Investigating sustainable approaches to late maturity and fungal infection of organic ‘Medjool’ date palm (*Phoenix dactylifera* L.) fruit in the Western Cape, South Africa

by

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Declaration

By submitting this assignment electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Summary

The commercial production of date palm in South Africa was established approximately 50 years ago in the Northern Cape with the largest orchard stretching over 100 hectares. The province has a hot and dry climate, similar to the regions of the Middle East and North Africa where date palms are traditionally produced. These conditions result in little to no issues regarding the growth and development of the fruit, the presence of pests and/or diseases during its cultivation. Date palm cultivation has since spread to climatically suitable regions in the Western Cape, which is one of the richest fruit-growing regions in the country. However, on one of the farms (approximately 30 hectares in the Hermon region), irregular ripening and high incidences of microbial spoilage were observed soon after cropping. Since the specific farm employs organic agriculture, a sustainable approach is required to address these two challenges to enable marketing of the crop. The aim of this study was to investigate the application of preharvest fruit bunch bagging as an environmentally sustainable approach to the acceleration of date fruit ripening, as well as the control of fungal infections in an organic date orchard in the Western Cape.

During the 2022 season on the Kleinplasie organic date orchard near Hermon in the Western Cape, ‘Medjool’ date palm trees underwent three different non-perforated bagging treatments (no bag, blue low-density polyethylene bag, white high-density polyethylene abg) at two different phenologically important times (Khalal at 17 February 2022, Khimri at 31 March 2022) during the fruit ripening period. Preharvest analyses found that the technique, particularly the blue low-density polyethylene bags implemented later in the fruit ripening process, significantly increased fruit weight, size, and improved fruit colour at harvest. However, the microbial load was found to significantly increase at harvest, leading to higher rates of fungal infection, when compared to the other bagged treatments ($p = 0.034$). Postharvest analyses concluded that bunch bagging, particularly blue low-density polyethylene bags implemented earlier in the fruit ripening process, could have a positive effect on ripening of fruit under the appropriate storage conditions, and the organoleptic properties of the fruit was significantly different between treatments.

According to the results of the study, it was recommended that implementing a blue low-density polyethylene bag later in the ripening process at Khalal until harvest could result in the accelerated ripening of date fruit, while applying a white high density polyethylene bag applied earlier at Khimri could aid in the control of fungal infection. This is due to the colour of the bagging material acting as a filter of photosynthetically active radiation, which refers to the range of wavelengths that aid in photosynthesis.

Opsomming

Die kommersiële produksie van dadel palmbome in Suid-Afrika was ongeveer 50 jaar terug in the Noord-Kaap gevestig, met die grootste boord wat oor 100 hektaar strek. Die provinsie het `n warm en droë klimaat wat amper identies is aan die streke van die Midde Ooste en Noord-Afrika waar die dadel palmbome tradisioneel geproduseer word. Hierdie klimaatstoestande lei na baie min of selfs geen probleme ten opsigte van die groei en ontwikkeling van die vrug, die teenwoordigheid van plae en/of siektes tydens die verbouing. Die verbouing van dadel palmbome het sedert versprei na geskikte streke in die Wes-Kaap, wat een van die rykste streke in die land in vir die groei van vrugte. Maar, een van hierdie dadel boorde (ongeveer 30 hektaar in die Hermon streek) ondervind egter probleme soos onreëlmatige rypwording and hoë gevalle van mikrobiese bederf. Omdat hierdie dadel boorde bestuur word onder organiese beginsels, is `n volhoubare benadering aan die uitdaging nodig. Die doel van hierdie studie was om voor-oes “bunch bagging” te ondersoek as `n omgewingsgewys volhoubare benadering aan die versnelling van dadel rypwording, sowel as die beheer van fungi infeksie in `n organies dadel boord in the Wes-Kaap.

Gedurende die 2022 seisoen op die Kleinplasie organiese dadel boord naby Hermon in the Wes-Kaap, het ‘Medjool’ dadel palmbome drie verskillende behandelings (geen sak, blou, lae digtheid poliëtileen sak, wit, hoë digtheid poliëtileen sak) ondergaan, by twee verskillende phenologies belangrike tye (Khalal op 17 Februarie 2022, Khimri op 31 Maart 2022) tydens die rypwordingsperiode. Die voor-oes ontleding het gevind dat die metode, met spesifiek die blou, lae digtheid poliëtileen sak wat later in die vrugrypwordingsproses opgesit is, na `n betekenisvolle verhoging in vruggewig en -grootte gelei het, sowel as vrug kleur betekenisvol verbeter het. Maar die mikrobiese lading het egter `n beduidende verhoging tydens die oes tydperk vertoon, wat gelei het na hoër gevalle van swam infeksie, in vergelyking met die ander sak behandelings ($p = 0.034$). Die na-oes ontleding het getoon dat die metode, spesifiek die blou, lae digtheid poliëtileen sak wat vroeër in die vrugrypwordingsproses opgesit is, `n positiewe effek op die rypwording van dadels kan hê onder gepaste opberg toestande, en dat die organoleptiese eienskappe van die dadel `n betekenisvolle verskil in die behandelings vertoon het.

Volgens die resultate van die studie, word dit aanbeveel dat die blou sak later, op Khalal, tot oestyd in die rypwordingsproses aangebring kan word, wat kan lei tot versnelde rypwording van dadels. Die wit sak kan vroeër, op Khimri, aangebring word, wat kan lei tot die beheer van swaminfeksie. Dit is te wyte aan die kleur van die sak at optree as filter van fotosinteties-aktiewe bestraling - die reeks golflengtes wat tot fotosintese bydra.

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Note

This thesis is presented in the format prescribed by the Faculty of AgriSciences at Stellenbosch University. The structure is in the form of two research chapters and is prefaced by an introduction chapter with the study objectives, followed by a literature review chapter and closing with a chapter for elaborating a general discussion and conclusion. The language, style and referencing format used are in accordance with the requirements of Scientia Horticulturae. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, as such, been unavoidable

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Chapter 1: General Introduction

The date palm (*Phoenix dactylifera* L.) is one of the most important fruit crops in the Middle East and North Africa, where they are traditionally grown and cultivated. This is due to their high nutritional and economic value, climate adaptation and cultural significance (Johnson, 2010; Yahia and Kader, 2011; Zaid and Piesik, 2021). While date palms adapt well to excessively high temperatures and water scarcity, they grow optimally in climates with long hot dry summers and rainy winters. Date palms start to produce fruit from four to seven years after its establishment, and fully mature in 15 to 20 years. Then, date palms are able to individually bear almost 100 kg fruit per season and continue to produce for up to 75 years (Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014).

Date palms are plagued by a wide range of pests and diseases during its production life. Various pests such as insects, birds, rodents, and snails are natural invaders of date orchards during its flowering and fruit ripening stages (Sharma *et al.*, 2014; El-Shafie, 2019). Fungi are the major causative agent of disease in date orchards and infect date palms at all stages of its growth and development. Calyx-end rot, side spot decay and blue or green mould caused by *Aspergillus spp*., *Alternaria spp.,* and *Penicillium spp*. respectively, are common fungal infections found on ripening fruit. Currently, the red palm weevil (*Rhyncophorus ferrugineus*) and the Bayoud fungal disease (*Fusarium oxysporium*) are major threats facing date palm productions (Abdullah *et al.*, 2010; El-Shafie, 2019).

Date fruit undergoes five stages of maturation viz. Hababouk, Khimri, Khalal, Rutab and Tamr. Depending on the cultivar, they may be harvested at three points during their maturation, namely Khalal (physiologically mature), Rutab (semi-ripe) or Tamr (fully ripe). However, dates are non-climacteric fruit, meaning that date fruits do not ripen further after its harvesting (Yahia and Kader, 2011; Mohamed *et al.*, 2019; Sarraf *et al.*, 2021). Indicators of maturity such as size, colour and taste are used to predict the most appropriate time for harvest. Typically, multiple parameters are used to improve the accuracy of the prediction. This is done to ensure the postharvest quality and safety of the fruit (Serrano *et al.*, 2004; Amorós *et al.*, 2009; Bajcar *et al.*, 2016).

Date cultivation has long since spread to areas outside of the Middle East and North Africa. By 2020, this distribution has led to an annual production of 9.45 million tonnes of date fruit produced by over 120 million commercially grown date palms worldwide (Johnson, 2010; Hanieh *et al.*, 2020; Statista, 2020). However, a decline in the productivity of traditional date-growing areas has been observed over the last few decades, due to many factors including political unrest, socio-economic divides, technical constraints, and climate change. This has created opportunities for climatically suitable but underutilised production areas of the world, such as South Africa (McCubbin, 2007; Oladzad *et al.*, 2021; Zaid and Piesik, 2021).

