date palm pollen (DPP) from two Tunisian cultivars. Arabian Journal of Chemistry 12(8): 3075-3086.

Darfaoui E, Assiri A. (2009). Response to Climate Change in the Kingdom of Saudi Arabia. Internal Working Paper FAO RNE. Cairo, Egypt.

De-Orduna RM. (2010). Climate change associated effects on grape and wine quality and production. Food Research International 43(7): 1844-1855.

Djanaguiraman M, Perumal R, Ciampitti IA, Gupta SK, Prasad PVV. (2018). Quantifying pearl millet response to high temperature stress: Thresholds, sensitive stages, genetic variability and relative sensitivity of pollen and pistil. Plant, Cell and Environment 41(5): 993-1007.

Djibril S, Mohamed OK, Diaga D, Diégane D, Abaye B, Maurice, S. (2005). Growth and development of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. African Journal of Biotechnology 4(9): 968-972.

Donkersley P, Silva FWS, Carvalho CM, Al-Sadi AM, Elliot SL. (2018). Biological, environmental and socioeconomic threats to citrus lime production. Journal of Plant Diseases and Protection 125(4): 339-356.

Dowson V. (1982). Date production and protection. Food and Agriculture organisation of the United Nations, Roma. FAO. Plant production and protection paper 35: 1-294.

Ebuen Y. (2019). In search of delicious locally-grown grapes. Oman Daily Observer. PO Box: 947 Code: 100 Muscat.

El Rabey HA, Al-Malki AL, Abulnaja KO, Rohde W. (2015). Proteome analysis for understanding abiotic stress (salinity and drought) tolerance in date palm (*Phoenix dactylifera* L.). International Journal of Genomics 2015: 1-11 (Article ID 407165).

El-Khawaga A. (2013). Effect of anti-salinity agents on growth and fruiting of different date palm cultivars. Asian Journal of Crop Science 5(1): 65-80.

Elshibli S, Elshibli MS, Korpelainen H. (2016). Growth and photosynthetic CO2 responses of date palm plants to water availability. Emirates Journal of Food and Agriculture 28: 58-65.

EPPO. (2004). Diagnostic protocols for regulated pests. European and Mediterranean

Plant Protection Organization (EPPO) Bulletin 34: 239-246.

Erskine W, Moustafa AT, Osman AE, Lashine Z, Nejatian A, and Badawi T. (2004). Date palm in the GCC countries of the Arabian Peninsula. Proc Regional Workshop on Date Palm Development in the Arabian Peninsula, Abu Dhabi, UAE.

Estrada-Luna A, Davies J, Egilla J. (2000). Mycorrhizal fungi enhancement of growth and gas exchange of micropropagated guava plantlets (*Psidium guajava* L.) during ex vitro acclimatization and plant establishment. Mycorrhiza 10(1): 1-8.

FAOSTAT. (2020). http://www.fao.org/faostat/ Last Accessed: 1 July 2020.

FAOSTAT (2019). http://www.fao.org/faostat/en/#data/QC/visualize (accessed 8 December 2019).

Fernandes L, Prereira JA, Lopéz-Cortés I, Salazar DM, Ramalhosa EC. (2015). Physicochemical changes and antioxidant activity of juice skin, pellicle and seed of pomegranate (cv. Mollar de Elche) at different stages of ripening. Food Technology and Biotechnology 53(4): 397-406.

Fischer UA, Carle R, Kammerer DR. (2013). Thermal stability of anthocyanins and colourless phenolics in pomegranate (Punica granatum L.) juices and model solutions. Food Chemistry 138(3): 1800-1809.

Fitchett JM, Grab SW, Thompson DI, Roshan G. (2014). Spatio-temporal variation in phenological response of citrus to climate change in Iran: 1960-2010. Agricultural and Forest Meteorology 198-199: 285-293.

Foster S, Pulido-Bosch A, Vallejos A, Molina L, Llop A, MacDonald AM. (2018). Impact of irrigated agriculture on groundwater-recharge salinity: a major sustainability concern in semi-arid regions. Hydrogeology Journal 26(8): 2781-2791.