In South Africa, the first commercial date orchard was established almost 50 years ago in the Northern Cape province, with the largest orchard stretching over 100 hectares. These date palms were propagated from ‘Medjool’ and ‘Barhee’ offshoots, which were sourced from the United States of America. Being in the Southern Hemisphere gives the country an advantage in producing out-of-season fresh fruit to markets in the Northern Hemisphere, particularly Western Europe and Northern America. Dates are grown in the Northern Cape, Limpopo, and very recently, the Western Cape, where some date orchards are managed organically (Vink and Tregurtha, 2005; McCubbin, 2007; Zaid and Piesik, 2021). Organic date palm production represents a resilient farming system that is well-adapted to climate change, has socio-cultural importance and high economic value due to its immense processing and valorisation potential (Yahia and Kader, 2011; Gomez and Thivant, 2015). Recently, organic fruit and vegetables have experienced a surge in demand, particularly in European and American markets. Many date-producing countries such as South Africa are taking advantage of this interest by adopting sustainable practices to ensure premium date fruit quality and value (Vink and Tregurtha, 2005; Johnson, 2010; Zaid and Piesik, 2021).

A review of current literature indicates that fruit bunch bagging has multiple beneficial outcomes and has shown its effectiveness and efficiency across a range of climates. A study by Awad (2007) in the United Arab Emirates showed that bunch bagging with different materials such as black or blue polyethylene bags, white polypropylene, and paper bags during the growing season of Helali dates significantly increased the rate of fruit ripening and increased Rutab yield per bunch. Similarly, Al-Obeed and Harhash, (2010) performed bagging treatments on ‘Succary’ and ‘Khalas’ dates in Saudi Arabia. They found that bagging with black, white, blue, and yellow plastic bags effectively accelerated fruit maturity and ripening, as well as increased fruit weight, length, and diameter compared with the untreated control. Mostafa *et al.* (2014) performed bunch bagging during the Khimri stage of ‘Seewy’ dates in Egypt. The results showed that bagging significantly increased the total bunch weight, as well as accelerated ripening when compared to unbagged bunches. Similarly, Kahramanoğlu and Usanmaz (2019) performed bunch bagging on ‘Medjool’ dates in North Cyprus and found that it enhances fruit ripening on the tree, increases the total soluble solids, and decreases titratable acidity of dates at both Tamr and Khalal stages.

The effect of fruit bunch bagging on pest and disease control has also been extensively (Sharma *et al.*, 2014; Buthelezi *et al.*, 2020; Ali *et al.*, 2021).The authors found that bagging is beneficial for pest control, as many studies on fruit such as apple, guava, litchi, and mango have shown reduced incidence of fruit flies, moths, aphids, and borers. Additionally, bagging fruits have shown a significant reduction in bird damage in particularly banana, mango, apple, and date orchards. In the case of disease control, fruit bunch bagging has been found to reduce the incidence of stem-end rot in mango, as well as fruit rot in loquat and guava fruits.

However, several Japanese apple and pear orchards have reported cases where black spot (*Trichothecium roseum*), as well as fruit russeting, has been associated with fruit bagging (Sharma *et al*., 2014; Buthelezi *et al*., 2020; Ali *et al*., 2021).

This study was carried out on an organic date orchard in the Western Cape, which has been experiencing slow fruit maturation, as well as a rise in fungal infections, in this climatic region. Fruit bunch bagging involves enclosing young fruits with bags to protect them from various biotic and abiotic factors during fruit maturation and ripening. This technique was proposed as a sustainable approach to accelerate the fruit ripening process, as well as alleviate the emergence of spoilage organisms. Results regarding recommendations of bunch bagging on organic fruit bunches have been inconsistent across literature sources. This is due to the variety of factors that influence the impact of bunch bagging, which include differences in climatic conditions and methodologies, the colour and composition of the cover, as well as the application and duration of the technique (Yahia and Kader, 2011; Sharma *et al*., 2014; Rajan *et al*., 2020). However, little to no research has been published on its implementation and impact on organic date palm orchards in Southern Africa recently, especially in emerging production areas such as the Western Cape. Thus, the following research questions will be addressed throughout the course of this study:

i. Can fruit bunch bagging be effective in the acceleration of date fruit ripening?

ii. Can fruit bunch bagging be effective in the control of pathogenic fungi causing fruit rot?

iii. Is fruit bunch bagging sustainable?

It is hypothesised that if bunch bagging is performed at the Khalal and/or Rutab stages of date maturation, it could lead to the acceleration of fruit ripening, while simultaneously reducing the incidence and severity of fungal infection on the ripening fruit. Sustainability in agriculture is typically defined as the efficient and effective long-term management of natural and human resources, in a manner that is environmentally non-degrading, economically viable and socially acceptable (FAO, 2014; DeClerck *et al*., 2016; Eyhorn *et al*., 2019). However, in this study, only the aspect of environmental sustainability will be considered. This means that if the bag used during the bunch bagging proves to be non-harmful to the date palm itself and its surrounding environment, as well as being either recyclable, reusable, or biodegradable, then the technique would be considered sustainable.

The major aim of this study is to investigate pre-harvest fruit bunch bagging as an environmentally sustainable approach to the acceleration of date fruit ripening, as well as the control of fungal infections in an organic date orchard in the Western Cape. During the 2022 growing season, date palm trees of the 'Medjool' variety were subjected to the following treatments: unbagged (control), blue low density polyethylene bags or white high density polyethylene bags. These treatments were implemented early and late during the fruit ripening period (17 February 2022 and 31 March 2022) which coincided with two phenologically important stages of date fruit maturation (Khalal and Khimri). Pre-harvest analyses include the assessment of specific physical, biochemical, and microbiological maturity, and quality parameters. Postharvest analyses included the evaluation of its shelf life potential and organoleptic properties. The results from this study will be used to make future recommendations on the colour, material, as well as when and how long the treatment should be implanted if results indicate positive treatment effects.

The literature review discusses date palm production in agricultural sustainability, when managed under organic principles. Chapter 1 assesses the effect of fruit bunch bagging on the acceleration of fruit maturation, by evaluating several maturity indices, as well as postharvest shelf-life potential and organoleptic properties. Chapter 2 looks into the effect of bunch bagging on the incidence and control of spoilage organisms causing fungal infection, by way of microbial analyses. Additionally, both papers judge fruit quality by comparing its results to international date fruit quality standards.

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Chapter 2: Literature Review

Organic date palm production and its role in advancing sustainable agriculture

1. Introduction

The intensification of agricultural production during the late 20th century was highly successful in its delivery of larger quantities of food grains such as wheat and rice, in a relatively short time period (Tilman *et al.*, 2011; Aune, 2012). This, known as the Green Revolution, was achieved through the development and use of high-yielding varieties, regular applications of synthetic pesticides and fertilisers, as well as deep tillage and heavy mechanisation (Tilman *et al.*, 2011; Gomez and Thivant, 2015; Eyhorn *et al.*, 2019). Almost half a century later, these approaches have resulted in a loss of biodiversity, soil and land degradation, pollution, as well as an increased incidence of pests and diseases. Moreover, these effects are exacerbated by global threats such as the rapid growth of the human population, acute food insecurity and climate change (Aune, 2012; Gomez and Thivant, 2015; Pareek *et al.*, 2020). In an effort to not only mitigate but combat the consequences of conventional farming, as well as provide for a population projected to reach 9.6 billion by 2050 and support changing dietary patterns, it is imperative to implement sustainable change to global food and agriculture systems (Food and Agriculture Organization, 2014; DeClerck *et al.*, 2016; Pareek *et al.*, 2020).

Sustainability in agriculture can be characterised by the efficient and effective long-term management of natural and human resources, in a manner that is environmentally non-degrading, economically viable and socially acceptable (Food and Agriculture Organization, 2014; DeClerck *et al.*, 2016; Semida *et al.*, 2019). These principles are readily apparent in organic agriculture, which is a farming system based on agro-ecological concepts promoting soil fertility and plant health, the banning of agro-chemicals or any other synthetic inputs, as well as diversification of farm enterprises and adaptive management. Farming practices such as reduced tillage, crop rotation, intercropping, mulching, composting, and biological control are some of the many tried and tested techniques used in organic agro ecosystems (Aune, 2012; Gomez and Thivant, 2015; Eyhorn *et al.*, 2019).

Originating in North Europe during the 1920s, organic agriculture as a philosophy and alternative farming system has spread worldwide (Gomiero *et al.*, 2011; Eyhorn *et al.*, 2019). Currently, over 160 countries globally practice organic farming, on a subsistence and commercial level. It is regulated by multiple national and international institutional bodies that classify and certify organic products from farming to marketing. The number of organic farms, the extent of organically farmed land, and the global market and demand for organically certified foods and beverages have steadily increased over the last few decades. Moreover, the amount of peer-reviewed research published annually clearly illustrates a growing interest by academics and funding bodies (Kristiansen *et al.*, 2005; Reganold and Wachter, 2016; Saffeullah *et al.*, 2021).

Organic date palm production represents a resilient farming system that is well-adapted to climate change, has socio-cultural importance and high economic value due to its immense processing and valorisation potential. However, traditional production and distribution systems currently dominate the date value chain, most commonly for subsistence or local markets (Augstburger *et al.*, 2002; Yahia and Kader, 2011). Recently, organic fruit and vegetables have experienced a surge in demand, particularly in European and American markets. Many date-producing countries such as South Africa are taking advantage of this interest by adopting sustainable practices to ensure premium date fruit quality and value (Johnson, 2010; Zaid and Piesik, 2021). This review will briefly discuss the history and spread of date palm production, describe the optimal growth conditions necessary for fruit development, as well as examine organic date fruit cultivation practices globally and in South Africa.

2. Date palm: Origin and distribution

The date palm (*Phoenix dactylifera* L.) is one of the oldest domesticated fruit crops in the world and grow in very hot arid regions, particularly the Middle East and North Africa, where it has been cultivated for approximately 5000 years (Johnson, 2010; Zaid and Piesik, 2021). Due to its long history of production and trade, it is difficult to pinpoint the exact origin of the date palm. The earliest record of its probable cultivation is around 3000 to 4000 BCE in ancient Mesopotamia, which is present day Iraq (Chao and Krueger, 2007; Johnson, 2010; Siddiq and Greiby, 2014). References to date palms have also been found in Ancient Egypt, and there seems to be a consensus that the earliest form of date palm cultivation originated in North-East Africa, stretching into the Euphrates and Tigris river system (Zaid, 2002; Johnson, 2010; Schorr *et al.*, 2018). Its cultivation then spread throughout the Arabian Peninsula and other countries in the Near East by means of a complex interplay involving European exploration and colonisation, as well as commerce and religion (Schorr *et al.*, 2018; Zaid and Piesik, 2021).

By 2021, over 120 million date palms are cultivated, producing 9.65 million tonnes of date fruit annually in over 30 countries on the Southern African Subcontinent, North and South America and Asia (Hanieh, Hasan and Assi, 2020; Farooq *et al.*, 2021). Over 89 percent of this production is concentrated in the Middle East and North Africa region, where it is traditionally cultivated for subsistence or local markets. Currently, Egypt is the world's largest producer of date, with Tunisia being the largest exporter and India the largest importing market (Farooq *et al.*, 2021; Oladzad *et al.*, 2021; Zaid and Piesik, 2021).

Date palms start to produce fruit four to seven years after its propagation. The trees may reach their full potential within 15 to 20 years and continue to produce for approximately 50 to 75 years. Fully mature trees are able to bear between 60 and 100 kg of fruit annually. The fruit are borne on clusters called bunches, the number of which can range from five to 30 per tree (Augstburger *et al.*, 2002; Chao and Krueger, 2007; Lobo *et al.*, 2014). Dates are single-seeded fruit and classified as a berry, usually with an oblong or rounded shape and vary from deep red to yellowish in colour (Zaid, 2002; Augstburger *et al.*, 2002; Lobo, Yahia and Kader, 2014). The shape, size, colour, and quality of the date fruit varies according to cultivar, environmental conditions and the technical care given during its growth and development (Al-Yahyai and Manickavasagan, 2013; Lobo *et al.*, 2014).

3. Date palm: Growth and development

The cultivation of date palms requires a hot and dry arid climate, with temperatures ranging between 25°C and 32°C, approx. < 12 mm rainfall and very low humidity during its fruit ripening period. While date palms adapt well to excessively high temperatures and water scarcity, they grow best in climates with long hot summers and rainy winters (Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014). The relative air humidity required by date palms are around 40% to 50%, depending on the cultivar and stage of fruit development. In a commercial setting, abundant volumes of water are required to ensure vigorous growth, high yields, and high-quality fruit. Sprinkler, micro, or drip irrigation systems are typically used in organic productions, in order to supply the palm's daily water uptake of 200 L during flowering and fruit ripening periods (Augstburger *et al.*, 2002; Chao and Krueger, 2007; Siddiq and Greiby, 2014). Diversification strategies such as intercropping are incorporated into date palm production, in order to promote the natural suppression of insect pests, pathogens, and weeds, as well as providing nutrients for neighbouring crops. The dense canopy of leaves created by mature date palms provides the microclimate and shade necessary for other arable crops to grow. The choice of intercrop depends on the site, technical care, and commercial objectives of the producer (Augstburger *et al.*, 2002; Yahia and Kader, 2011).

Date palms can grow in different types of soil, but optimal growth and development is achieved with permeable, deep sandy loam with a good water holding and drainage capacity. The date palm can also be cultivated in alkaline soils, with a pH up to 8. Additionally, date palms are able to grow in high salinity soils, but the productivity of the palm decreases as the salt concentration in the soil increases (Zaid, 2002; Chao and Krueger, 2007; Siddiq and Greiby, 2014). Nitrogen, phosphorus, and potassium are some of the essential mineral elements in the nutrient requirements of date palms, and the optimal amount depends on the cultivar, soil type and orchard management. In an organic date palm production, fertilisation strategies involve the regular application of compost, green or animal manure. Additionally, the practice of intercropping with peas, lentils and other legumes provides the soil with the necessary nitrogen enrichment to support the growth and development of date fruit during the maturation and ripening process (Zaid, 2002; Augstburger *et al.*, 2002; Siddiq and Greiby, 2014).

The growth and development of date fruit occurs over a period of six to eight months, during which the fruit grows rapidly, develops the colour and appearance characteristic to its cultivar, accumulates sugars while losing moisture and achieves a completely ripened state (Yahia and Kader, 2011; Lobo, Yahia and Kader, 2014; Siddiq and Greiby, 2014). Date maturation is divided into five stages known by their Arabic terms: Hababouk, Khimri, Khalal, Rutab and Tamr. Date fruits can be harvested during its Khalal, Rutab or Tamr stage (Mahmoudi *et al.*, 2008; Yahia and Kader, 2011; Lobo *et al.*, 2014). The stage of maturity at which dates are harvested depends on the cultivar, agro-climatic conditions, as well as sufficient access to markets. Dates are harvested from September to December in northern hemisphere production regions, while production regions in the southern hemisphere reach harvest season in February to April. That said, early harvest is commonly practiced in commercial date orchards, as it extends the supply chain and leads to higher revenue (Augstburger *et al.*, 2002; Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011). Since the ripening process in a fruit bunch is progressive, selective picking is often practiced ensuring dates are harvested at prime maturity and quality appearance. Most dates are harvested at Rutab or Tamr stage, due to its high sugar, low moisture, and astringency, as well as softer texture (Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011; Ghnimi *et al.*, 2017).

4. Date palm cultivation and sustainable agriculture

According to the Food and Agriculture Organisation (2014), sustainable agriculture can be defined as "the management and conservation of the natural resource base, and the orientation of technological change in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations. It conserves land, water, and plant and animal genetic resources, and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable". The mandate of the FAO is to eradicate food insecurity and malnutrition, improve agricultural productivity and sustainability, improve livelihoods, and enable inclusive and efficient agricultural food systems. Similarly, date palm production has numerous environmental, economic, and social implications, contributing to this mandate and thus promoting the system and goals of sustainable agriculture (Food and Agriculture Organization, 2014; Arias *et al.*, 2016).

Environmental benefits. Climate change poses enormous challenges to the continued productivity of global agriculture, which in itself is an exacerbating factor. Agriculture contributes to the climate change crisis, by causing and further driving nitrogen- and phosphorus-driven pollution of terrestrial, freshwater, and near-shore marine ecosystems, destructive greenhouse gas emissions, as well as severe losses in biodiversity, often leading to species extinctions (Tilman *et al.*, 2011; Aune, 2012; Kamil and Naji, 2012). In a highly connected and globalised society like today, food insecurity in one region may have widespread political and economic consequences on another. It is clearly critical to adapt current practices or adopt alternative practices to achieve sustainable agricultural development (Kamil and Naji, 2012; Wakil *et al.*, 2015; Zaid and Piesik, 2021).

While date palms can withstand and adapt to harsh climatic conditions, its development and productivity is noticeably affected by climate change. This is evident when looking at the numerous challenges that its cultivation faces. These include its declining genetic diversity due to the prevalence of elite cultivars, inefficient technical practices and storage affecting the management of pests and diseases, as well as water scarcity and soil degradation (Sharif *et al.*, 2010; Lobo *et al.*, 2014; Wakil *et al.*, 2015). However, the date palm has a variety of attributes and abilities which makes it suitable in climate change mitigation strategies, strengthening food and nutrition security, as well as encouraging economic development through employment opportunities (Kamil and Naji, 2012; Gomez and Thivant, 2015; Zaid and Piesik, 2021).