Frison EA, Taher MM. (1991). FAO/IBPGR technical guidelines for the safe movement of citrus germplasm. FAO, Rome, Italy.

Furr J, Armstrong W. (1975). Water and salinity problems of Abadan Island date gardens. Annual Date Growers Institute Journal 52: 14-17.

García-Caparrós P, Hasanuzzaman M, Lao MT. (2018). Ion homeostasis and antioxidant defense toward salt tolerance in plants. Plant Nutrients and Abiotic Stress Tolerance. Springer. p. 415-436.

Garnier M, Zreik L, Bové JM. (1991). Witches' broom, a lethal mycoplasmal disease of lime trees in the Sultanate of Oman and the United Arab Emirates. Plant Disease 75(1): 546-551.

Ghalati ER, Shamili M, Homaei A. (2020). Effect of putrescine on biochemical and physiological characteristics of guava (Psidium guajava L.) seedlings under salt stress. Scientia Horticulturae, 261.

Ghosh DK, Das AK, Singh S, Singh SJ, Ahlawat YA, (1999). Occurrence of witches' broom, a new phytoplasma disease of acid lime (*Citrus aurantifolia*) in India. Plant Disease 83(3): 302.

Gomes FP, Prado CHBA. (2007). Ecophysiology of coconut palm under water stress. Brazilian Journal of Plant Physiology 19(4): 377-391.

Hadley J, Smith W. (2011). Influence of leaf surface wax and leaf-area to water-content ratio on cuticular transpiration in western Conifers. USA. The Canadian Journal of Forest Research 20(9): 1306-1311.

Hameed CA, Nadiya AA, Ali HA, Saleem KN. (2017). The Effect of Climate Change on PlanGenetic Resources and Agriculture in Oman. International Journal of Agriculture Innovations and Research 5(5): 2319-1473.

Hanson AD, Beaudoin GA, McCarty DR, Gregory JF. (2016). Does abiotic stress cause functional B vitamin deficiency in plants? Plant Physiology 172(4): 2082-2097.

Haplogypsids TC, Haplocalcids T, Torrifluvents T. (2006). Causes, origin, genesis and extent of soil salinity in the Sultanate of Oman. Pakistan Journal of Agricultural Science 43: 1-2.

Hardie WJ, Martin SR. (2000). Shoot growth on de-fruited grapevines: A physiological indicator for irrigation scheduling. Australian Journal of Grape and Wine Research 6(1): 52-58.

Harmeling S. (2010). Global Climate Risk Index 2010. Briefing paper of German watch, Bonn, Germany.

Hazzouri KM, Flowers JM, Nelson D, Lemansour A, Masmoudi K, Amiri KMA. (2020). Prospects for the study and improvement of abiotic stress tolerance in date palms in the post-genomics era. Frontiers in Plant Science 11: 293.

He C, Yang, A, Zhang W, Gao Q, Zhang J. (2010). Improved salt tolerance of transgenic wheat by introducing betA gene for glycine betaine synthesis. Plant Cell, Tissue and Organ Culture 101: 65-78.

Hegde DM, Srinivas K . (1989). Yield and quality of banana in relation to post-flowering moisture stress. South Indian Horticulure 37: 131-134.

Hussain, N., Al-Rasbi, S., Al-Wahaibi, N. S., Al-Ghanum, G., and El-Sharief Abdalla, O. A. (2012). Salinity Problems and their management in date palm production. In, Dates: Production, Processing, Food, and Medicinal Value, eds A. Manickavasagan, M. M. Essa, and E. Sukumar, CRC Press, Boca Raton, FL, pp. 442.

Ibraheem Y, Pinker I, Böhme M, Al-Hussin Z. (2011). Screening of some date palm cultivars to salt stress in vitro. VII International Symposium on In Vitro Culture and Horticultural Breeding 961.

IPCC. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2007.