Resilience in farming can be characterised by the amount of change a system can undergo while still maintaining its structure and function, as well as its adaptive and self-organisational capabilities (Milestad and Darnhofer, 2003; Luvuno *et al.*, 2018). Date palms have maintained their ability to produce highly nutritious fruit, throughout thousands of years of cultivation and global regime shifts in nature and society. Techniques such as tissue culture seedlings, mechanical pollination and artificial ripening illustrate the technological innovation its cultivation has inspired, while its growth cycles haven remained relatively unchanged. The Medjool cultivar obtaining a landrace status speaks of its ability to adapt to the harshest of climatic conditions and remaining a premium fruit crop (Elhoumaizi *et al.*, 2006; Chao and Krueger, 2007). In addition, the global distribution of date palm production exemplifies the variety of not only climatic, but socio-economic conditions it may be cultivated under, as well as prosper in. Therefore, the production of date palms can be an inherently resilient farming system, which only may be reinforced by the principles of organic agriculture (Chao and Krueger, 2007; Yahia and Kader, 2011; Zaid and Piesik, 2021). For instance, Sharif (2010) examined the impact of date palm cultivation on the environment and asserts that an overall positive contribution is made to the orchard. This is due to the adaptation features of the date palm, leading to the enhancement of ecological balance and reducing desertification, as well as the potential for carbon sequestration given the physical capacity of the leaf fronds and trunk to absorb and store large amounts of carbon dioxide from the atmosphere.

Date palms are able to absorb carbon dioxide and produce sugars, oxygen, and water through the process of photosynthesis. Furthermore, date palms are large trees with dense canopies of leaves and leaflets, as well as trunk heights reaching more than 30 meters. This leads to significantly higher carbon dioxide absorption compared to trees of a similar size (Sharif *et al.*, 2010; Wakil *et al.*, 2015). One mature palm may be able to absorb more than 400 L of carbon dioxide per day. It is estimated that one million mature palms are able to absorb roughly two million tonnes of carbon dioxide annually. Alongside its high carbon dioxide absorption rates, date palms also have the capacity for high rates of carbon sequestration, given its large stem size, extensive root system and long lifespan (Siddiq and Greiby, 2014; Gomez and Thivant, 2015; Zaid and Piesik, 2021).

A particularly devastating ramification of climate change is the global expansion of desertification, which is characterised by extensive land degradation accompanied by rapidly decreasing water bodies, as well as reductions in vegetal and wildlife diversity. Desertification converts already dry regions into highly arid and sometimes barren land. This makes farming in dry regions increasingly challenging (Gomez and Thivant, 2015; Wakil *et al.*, 2015). Date palms have been found to be a potential resource in the control of desertification and land reclamation due to its ability to withstand unfavourable climatic conditions such as fluctuating temperatures, high salinity soil and water stress. Recently, date palms have been used in afforestation and reforestation programmes across the Arabian Peninsula. Additionally, these palms act to protect other crops from heat waves and frost, along with reducing damage caused by sandstorms and wind erosion (Wakil *et al.*, 2015; Zaid and Piesik, 2021).

Date palms are able to create a microclimate underneath its dense canopy of leaves, thereby providing a habitat suitable to local flora and fauna The root type and distribution of the date palm aids in the creation of this microclimate – its lack of root growth in the topsoil allows the development of other crops in the same space (Zaid, 2002; Yahia and Kader, 2011). The deep presence and high concentration of the roots allows date palms to benefit from groundwater and tolerate water stress or drought. In addition, date palms act as a protective barrier for this diverse habitat, against harsh climatic conditions or environmental damage (Augstburger *et al.*, 2002; Chao and Krueger, 2007). This role is especially evident in oasis ecosystems, where date palms have a central role in its ecological balance. An oasis refers to an area of isolated vegetation in a desert, which develops in the presence of a water source close to the surface. Oasis ecosystems are widely present in arid and semi-arid regions across Africa, Asia, America, Australia, and southern Europe (Yahia and Kader, 2011; Wakil *et al.*, 2015; Zaid and Piesik, 2021). They provide essential ecosystem services such as soil formation, nutrient cycling, and access to water reserves, as well as cultural services including ecotourism, heritage, and religious significance (Sharif *et al.*, 2010; El Bouhssini and Faleiro, 2018; Zaid and Piesik, 2021).

Social implication. The cultivation of date palm has long since had enormous historical and spiritual impacts on the people of the Middle East and North Africa and is highly regarded as part of the national heritage. Archaeological research into the remains of ancient Sumerian, Babylonian and Assyrian civilisations depict date palms and fruit on drawings and sculptures (Zaid, 2002; Siddiq and Greiby, 2014; Schorr *et al.*, 2018). For instance, the Code of Hammurabi is a well-preserved Babylonian legal text outlining societal laws, wherein rules and regulations regarding date cultivation and sales can be found. It is currently on display in the Louvre in Paris. Additionally, a Neo-Assyrian cylinder seal exhibited at the Metropolitan Museum in New York City, depicts the goddess Ishtar on a crouching lion surrounded by date palm trees. References to the date palm tree have also been recovered in ancient Egyptian, Syrian, Palestinian, and Libyan writings, where it was used for ornamental, landscape and aesthetic purposes (Zaid, 2002; Chao and Krueger, 2007; Siddiq and Greiby, 2014).

Dates and date palms are found throughout the Christian, Jewish and Islamic religions. The Christian Bible and Jewish Torah contain numerous references to date palms and its fruit, as well as describing its participation in religious ceremonies such as Palm Sunday and Passover. The date palm has been referred to as “the tree of life” in the Bible. Moreover, the date fruit is considered one of seven holy fruits in Judaism (Zaid, 2002; Siddiq and Greiby, 2014). In Islam, the date palm and fruit are directly mentioned multiple times in the Qur’an, as well as in the Hadith of the Prophet Muhammed. Date consumption noticeably peaks during the month of Ramadan where fasting is broken with dates, as well as during the annual Hajj to the city of Mecca (Siddiq and Greiby, 2014; Schorr *et al.*, 2018; Zaid and Piesik, 2021). The date palm has also gained cultural significance outside of its traditional growing areas. For instance, De Grenade (2013) discusses how the geographically extensive date palm groves on the Baja California peninsula in Mexico has become a cultural keystone due to its prominent role in the language, ceremonies, and narratives of the surrounding communities (De Grenade, 2013).

Economic potential. Considered a staple in many countries, the date fruit is able to make a substantial contribution to food, nutrition, and income security (Augstburger *et al.*, 2002; Zaid and Piesik, 2021). Date palms are very productive – one tree may produce eight to 10 kg during its first five to eight years after the completion of its juvenile growth phase. At the peak of its production, the annual yield of dates from a single fully mature tree could exceed 100 kg and continue to produce at a stable rate for decades. While known to be labour-intensive, commercial date cultivation has the potential to generate consistently high profits, diverse employment opportunities and skills development (Augstburger *et al.*, 2002; Chao and

Krueger, 2007; Yahia and Kader, 2011). Due to its high nutritional value, dates have long since believed to possess medicinal qualities, and alongside its potential as a high-energy option in emergency food relief programmes, it may also be used in the treatments of various ailments (Yahia and Kader, 2011; Siddiq and Greiby, 2014). Additionally, the efficient utilisation of the date fruit, its seed, and the palm itself, is able to generate a wide range of value-added products via postharvest processing. Oftentimes the expansion of postharvest processing incorporates a range of specialised techniques and equipment, which could lead to the development of expert skills in labourers (Chao and Krueger, 2007; Ashraf and Hamidi-Esfahani, 2011; Ghnimi *et al.*, 2017). Moreover, the expansion of date palm and fruit processing, as well as its valorisation has the potential to generate new market opportunities in food, pharmaceutical and textile industries, and transform the palm fruit into a more economically viable commodity. This can lead to the increased global production of dates, which will significantly improve income generation of date farmers and labourers, especially those in developing countries (Chao and Krueger, 2007; Ashraf and Hamidi-Esfahani, 2011; Zaid and Piesik, 2021). Many sources in literature supports the role that date palm cultivation has on economic sustainability. Sharif, Sanduk and Taleb (2010) stated that date cultivations have the potential to generate both high revenues, as well as employment opportunities, due to its high yielding capability given its large size and long life. According to Mihi, Tarai and Chenchouni (2019), the date palm offers a multitude of valorisation opportunities, thereby generating multiple streams of income (Sharif *et al.*, 2010; Mihi *et al.*, 2019).

The chemical composition of ripe date fruits makes it suitable for applications in medicinal and pharmaceutical industries. In the manufacturing of healthy foods, dates can act as a functional food ingredient, and its naturally antioxidant-rich compounds are ideal as a healthy substitute for synthetic antioxidants, such as butylated hydroxytoluene and propyl gallate (Tang *et al.*, 2013; Idowu *et al.*, 2020). In addition, date fruits have immense value as nutraceuticals and can be considered as one of the most appropriate substrates for manufacturing date-derived products such as organic acids, exopolysaccharides, antibiotics, and bakery yeasts (Al-Farsi and Lee, 2008; Vayalil, 2012; Oladzad *et al.*, 2021). Moreover, date seeds are a valuable by-product of date fruit processing and are characterized by a high level of bioactive fibres. Traditionally, it has been used as a fiber supplement in livestock feed, as well as decorative beads. Currently, date seed oil has been used in the manufacture of soap, as well as being a food additive, to enhance the fiber content of healthy food products (Yahia and Kader, 2011; Ghnimi *et al.*, 2017; Oladzad *et al.*, 2021).