Jana GA, Al Kharusi L, Sunkar R, Al-Yahyai R, Yaish MW. (2019). Metabolomic analysis of date palm seedlings exposed to salinity and silicon treatments. Plant Signaling and Behavior 14(11): Article 1663112.

Jarvis P, Jarvis M. (1963). The water relations of tree seedlings.: IV. Some aspects of the tissue water relations and drought resistance. Physiologia Plantarum 16(3): 501-516.

Johnston PJ. (2009). Climate change risk model for table grape growers, prepared for the Fynbos Foundation, Cape Town, South Africa.

Karahara I, Ikeda A, Kondo T, Uetake Y. (2004). Development of the Casparian strip in primary roots of maize under salt stress. Planta 219(1): 41-47.

Karlen SD, Smith RA, Kim H, Padmakshan D, Bartuce A, Mobley, JK. (2017). Highly decorated lignins in leaf tissues of the Canary Island date palm Phoenix canariensis. Plant Physiology 175(3): 1058-1067.

Khan IA. (2000). Present Status of lime and investigations on the witches' broom disease of lime in Oman. In. I*n: Davies F.S. and L.W. Timmer. Eds. Proc. Int. Soc. Citricult. IX Congr.*, 935-938.

Khattab MM, Shaban AE, El-Sherief AH, Mohamed AS. (2011). Growth and productivity of pomegranate trees under different irrigation levels I: Vegetative growth and fruiting. Journal of Horticultural Science & Ornamental Plants 3(2): 194-198.

Kheiry HMI. (2017). Dates Palm Farming Systems Sustainability and Risk Efficiency in Oman. Sustainable Agriculture Research 6(1): 39-50.

Koch W, Kukula-Koch W, Głowniak K. (2017). Catechin composition and antioxidant activity of black teas in relation to brewing time. Journal of AOAC International 100(6): 1694-1699.

Kumar L, Shabani F. (2016). Climate change impacts on the future distribution of date palm in Oman. University of New England, Progress report: 2. pp.1-48.

Kumar V, Wani SH, Suprasanna P, Tran LSP. (2018). Salinity responses and tolerance in Plants, volume 1: targeting sensory, transport and signaling mechanisms. Springer.

Kurup SS, Hedar, YS, Al Dhaheri MA, El-Heawiety AY, Aly MA, Alhadrami G. (2009). Morpho-physiological evaluation and RAPD markers-assisted characterization of date palm (*Phoenix dactylifera* L.) varieties for salinity tolerance. Journal of Food Agriculture and Environment 7(3): 3-50.

Labbé M, Ulloa PA, López F, Sáenz C, Peña A, Salazar FN. (2016). Characterization of chemical compositions and bioactive compounds in juices from pomegranates ('Wonderful', 'Chaca' and 'Codpa') at different maturity stages. Chilean Journal of Agricultural Research 76(4): 479-486.

Larcher W. (2003). Physiological plant ecology: ecophysiology and stress physiology of functional groups. Berlin: Springer.

Laxman RH, Bhatt RM. (2017). Abiotic stress management in fruit crops. In: Minhas PS, editor. Abiotic stress management for resilient agriculture. Springer Nature, Singapore, pp. 399-412.

Lee RF, Bar-Joseph M. (2000). Tristeza. In: Compendium of citrus diseases, p 92. Timmer, L. W. Garnsey, S. M and Graham. J. H. eds., APS Press, St. Paul, USA.

Levy Y, Syvertsen J. (200)4. Irrigation water quality and salinity effects in citrus trees. Horticultural Reviews 30: 37-82.

Lobell DB, Schlenker W, Costa-Roberts J. (2011). Climate trends and global crop production since 1980. Science 333(6042): 616-620.

López-Arroyo JI, Jasso J, Reyes MA, Loera-Gallardo J, Cortez-Mondaca E, Miranda MA. (2009). Perspectives for biological control of *Diaphorina citri* (Hemiptera: Psyllidae) in Mexico. In: Gottwald TR, Graham JH, editors. Proceedings of the International Research Conference on Huanglongbing; 1-5 December 2008; Orlando, Florida. Plant Management Network. pp. 329-330.