As a result of its long history, almost every part of the tree has been utilised during and after its cultivation. Aside from timber and firewood, fiber from the trunk and leaves can be made into bags, baskets, fans, furniture, mats, paper, rope, and twine. The pith of the palms can be made into date palm flour, while the terminal buds of the palm can be eaten as a cooked vegetable (Zaid, 2002; Chao and Krueger, 2007). Traditionally, dried bundles of date palm leaves called “Barusti” were used as roofing material, as well as separating walls and shades. In addition, the ribs of the leaves were used to build small fishing boats called “Shasha”, as well as fishing traps (Augstburger *et al.*, 2002; Chao and Krueger, 2007). Another application of date palm organic wastes is biochar, which is charcoal produced from organic matter and applied as a soil amendment, with the aim of increasing soil health and sequestering carbon (Semida *et al.*, 2019; Oladzad *et al.*, 2021). Biofuels such ethanol, butanol, and hydrogen can be produced from dates using fermentation, which is feasible due to the high sugar content of the fruit. Moreover, the production of biofuel does not compete with the use of dates as food as major losses, as high as two million tons per year, are globally observed during its harvest, processing, and storage (Ghnimi *et al.*, 2017; Schorr *et al.*, 2018; Oladzad *et al.*, 2021).

The advancement of sustainable agriculture can be clearly seen in the production of date palm, as it has been shown to support environmental conservation through climate change mitigation, aid in socio-economic growth through the increased awareness and demand of dates and date-based products, as well as acknowledge their cultural and nutritional significance (Kamil and Naji, 2012; Zaid and Piesik, 2021). However, several challenges in organic date production persist, which may affect its success in achieving profitable yields, while still utilising sustainable approaches to crop, soil, and water management. Nevertheless, many opportunities exist which may lead to the improvement of current practices or the development of new techniques to overcome challenges in organic date fruit cultivation (Gomez and Thivant, 2015; Zaid and Piesik, 2021).

5. Commercial date palm production in an organic context

Organic agriculture is a farming system that promotes sustainable agriculture, with the aim of producing nutritious food, while minimizing the environmental impact of the food industry, preserving the long-term fertility of soil, and reducing the use of non-renewable resources. This is done by relying on ecological processes, enhancing biodiversity, and banning the use of synthetic agrochemicals during its cultivation (Gomiero *et al.*, 2011; Eyhorn *et al.*, 2019). Initially, many had doubts about the long-term sustainability of organic farming.

Organic farming is often seen as an alternative approach to its conventional counterpart. However, the cultural practices now synonymous to organic agriculture such as mulching, composting, or integrated crop-livestock are not new approaches to farming and have been utilised across a variety of agricultural systems. The difference is that farming systems under organic agriculture are bound to several legislations and certifications, which indicates the assurance in the effectiveness and efficacy of its principles and practices (Saffeullah *et al.*, 2021).

Furthermore, while the movement is still regarded with some scepticism, the concept of organic farming has strong marketing appeal, positive growth forecasts and the scientific evidence to back up its claims. Organic agriculture is one of the fastest growing agribusiness sectors in the world, with steady growth in land under organic cultivation, value of organic produce as well as number of organic farmers (Kristiansen *et al.*, 2005).

Organic agriculture has a number of benefits to the health of soils, ecosystems, and people, including conservation of soil fertility, the capture and storage of carbon dioxide, fossil fuel reduction, as well as the preservation of biodiversity in natural landscapes. However, challenges in organic agriculture remain crop yield, especially during the initial establishment of conversion to organic systems, as well as the effective and efficient management of pests and diseases (El-Shafie, 2019; Saffeullah *et al.*, 2021).

Organic productions of date palm share similar challenges to organic agriculture as a whole. Since date palms only start to bear fruit at four to five years after its propagation, the problem often faced in organic farming where crop yields are low during the first few years of establishment or conversion is inconsequential. During its long juvenile period, date palms are able to adjust to the effects of organic practices long before its fruit production. Thereafter, the full benefit of organic cultivation is able to coincide with the first harvest of date fruits (Augstburger *et al.*, 2002; Yahia and Kader, 2011; Gomez and Thivant, 2015). However, the ineffective management of pests and diseases, as well as losses during postharvest handling are major obstacles facing date palms and its quality in fruit (Chao and Krueger, 2007; El-Shafie, 2019; Saffeullah *et al.*, 2021).

Propagation and pollination. The cultivation of a healthy, vigorous date palm that is able to yield a large quantity of quality dates can be influenced by its method of propagation. Whether by tissue culture seedlings, transplanted offshoots, or mature palms, the orchard must have undergone strict agricultural quarantine controls before its establishment, in order to avoid infection from the eggs of various pests (Yahia and Kader, 2011; Lobo *et al.*, 2014; El-Shafie, 2019). Pollination is an essential process during date palm production, since without it there would be no fruit production. For instance, date palms may undergo parthenogenesis if not pollinated properly, in which vegetative but not reproductive growth occurs (Chao and Krueger, 2007; Lobo *et al.*, 2014). In a commercial orchard, a majority of female palms are cultivated, along with one male tree able to produce pollen for approximately 50 female palms. While date palm is naturally pollinated via wind or insects, artificial pollination by hand or specialised equipment is a common practice in modern orchards (Augstburger *et al.*, 2002; Siddiq and Greiby, 2014).

Organic fertilisation and irrigation. Although date palms can withstand long periods of high temperatures and water stress, large amounts of water are required in a commercial orchard, in order to obtain and maintain vigorous growth, high yield, and high-quality fruit. Thus, organic date palm productions are dependent on an effective irrigation and fertilisation routine, in order to cultivate healthy palms able to withstand attacks from opportunistic insect pest and diseases (Chao and Krueger, 2007; Al-Karaki, 2013). Irrigation is an important soil conditioning practice in organic farming, as it can be used to maintain soil health and palm immunity. Constant high soil moisture levels, as achieved by traditional flood irrigation and basin irrigation, may increase the infestation by red palm weevils in date palm orchards. As such, these are avoided by employing systems such as drip irrigation or micro-irrigation (Chao and Krueger, 2007; Yahia and Kader, 2011; Al-Karaki, 2013). In the organic cultivation of dates, soils are typically fertilised with green manures, animal manures and compost. However, extreme care has to be taken when applying organic manure and compost as it may contain eggs of the rhinoceros beetles, which are considered serious pests of date palm (Mahmoudi *et al.*, 2008; Pergola *et al.*, 2017). Intercropping date palms with leguminous plants such as alfalfa, peas and beans is able to supplement organic fertilisation, particularly nitrogen. Regular applications of organic material have been shown to improve water holding capacity, and thereby the efficiency of irrigation systems (Chao and Krueger, 2007; Pergola *et al.*, 2017; El-Shafie, 2019). Another form of organic fertilisation involves the use of bio-fertilisers, which are microbial inoculants containing live or dormant cells, and is applied as a nutrient amendment to seeds, plants, or soil. They are made up of nitrogen fixing, phosphate solubilizing, and phytohormone-producing microorganisms, which promotes plant growth by increasing the supply of nutrients to the host plant (Mahanty *et al.*, 2017; Saffeullah *et al.*, 2021). Several microorganisms are commonly used as biofertilizers - these include nitrogen-fixing soil bacteria (*Azotobacter spp*., *Rhizobium spp*.), nitrogen-fixing cyanobacteria, phosphate solubilizing bacteria (*Pseudomonas spp.),* as well as arbuscular mycorrhizal fungi. Bio-fertilisers are widely used to accelerate soil microbial processes, whereby nutrients can be more easily assimilated by the plant (Gomez and Thivant, 2015; Mahanty *et al.*, 2017; Umesha *et al.*, 2017).

Fungal pathogens affecting dates. Date palm orchards also suffer from fruit rot diseases, which are commonly caused by *Aspergillus spp*., *Fusarium spp., Penicillium spp., Rhizopus spp., Cladosporium spp*., *Alternaria spp., Mucor spp.* and *Torula spp*. (Kader and Hussein, 2009; Al Hazzani *et al.*, 2014). Fungal infection may occur during the growing season, during harvesting, or during postharvest storage. In general, the fungal spore functions as the infection vehicle for the further development of disease. The spore germinates under favourable conditions, of which humidity and temperature are most important for infection and reproduction. The pathogen may enter the fruit either directly through the skin, or by gaining entrance through natural openings such as stomata, lenticels, or wounds such as abrasions, punctures and bruises. The incidence and severity of the fungal infection depends on factors such as date fruit composition, climatic conditions, and cultural management (Shenasi *et al.*, 2002; Yahia and Kader, 2011; Sharma *et al.*, 2014). Date fruit has five stages of maturation (Hababouk, Khimri, Khalal, Rutab and Tamr), three of which may indicate commercial maturity and serve as a point of harvest (Khalal, Rutab, and Tamr). Date fruit at the Tamr stage is relatively resistant to fungal development due to high sugar and low moisture contents, but microbial spoilage can still be a problem if soft cultivars of dates are not appropriately stored. However, fruit in the previous Khalal and Rutab stages are much more susceptible to the development of fungal infection (Yahia and Kader, 2011; Haider *et al.*, 2014; El-Shafie, 2019).

Alternaria spp. are ubiquitous fungi, and its spores can frequently occur in a wide range of different habitats and substrates such as the atmosphere, plants, soil, and agricultural commodities (Troncoso-Rojas and Tiznado-Hernández, 2014; Abass, 2016; Matrood *et al.*, 2021). The most commonly occurring species in an agricultural context is *Alternaria alternata*, which contains host-specific pathogenic strains, opportunistic forms on ripening crops and saprophytic strains causing spoilage of freshly harvested crops. Fungal proliferation of *Alternaria* species is fostered at high relative humidity, with an optimal temperature ranging from 25°C to 35°C and a pH of 4 to 5 (Troncoso-Rojas and Tiznado-Hernández, 2014; Meena *et al.*, 2017; Fontaine *et al.*, 2021).

Similarly, the genus *Aspergillus* is widely distributed in nature and the most common member of microbial communities found in air and soil environments. *Aspergillus* is a necrotrophic and destructive fungus that secretes a wide range of oxidative and hydrolytic enzymes with a saprophytic activity in order to enter the fruit host. Thereafter, the fungal spore may remain quiescent until the fruit ripens, and the conditions are more favourable for disease development (Samson *et al.*, 2007; Varga *et al.*, 2008; Plascencia-Jatomea *et al.*, 2014). *Aspergillus* has a wide range of growth conditions, which includes a high moisture environment, growing temperature and pH ranging between 10°C to 50°C and 2 to 11, respectively. However, it has adapted to elevated temperatures and reduced water levels, and as such are common post-harvest spoilage fungi of a range of fresh and dried foods. This includes fruit, vegetables, spices, nuts and even smoked and cured fish (Varga *et al.*, 2008; Plascencia-Jatomea *et al.*, 2014; Piombo *et al.*, 2020). The most predominant species which contaminates food is *Aspergillus niger*, recognized as the causative agent of black moulds. Interestingly, the black colour of the spores is thought to provide protection from sunlight and UV light, providing a competitive advantage (Omamor and Hamza, 2007; Varga *et al.*, 2008; Plascencia-Jatomea *et al.*, 2014).

Like fungi from the *Aspergillus* genus, *Penicillium spp.* is one of the most common fungi occurring in a diverse range of habitats, from soil to vegetation to air, indoor environments, and various food products (Houbraken *et al.*, 2014; Palou, 2014; Visagie *et al.*, 2014). Blue or green mould caused by *Penicillium* species occurs mainly as fruit ripens, through wounds, or through direct contact between healthy and decayed fruit.. This fungus grows readily at 0°C, becoming more active in germination and growth from 4°C to 30°C, especially if humid weather precedes harvest (Varga *et al.*, 2008; Fourie, 2010; Visagie *et al.*, 2014). While infections and decay may occur in the orchard on wounded fruit or decaying organic material, *Penicillium* species are oftentimes most active on fruit during storage. This is because *Penicillium* spores are extremely resistant to drying and may survive for long periods on picking and packing equipment (Varga *et al.*, 2008; Palou, 2014; Visagie *et al.*, 2014).

Penicillium spp. and *Cladosporium spp.* are typical wound pathogens that have been reported as date spoilage fungi (Briceño and Latorre, 2008; Bensch *et al.*, 2012; El-Dawy *et al.*, 2021). *Cladosporium* species have an extremely wide ecological range, occurring on all kinds of substrates, and on a wide range of hosts, either biotrophically or on dead or senescing tissue (Bensch *et al.*, 2012; Ghiaie *et al.*, 2017; Iturrieta-González *et al.*, 2021). Optimal conditions for the proliferation of *Cladosporium spp*. occur within a temperature range of 18°C to 28°C , relative humidity of 40% to 60%, and a pH between 4 and 7. However certain species have been found to grow below 0°C or between 35°C to 37°C (Briceño and Latorre, 2008; Bensch *et al.*, 2012; Wu and Wong, 2022).

Botrytis cinerea has been very rarely found on date fruit (Williamson *et al.*, 2007; Romanazzi *et al.*, 2016; Petrasch *et al.*, 2019). *B. cinerea* grows at temperatures near 0°C but becomes more active at 5°C to 32°C. *Botrytis* species are regarded as high humidity pathogens and their conidia germinate at high humidity (Williamson *et al.*, 2007; Fillinger and Elad, 2015; Romanazzi *et al.*, 2016).

6. Commercial date palm cultivation in South Africa

The earliest written mention of date fruit cultivation may be from a bulletin published by a farming magazine in 1932, in which it was concluded that commercial date production had the best chance of success in the Northern Cape due to suitable climatic conditions (Marloth, 1932). The first commercial date orchard in South Africa was established almost 50 years ago in the Northern Cape province. These date palms were propagated from Medjool and Barhee offshoots, which were obtained through growers in the United States. The country’s location in the Southern Hemisphere gives it an advantage in producing out-of-season fresh fruit to markets in the Northern Hemisphere (McCubbin, 2007; Johnson, 2010;

Zaid and Piesik, 2021). Currently, dates are grown in the Northern Cape, Limpopo, and the Western Cape.

Agroclimatic conditions. As previously mentioned, date palms are adapted to arid environments but long, hot summer and low-rainfall winters are the preferred climates that make for highly productive date cultivation. During fruit maturation, temperatures ranging between 25 °C and 32 °C, low rainfall and very low humidity is preferred, as well as permeable, deep sandy loam with good water holding and drainage capacities (Zaid, 2002; Chao and Krueger, 2007; Gomez and Thivant, 2015). Moreover, large volumes of water are required to ensure vigorous growth, high yields, and high-quality fruit in commercial cultivation (Augstburger *et al.*, 2002; Chao and Krueger, 2007; Siddiq and Greiby, 2014).

The Northern Cape province is a large hot and dry region, with dry summers and sparse winter rainfall, with 50 to 75 mm annual rainfall. Date palm productions can be found in Pofadder, Upington, Henkries, Kakamas, Loeriesfontein and Ceres, with orchards stretching up to 100 hectares. Although these regions experience high temperatures and periods of drought, the orchards are supplied with water from the Orange River (McCubbin, 2007; Johnson, 2010). This creates cultivation conditions which are ideal for the production of high-quality date palm fruit, resulting in premium export prices. This is particularly the case for the Medjool variety - a uniform amber colouration is obtained with no or little loose skin on the fruit, which is a common physiological problem associated with unfavourable conditions such as high humidity during its ripening (Ashraf and Hamidi-Esfahani, 2011; El-Shafie, 2019). Other varieties produced in the region include Barhee, Khadrawy, Deglet Noor and Khalas. Approximately 60% of total date fruit is exported and the remaining 40% is used for the local market. Date production in the Northern Cape has grown to be a competitive enterprise in the export and local markets, due to high quality fruit and market access. A major strength in this area is that there is little, or no disease is observed, but challenges are still found in the reliable provision of energy, rising fuel prices and effective orchard management (McCubbin, 2007; Johnson, 2010). Another date growing region is found in the hot and humid Limpopo province, with little information available regarding its area or production value. However, this region has a summer rainfall during fruit set, which often results in proliferation of fungal and bacterial diseases causing rotting of the fruit. In addition, the African palm weevil (*Rhynchophorus phoenicis F*) and black scorch disease (*Thielaviopsis paradoxa*) are prevalent throughout production areas (McCubbin, 2007; Johnson, 2010).

Production practices. Although spread across multiple provinces throughout South Africa, date growers have similar production practices, particularly when cultivated in a commercial setting. One of the largest commercial date farms in the Southern Hemisphere can be found in the Northern Cape province of South Africa, along the lower Orange River region. In this area, almost 14 000 date palms are being cultivated across more than 80 hectares, with the largest date grower managing over 200 hectares. Propagation has historically been done with Medjool off-shoots, and in the past few years, with plantings of Medjool tissue culture plants (McCubbin, 2007; Marais, 2015; Smith, 2018). Date growers in this region are able to irrigate orchards with water from the river, traditionally applying flood irrigation, but have recently installed micro-sprinkler systems. Cultivated in sandy loam soils found along the riverbanks, date growers in the area produce an average of 1 000 tons of date fruit annually, the bulk of which is the popular Medjool variety. Other cultivars grown in this area include the Barhee, Zahidi and Pella varieties (Marais, 2015; Smith, 2018; The Karsten Group, 2021).