MAF (Ministry of Agriculture and Fisheries). (2002). Report of eradicated mango trees in Al-Batinah region in 2001. Ministry of Agriculture and Fisheries, Sultanate of Oman.

MAF. (2006). Annual report. Ministry of Agriculture, Sultanate of Oman

MAF. (2003). Disease incidence survey in Al Batinah region (2003). Ministry of Agriculture and Fisheries, Sultanate of Oman.

MAF. (2004). Agricultural census 2002/2003. Ministry of Agriculture and Fisheries, Sultanate of Oman.

MAF. (2006). Integrated management of mango decline disease. Ministry of Agriculture and Fisheries, Sultanate of Oman.

MAF. (2009). Agriculture and Livestock Research Annual Report. Ministry of Agriculture, Sultanate of Oman.

MAF. (2014). Agricultural census 2012/2013. Ministry of Agriculture and Fisheries, Sultanate of Oman.

MAF. (2017). Annual Statistical Yearbook, Directorate General of Planning and Investment Promotion, Ministry of Agriculture & Fisheries, Muscat, Sultanate of Oman.

Mahouachi J, Socorro AR, Talon M. (2006). Responses of papaya seedlings (*Carica papaya* L.) to water stress and re-hydration: Growth, photosynthesis and mineral nutrient imbalance. Plant Soil 281: 137-146.

Mahouachi J, Arbona V, Gómez-Cadenas A. (2007). Hormonal changes in papaya seedlings subjected to progressive water stress and re-watering. Plant Growth Regulation 53(1): 43-51.

Mahouachi J, Argamasilla R, Gómez-Cadenas A. (2012). Influence of exogenous glycine betaine and abscisic acid on papaya in responses to water-deficit stress. Journal of Plant Growth Regulation 31(1): 1-10.

Mantri N, Patade V, Penna S, Ford R, Pang E. (2012). Abiotic stress responses in plants: Present and future. In: Ahmad P, Prasad M, editors. Abiotic stress responses in plants. Springer, New York, p.1-19.

Marashi SS, Hajilou J, Tabatabaei SJ, Nahandi FZ, Toorchi M. (2017). Screening date palm cultivars for salinity tolerance using physiological indices. Pakistan Journal of Botany 49: 413-419.

Martínez-Minaya J, Conesa D, López-Quílez A, Vicent A. (2015). Climatic and spatial factors associated with citrus black spot. A Bayesian analysis of disease spread in South Africa. Proceedings CEB-EIB 23-25 September 2015; Bilbao, Spain. p. 4.

Masri M, Razak AS, Ghazalli MZ. (1990). Response of papaya (*Carica papaya* L.) to limited soil moisture at reproductive stage. Mardi Research Journal 18: 191-196.

Moneem MM. (2005). Handbook of Aphid in Oman. Ministry of Agriculture and Fisheries. Sultanate of Oman.

Morel I, Lescoat G, Cogrel P, Sergent O, Pasdeloup N, Brissot P. (1993). Antioxidant and iron-chelating activities of the flavonoids catechin, quercetin and diosmetin on iron-loaded rat hepatocyte cultures. Biochemical Pharmacology 45(1): 13-19.

Munné-Bosch S, Alegre L. (2004). Die and let live: Leaf senescence contributes to plant survival under drought stress. Functional Plant Biology 31(3): 203-216.

Munns R. (2002). Comparative physiology of salt and water stress. Plant, Cell & Environment 25(2): 239-250.

Munns R, Tester M. (2008). Mechanisms of salinity tolerance. Annual Review Plant Biololgy 59: 651-681.

Murali K, Srinivas K, Shivakumar HR, Kalyanamurthy KN. (2005). Effect of soil moisture stress at different stages on yield and yield parameters of “Elakki” banana. Advances in Plant Sciences 18(2): 817-822.