Production practices in a commercial date orchard is labour intensive and occurs continually throughout the year. An example of the annual technical calendar can be seen in Figure 1, which summarises the climatic conditions and technical operations of commercial date palm production in Namibia. Duties include regularly removing fronds and thorns that may later interfere with the harvest, as well as manual and/or mechanical pollination to initiate the flowering season, which is common in commercial orchards. This is due to female palms flowering before male palms, resulting in inadequate pollination and a low fruit set. Commercial orchards often collect pollen from male trees and store it under controlled conditions until the next growth season (Somewhere in Pofadder, 2000; Marais, 2015; Smith, 2018).

A few weeks after pollination, bunches on the palms undergo fruit thinning in order to control the number of fruits, which is typically 300 dates per bunch. As fruit bunches can become quite heavy, these clusters are tied to the branches in order to prevent them breaking off during the fruiting process. Additionally, each fruit bunch may be covered with a durable bag in order to protect the ripening fruit against pests such as birds, insects, and baboons, as well as catch any fallen fruit. Commercial harvest typically occurs during March and April, whereafter the fruit is then marketed until October. Harvesting of date fruits in the area is a highly selective manual process where only ripe fruit with a moisture content of 20 to 24 % is picked. This means that the fruit is harvested multiple times over a period of a few weeks (Marais, 2015; The Karsten Group, 2021).

A major strength in the Northern Cape date growing region, is that there is little, or no disease found on the palms, resulting in lower concentrations of pesticides utilised on and around the palms. Commercial date producers in the Northern Cape are well-established and are known to consistently produce high quality date fruit, as well as successfully export out-of-season fresh fruit to markets in the Northern Hemisphere for several years (McCubbin, 2007; Johnson, 2010). This is due to the near identical hot and dry climate to the Middle East where date palms are traditionally produced, resulting in little to no issues of pests, disease, or irregular ripening during its cultivation. In addition, most date producers in the Northern

Cape utilise conventional methods of agriculture, where practices such as the use of synthetic chemical fertilizers and pesticides, growth regulators, heavy irrigation, intensive tillage, and concentrated monoculture production aid in the high quantity and quality of fruits. However, date fruits undergo fumigation treatments in order to prevent damage from insects, whereafter they are sorted and graded according to their size and moisture content. The fruit that meets premium quality requirements are immediately packed and stored at -18 °C until its export (Marais, 2015; Smith, 2018).

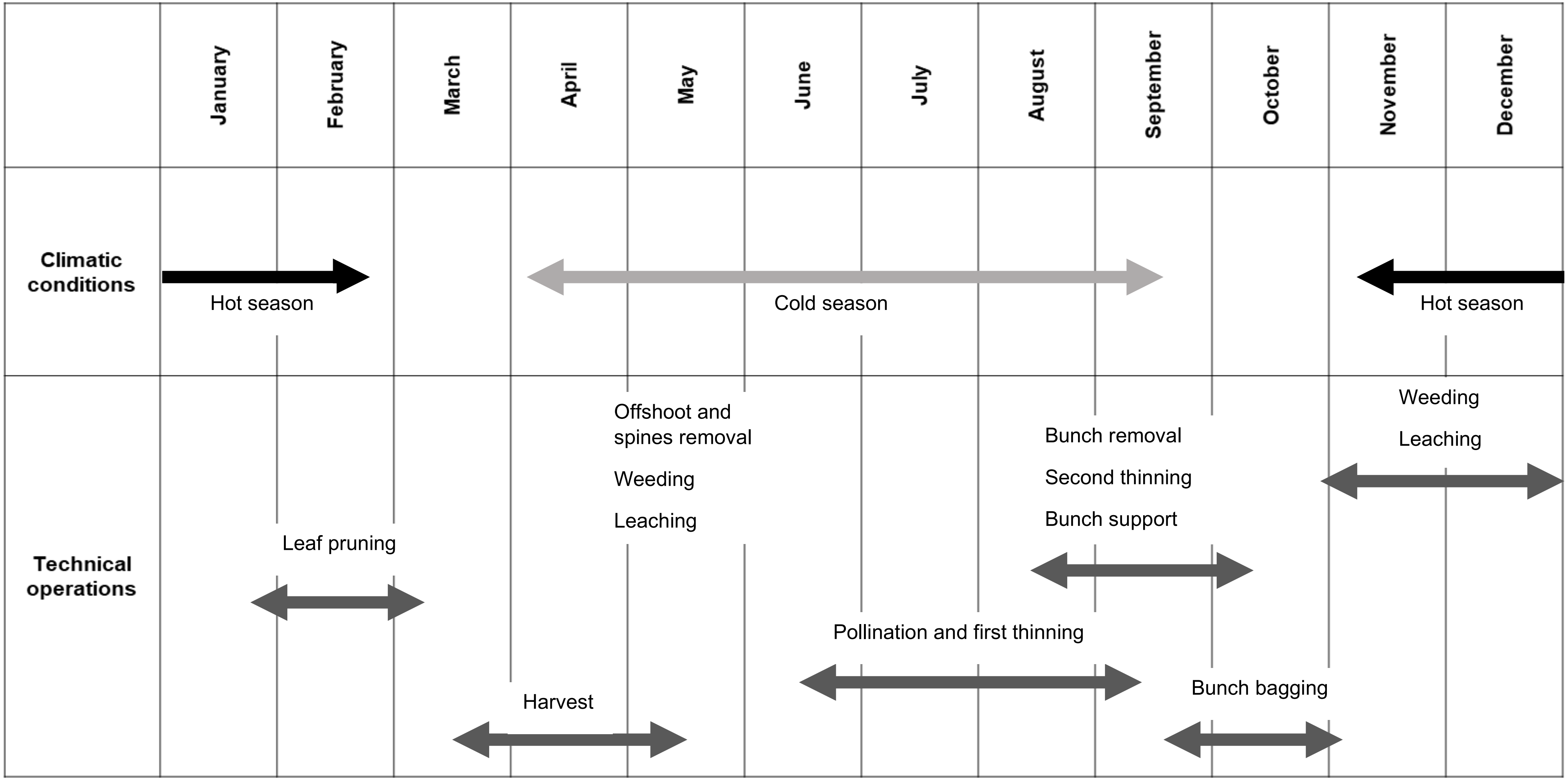

Figure 1. Date palm annual technical calendar based on Southern Africa (Keetmanshoop, Namibia). (Zaid 2002)

Date palm cultivation has since spread to the Western Cape, which is one of the richest fruit growing regions in the country (Vink and Tregurtha, 2005; Hoffmann and Harrison, 2014). The winter rainfall region of the Boland and the perennial rainfall of the Southern Cape provide agricultural conditions that make the crop mix and productive potential of the Western Cape unique. A main feature of agriculture in the Western Cape is production stability, based on stable and relatively adequate winter rainfall and supported by well-developed infrastructure for both input supply and output processing. This makes the province an ideal area for the implementation of commercial date palm cultivation. Interestingly, a rising trend in the Swartland region in particular has been to reduce conventional monocultural production and establish or convert to organic systems. While the adoption of organic productions in South Africa has been low, with only 154 certified organic producers from 1999 to 2019, the cultivation of date palm is particularly suited to organic agriculture. This is due to its long juvenile period, its low demand of nutritional and water requirements and its high valorisation potential (Vink and Tregurtha, 2005). However, very little information has been published on the production and quality of date fruit in the Western Cape, particularly when cultivated in a region with a Mediterranean-type climate using organic practices.

7. Future perspectives and conclusion

Date palm production has the potential to be a sustainable and resilient farming system due to its high nutritional and economic value, climate adaptation and cultural significance, particularly when cultivated under organic agriculture. Organic date palm production promotes sustainable agriculture, as it incorporates and enhances each pillar of sustainability through high-value products, history, and environmental benefits. Furthermore, date palms and its fruit have socio-economic significance due to its prominent presence in lives and livelihoods across the world, as well as its highly documented multifunctional utilisation across food, pharmaceutical, and manufacturing industries. The highly nutritious date fruit has enormous potential in food security programmes, and its production and marketing may generate diverse employment and entrepreneurship opportunities. Zaid and Piesik (2021) suggested that the date palm industry be transformed into a bio-circular economy, which emphasises the conversion of biological resources into value added products, such as food, feed, bio-based products, and bioenergy, simultaneously managing organic wastes and encouraging economic growth. This means allowing space for technological advancement in the processing of its palm and fruit, as well as the innovative development of good agricultural practices throughout its cultivation. The digitisation of records, as well as access to information and communications technology may aid in regional and international collaboration, easing the access to markets, support, and knowledge in rural communities. While organic date palm production has many areas of research still to be covered, currently, the major focus is on the sustainable development of the date palm value chain, especially in underutilised date-producing countries.