Nainanayake A, Ranasinghe CS, Tennakoon NA. (2008). Effects of drip irrigation on canopy and soil temperature, leaf gas exchange, flowering and nut setting of mature coconut (*Cocos nucifera* L.). Journal of the National Science Foundation of Sri Lanka 36(1): 33-40.

Navarro, L., Juarez, J., Pina, J. A. and Ballester, J. F. (1984). The citrus quarantine station in Spain. In: Proceedings of the 9th Conference of the International Organization of Citrus Virologists, pp. 365-370. Garnsey, S. M., Timmer, L. W., Dodds, J. A. (Eds), Department of Plant Pathology, University of California, Riverside, USA.

Navarro, L., Juarez, J., Pina, J. A., Ballester, J. F. and Arregui, J. M. (1988). The citrus variety improvement programme in Spain. In: Proceedings of the 10th Conference of the International Organization of Citrus Virologists, pp. 400-406. Timmer, L. W., Garnsey, S. M. and Navarro, L. (Eds). Department of Plant Pathology, University of California, Riverside, USA.

Opara UL, Al-Yahyai R, Al-Waili N, Said FA, Al-Ani M, Manickavasagan A, Al-Mahdouri A. (2013). Postharvest Responses of ‘Malindi’ Cavendish Banana to Various Storage Conditions. International Journal of Fruit Science 13(4): 373-388.

Opara UL, Al-Yahyai R, Al-Waili N, Said FA, Al-Ani M, Manickavasagan A, Al-Mahdouri A. (2012). Effect of storage conditions on physico-chemical attributes and physiological responses of milk (Musa spp., AAB group) banana during fruit ripening. International Journal of Postharvest Technology and Innovation 2(4): 370-386.

Oshino T, Abiko M, Saito R, Ichiishi E, Endo M, Kawagishi-Kobayashi M, Higashitani A. (2007). Premature progression of anther early developmental programs accompanied by comprehensive alterations in transcription during high-temperature injury in barley plants. Molecular Genetics and Genomics 278(1): 31-42.

Passos CD, Passos EEM, Prado CHBA. (2005). Seasonal performance of water potential and gas exchange in four varietes of dwarf coconut. Revista Brasileira de Fruticultura 27(2): 248-254.

Patankar HV, Assaha DV, Al-Yahyai R, Sunkar R, Yaish MW. (2016). Identification of reference genes for quantitative real-time PCR in date palm (*Phoenix dactylifera* L.) subjected to drought and salinity.

Patankar HV, Al-Harrasi, I, Al Kharusi L, Jana GA, Al-Yahyai R, Sunkar R. (2019a). Overexpression of a Metallothionein 2A gene from date palm confers abiotic stress tolerance to yeast and Arabidopsis thaliana. International Journal of Molecular Sciences 20(12): 1-21.

Patankar HV, Al-Harrasi I, Al-Yahyai R, Yaish MW. (2019b). Functional characterization of date palm aquaporin gene PdPIP1; 2 confers drought and salinity tolerance to yeast and Arabidopsis. Genes 10(5): 1-18.

Peng Z, Wang M, Li F, Lv H, Li C, Xia G. (2009). A proteomic study of the response to salinity and drought stress in an introgression strain of bread wheat. Molecular & Cellular Proteomics 8(12): 2676-2686.

Pourghayoumi M, Rahemi M, Bakhshi D, Aalami A, Kamgar-Haghighi AA. (2017). Responses of pomegranate cultivars to severe water stress and recovery: Changes on antioxidant enzyme activities, gene expression patterns and water stress responsive metabolites. Physiology and Molecular Biology of Plants 23(2): 321-330.

Quartacci MF, Pinzino C, Sgherri CL, Dalla Vecchia F, Navari- Izzo F. (2000). Growth in excess copper induces changes in the lipid composition and fluidity of PSII- enriched membranes in wheat. Physiologia Plantarum 108(1): 87-93.

Queiroz RB, Donkersley P, Silva FN. (2016). Invasive mutualisms between a plant pathogen and insect vectors in the Middle East and Brazil. Royal Society Open Science 3: 1-12 (Article 160557).

Ramoliya P, Pandey A. (2003). Soil salinity and water status affect growth of *Phoenix dactylifera* seedlings. New Zealand Journal of Crop and Horticultural Science 31(4): 345-353.

Ravi I, Vaganan MM. (2016). Abiotic stress tolerance in banana. In: Rao NKS, Shivashankara KS, Laxman RH, editors. Abiotic stress physiology of horticultural crops. Springer, India, pp. 207-222.

Reinhardt D, Rost T. (1995). Salinity accelerates endodermal development and induces an exodermis in cotton seedling roots. Environmental and Experimental Botany 35(4): 563-574.

Reis SPD, Lima AM, and Souza CRB. (2012). Recent molecular advances on downstream plant responses to abiotic stress. International Journal of Molecular Sciences 13(7): 8628-8647.

Robinson JC, Alberts AJ. (1986). Growth and yield responses of banana (cultivar 'Williams') to drip irrigation under drought and normal rainfall conditions in the subtropics. Scientia Horticulturae 30: 187-202.

Ruiz-Sanchez MC, Domingo R, Castel JR. (2010). Review. Deficit irrigation in fruit trees and vines in Spain. Spanish Journal of Agricultural Research 8: 5-20.

Sané D, Kneyta M, Diouf D, Diou D, Badiane F, Sagna M. (2005). Growth and development 608 of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. African Journal of Biotechnology 4: 968-972.

Satisha, J., R. Laxman, K. Upreti, K. Shivashankara, L. Varalakshmi and M. Sankaran. (2020). Mechanisms of Abiotic Stress Tolerance and Their Management Strategies in Fruit Crops. New Frontiers in Stress Management for Durable Agriculture. Springer, p. 579-607.

Schaffer B, Whiley AW, Crane JH. (1994). Mango. In: Schaffer B, Andersen PC, editors. Handbook of environmental physiology of fruit crops, vol 2, Sub tropical and tropical crops. Boca Raton: CRC Press, pp.165-197.

Schnyder H. (1993). The role of carbohydrate storage and redistribution in the source-sink relations of wheat and barley during grain filling-A review. New Phytologist 123(2): 233-245.

Scholefield PB, Oag DR, Sedgley M. (1986). The relationship between vegetative and reproductive development in mango in northern Australia. Australian Journal of Agricultural Research 37(4): 425-433.

Schreiber L, Franke R, Hartmann K. (2005). Effects of NO 3 deficiency and NaCl stress on suberin deposition in rhizo-and hypodermal (RHCW) and endodermal cell walls (ECW) of castor bean (*Ricinus communis* L.) roots. Plant and Soil 269(1-2): 333-339.

Serra I, Strever A, Myburgh P, Deloire A. (2014). Review: The interaction between rootstocks and cultivars (*Vitis vinifera* L.) to enhance drought tolerance in grapevine. Australian Journal of Grape and Wine Research 20(1): 1-14.

Serret MD, Al-Dakheel, AJ, Yousfi S, Fernáandez-Gallego JA, Elouafi IA, Araus JL. (2020). Vegetation indices derived from digital images and stable carbon and nitrogen isotope signatures as indicators of date palm performance under salinity. Agricultural Water Management 230.

Shabala S, Shabala L. (2011). Ion transport and osmotic adjustment in plants and bacteria. Biomolecular Concepts 2(5): 407-419.

Shabala S, Cuin TA, Shabala L, Newman I. (2012). Quantifying kinetics of net ion fluxes from plant tissues by non-invasive microelectrode measuring MIFE technique. *In Plant Salt Tolerance* (pp. 119-134). Humana Press, Totowa, NJ.

Shabala S. (2013). Learning from halophytes: physiological basis and strategies to improve abiotic stress tolerance in crops. Annals of Botany 112(7): 1209-1221.

Shabala S. (2017). Plant stress physiology. CABI, UK.Shabani F, Kumar L, Hamdan Saif Impacts of climate change on infestations of Dubas bug (Ommatissus lybicus Bergevin) on date palms in Oman. Peer Journal 6.

Shabani F, Kumar L, Taylor S. (2015). Distribution of date palms in the Middle East based on future climate scenarios. Experimental Agriculture 51: 244–263.

Shukla SK, Adak T, Singha A, Kumar K, Singh VK, Singh A. (2014). Response of guava trees (*Psidium guajava*) to soil applications of mineral and organic fertilisers and biofertilisers under conditions of low fertile soil. Journal of Horticultural Research 22(2): 105-114.

Singh RN, Majumder PK, Sharma DK, Sinha GC, Bose PC. (1974). Effect of de-blossoming on the productivity of mango. Scientia Horticulturae 2(4): 399-403.

Singh Z. (2005). Embryo abortion in relation to fruit size, quality and concentrations of nutrients in skin and pulp of mango. Journal of Plant Nutrition 28(1): 1723-1737.

Slattery RA, VanLoocke A, Bernacchi CJ, Zhu XG, Ort DR. (2017). Photosynthesis, light use efficiency, and yield of reduced-chlorophyll soybean mutants in field conditions. Frontiers in Plant Science 8: (Article 549).

Smirnoff N, Stewart G. (1985). Stress metabolites and their role in coastal plants. Ecology of coastal vegetation. Springer. pp. 273-278.

Sobhanian H, Pahlavan S, Meyfour A. (2020). How does proteomics target plant environmental stresses in a semi-arid area? Molecular Biology Reports 47: 3181-3194.

Sperling O, Lazarovitch N, Schwartz A, Shapira O. (2014). Effects of high salinity irrigation on growth, gas-exchange, and photoprotection in date palms (*Phoenix dactylifera* L., cv. Medjool). Environmental and Experimental Botany 99: 100-109.

Syvertsen J, Levy Y. (2005). Salinity interactions with other abiotic and biotic stresses in citrus. HortTechnology 15(1): 100-103.

Tahir FM, Ibrahim, Hamid K. (2003). Effect of drought stress on vegetative and reproductive growth behavior of mango (*Mangifera indica* L.). Asian Journal of Plant Sciences 2: 116-118.

Takahashi F, Shinozaki K. (2019). Long-distance signaling in plant stress response. Current Opinion in Plant Biology 47: 106-111.

Talwar HS, Takeda H, Yashima S, Senboku T. (1999). Growth and photosynthetic responses of groundnut genotypes to high temperature. Crop Science 39: 460-466.

Tavousi M, Kaveh F, Alizadeh A, Babazadeh H, Tehranifar A. (2015). Effects of drought and salinity on yield and water use efficiency in pomegranate tree. Journal of Materials and Environmental Science 6(7): 1975-1980.

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, De-Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, Van-Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE. (2004). Extinction risk from climate change. Nature 427: 145-148.

Thornton P, Cramer L. (2012). Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. CCAFS Working Paper 23. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Tripler E, Ben-Gal A, Shani U. (2007). Consequence of salinity and excess boron on growth, evapotranspiration and ion uptake in date palm (*Phoenix dactylifera* L., cv. Medjool). Plant and Soil 297: 147-155.

Tripler E, Shani U, Mualem Y, Ben-Gal A. (2011). Long-term growth, water consumption and yield of date palm as a function of salinity. Agricultural Water Management 99: 128-134.

Tripler E, Shani U, Ben-Gal A, Mualem Y. (2012). Apparent steady state conditions in high resolution weighing-drainage lysimeters containing date palms grown under different salinities. Agricultural Water Management 107: 66-73.

Van Wyk M, Al Adawi AO, Khan IA, Deadman ML, Al Jahwari AA, Wingfield BD, Ploetz R, Wingfield MJ. (2007). *Ceratocystis manginecans* sp. nov., causal agent of a destructive mango wilt disease in Oman and Pakistan. Fungal Diversity 27: 213-230.

Van-Leeuwen C, Tregoat O, Choné X, Bois B, Pernet D, Gaudillére JP. (2009). Vine water status is a key factor in grape ripening and vintage quality for red Bordeaux wine. How can it be assessed for vineyard management purpose? Journal International de la Science de la Vigne et du Vin 43: 121-134.

Wahid A, Gelani S, Ashraf M, Foolad MR. (2007). Heat tolerance in plants: An overview. Environmental and Experimental Botany 61: 199-223.

Waqas MA, Kaya C, Riaz A, Farooq M, Nawaz I, Wilkes A, Li Y. (2019). potential mechanisms of abiotic stress tolerance in crop plants induced by thiourea. Frontiers in Plant Science 10: 1-14.

Wegner LH, Shabala S. (2020). Biochemical pH clamp: the forgotten resource in membrane bioenergetics. New Phytologist 225: 37-47.

Wei J, Liu G, Liu D, Chen Y. (2017). Influence of irrigation during the growth stage on yield and quality in mango (*Mangifera indica* L). PLoS ONE 12(4): (Article e0174498).

Yaish MW. (2015). Proline accumulation is a general response to abiotic stress in the date palm tree (*Phoenix dactylifera* L.). Genetics and Molecular Research 14: 9943-9950.

Yaish, M. W., & Kumar, P. P. (2015). Salt tolerance research in date palm tree (Phoenix dactylifera L.), past, present, and future perspectives. Frontiers in plant science, 6, 348.

Yaish MW, Sunkar R, Zheng Y, Ji B, Al-Yahyai R, Farooq SA. (2015). A genome-wide identification of the miRNAome in response to salinity stress in date palm (*Phoenix dactylifera* L.). Frontiers in Plant Science 6: 946.

Yaish MW, Patankar HV, Assaha DV, Zheng Y, Al-Yahyai R, Sunkar R. (2017). Genome-wide expression profiling in leaves and roots of date palm (Phoenix dactylifera L.) exposed to salinity. BMC Genomics 18: 246.

Youssef T, Awad MA. (2008). Mechanisms of enhancing photosynthetic gas exchange in date palm seedlings (*Phoenix dactylifera* L.) under salinity stress by a 5-aminolevulinic acid-based fertilizer. Journal of Plant Growth Regulation 27: 1.

Zandalinas SI, Mittler R, Balfagón D, Arbona V, Gómez-Cadenas A. (2018). Plant adaptations to the combination of drought and high temperatures. Physiologia Plantarum, 162(1): 2-12.

Zarei M, Azizi M, Bashir-Sadr Z. (2011). Evaluation of physicochemical characteristics of pomegranate (*Punica granatum* L.) fruit during ripening. Fruits 66(2): 121-129.

Zhang XY, Liang C, Wang GP, Luo Y, Wang W. (2010). The protection of wheat plasma membrane under cold stress by glycine betaine overproduction. Biologia Plantarum 54(1): 83-88.

Zhou R, Hyldgaard B, Yu X, Rosenqvist E, Ugarte RM, Yu S. (2018). Phenotyping of faba beans (*Vicia faba* L.) under cold and heat stresses using chlorophyll fluorescence. Euphytica 214(4): 68.

Zimmermann HM, Hartmann K, Schreiber L, Steudle E. (2000). Chemical composition of apoplastic transport barriers in relation to radial hydraulic conductivity of corn roots (*Zea mays* L.). Planta 210(2): 302-311.

Zörb C, Geilfus CM, Dietz KJ. (2019). Salinity and crop yield. Plant Biology 21: 31-38.

Zreik L, Carle P, Bové JM, Garnier M, (1995). Characterization of the Mycoplasma like Organism Associated with Witches'-Broom Disease of Lime and Proposition of a Candidatus Taxon for the Organism, ''Candidatus Phytoplasma aurantifolia''. International Journal of Systematic Bacteriology 45: 449-453.