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Chapter 3: Paper 1

Assessing the effect of bunch bagging treatments at different phenological stages on the development of organic 'Medjool' date fruit maturity and quality characteristics

Abstract

A commercial 'Medjool' date palm (*Phoenix dactylifera* L.) orchard was recently established in the Hermon region of the Western Cape, South Africa. While high yields were obtained, slow fruit maturation was observed. The orchard practices organic agriculture, necessitating a sustainable approach to the acceleration of fruit maturation. In this study, the impact of preharvest fruit bunch bagging was investigated as a sustainable approach to the enhancement of organic date fruit maturity and quality. The study was conducted from February to May of 2022. Three different bunch bagging treatments (blue low-density polyethylene, white high-density polyethylene, no bagging as control) were implemented at an early (17 February 2022) and late (31 March 2022) interval during fruit maturation and removed at commercial harvest in May. Date fruit maturity and quality characteristics were recorded at two phenological stages, viz. Khalal and Rutab. Postharvest experiments such as shelf life potential and sensory analysis based on taste were conducted. Results showed that bunch bagging, particularly the late blue bagging treatment, accelerated fruit ripening at Khalal and Rutab, as seen in the increase of fruit weight ($p = 0.001$) and diameter ($p = 0.009$), as well as improving fruit coloration ($p = 0.001$) when compared to the control. Climatic data confirmed that bagging treatments modified fruit bunch microclimate when compared to regional climate. Bunch bagging, in particular the early blue bagging treatment, also showed positive effects on postharvest ripening rates ($p = 0.033$) and organoleptic condition ($p = 0.000$). Overall, the late blue bagging treatment was found to be the most effective in enhancing date fruit maturity and quality.

Key words: Date palm, fruit ripening, organic agriculture, polyethylene, South Africa

1. Introduction

Date palm (*Phoenix dactylifera* L.) is one of the oldest domesticated fruit crops in the world, originating from the arid and semi-arid regions of the Middle East and North Africa. (Johnson, 2010; Schorr *et al.*, 2018; Zaid and Piesik, 2021). While it may be grown across a wide geographic range in severe climates, specific growth conditions are vital for optimal flower and fruit development. Ideally, date palms are commercially cultivated in a hot and dry climate, with temperatures ranging between 25ºC to 32ºC, as well as low rainfall and humidity during the fruit ripening period (Fageria *et al*., 2000; Sharif *et al*., 2010; Lobo *et al*., 2014). High humidity and rainfall during critical stages of date palm cultivation, such as pollination, flowering, or fruit maturation, have an adverse impact on the development and quality of date fruit. This may lead to inadequate fruit set, inflorescence rot, physiological disorders, as well as an escalation of pest and pathogen incidence and disease (Chao and Krueger, 2007; Siddiq and Greiby, 2014; Hussain *et al*., 2020). Optimal growth conditions are further encouraged with sprinkler, micro, or drip irrigation systems, as a daily water uptake of approximately 200 L is necessary during the crucial flowering and fruit ripening periods (Carr, 2013; Schorr *et al.*, 2018; Dhaouadi *et al.*, 2021). Moreover, common organic practices such as intercropping, mulching, and composting in conjunction with practices specific to date palm productions such as artificial pollination, fruit thinning, bunch thinning, and bunch bagging, are implemented in order to ensure vigorous growth, high yields, and high-quality fruit (Yahia and Kader, 2011; Ali *et al.*, 2021; Saffeullah *et al.*, 2021).

Over 3 000 date palm varieties have been identified worldwide, each varying in their physical, compositional, and organoleptic characteristics. Currently, the ‘Medjool’ date variety dominates global demand, cultivation, and consumption. This cultivar has recently gained landrace status, which makes it uniquely adapted to the particular agricultural practices associated with commercial date palm production (Elhoumaizi *et al.*, 2006; Chao and Krueger, 2007). Known to be a large fruit when fully ripe, the ‘Medjool’ date has a characteristic golden to dark brown colour, and a soft, sweet taste with a distinctive caramel flavour when fully ripe (Chao and Krueger, 2007; Yahia and Kader, 2011; Zaid and Piesik, 2021).

The ripening of date fruit occurs over a period of six to eight months following pollination, and includes five distinct maturation stages, namely Hababouk, Khimri, Khalal, Rutab and Tamr. During the course of ripening, date fruits show two distinctive respiratory patterns: climacteric and non-climacteric (Serrano *et al.*, 2004; Ali *et al.*, 2021; Kou *et al.*, 2021). Date fruit are non-climacteric, meaning that they do not have an increase in the production of ethylene or the rate of respiration during ripening and that the fruits cannot ripen after harvest (Serrano *et al.*, 2004; Paul and Pandey, 2014; Kou *et al.*, 2021). Compared with climacteric fruit, the ripening of non-climacteric fruits is regulated by abscisic acid (ABA) in a manner independent of ethylene. However, the function of its role during non-climacteric ripening is not yet fully understood (Serrano *et al.*, 2004; Diboun *et al.*, 2015; Kou *et al.*, 2021). Understanding the ripening pattern of date fruit is critical for implementing suitable preharvest cultivation practices, determining the optimum point of harvest, as well as designing appropriate postharvest storage procedures (Lobo *et al.*, 2014; Paul and Pandey, 2014; Kou *et al.*, 2021).

It is necessary to understand the interconnected parameters of fruit maturity, ripeness, and quality, as the maturity of fruit at harvest will significantly affect its quality along the postharvest value chain (Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014). Oftentimes the maturity of date fruit and its readiness to be harvested can be assessed by a number of physical and chemical characteristics, termed maturity indices, many of which directly relates to quality traits. The maturity indicators for date fruit often typically include fruit weight and size, texture, the concentration of total soluble solids, colour gradient, moisture content, and acidity (Serrano *et al.*, 2004; Amorós *et al.*, 2009; Bajcar *et al.*, 2016). It is worth noting that a single maturity index cannot reliably assess the maturity of fruits, hence a variety of parameters are typically used to improve the accuracy of the assessment (Amorós *et al.*, 2009; Bajcar *et al.*, 2016; Ghnimi *et al.*, 2018).

Fruit quality implies the degree of excellence of a product or its suitability for a particular use (Kamal-Eldin and Ghnimi, 2018; Costa, 2019). For date fruits, quality indices include size, shape, colour, texture, and taste. Furthermore, traits such as sweetness, astringency, aroma, and mouthfeel are internal quality characteristics, which may be represented by measurable parameters including total soluble solids, titratable acidity, phenolic compounds, and flesh firmness (Al-Yahyai and Manickavasagan, 2013; Siddiq and Greiby, 2014; Al-Alawi *et al.*, 2017). In general, high quality date fruit possess a uniform colour and shape, thick flesh and small kernels, freedom from dirt, sand or leaf particles, no evidence of bird, insect, or rodent damage, no mould or decay, and no evidence of physiological damage or defects. Additionally, the skin of dates should be smooth, with little or no shrivelling, as well as the appropriate colour and texture (Kader and Hussein, 2009; Yahia and Kader, 2011; Siddiq and Greiby, 2014).

However, very little information has been published on the production of date fruit in the Western Cape, particularly when cultivated in a region with a Mediterranean-type climate using organic practices. While commercial date production in the Western Cape may benefit from fertile soil and regular rainfall leading to vigorous growth and high yields, issues such as slow maturation rates, fruit physiological disorders and low-quality fruit may hinder successful commercial production (Yahia and Kader, 2011; Lobo *et al.*, 2014). Since an organic system is practiced, the use of synthetic chemical-based growth stimulators and inorganic fertilisers are prohibited. This is because the overuse or misuse of synthetic fertilisers and growth regulators may lead to soil, water, and air pollution, as well as have an adverse effect on the health and safety of beneficial fauna and flora, agricultural employees, and consumers. Therefore, a sustainable approach is necessary to alleviate the potential issues that may arise during date fruit cultivation (Chao and Krueger, 2007; El-Shafie, 2019). One such approach is the use of fruit bunch covers or bags.

Fruit bunch bagging is a protective measure against birds, insects, unfavourable climatic conditions, and other forms of mechanical damage. The bag provides a physical barrier between the fruit and external stress factors, which helps in improving their external and internal quality. Furthermore, the technique is able to regulate the temperature, relative humidity, light intensity, and air movement inside the bag, leading to a microclimate adapted for optimal growth and development (Lobo *et al.*, 2014; Sharma *et al.*, 2014; Buthelezi *et al.*, 2020). Overall, bunch bagging has been shown to increase the rate and uniformity of fruit maturation, lead to higher quality date fruit in terms of enhanced physical and chemical features, as well as minimise the incidence of several microbial and physiological disorders (Yahia and Kader, 2011; El-Shafie, 2019; Buthelezi *et al.*, 2020). However, results have been inconsistent across literature sources. This is due to the variety of factors that influence the impact of bunch bagging, which include differences in climatic conditions and methodologies, the colour and composition of the cover, as well as the application and duration of the technique (Yahia and Kader, 2011; Sharma *et al.*, 2014; Rajan *et al.*, 2020). However, little to no research has been published on its efficacy in Mediterranean climates such as the Swartland region in the Western Cape.

Accordingly, the purpose of this study was to assess fruit bunch bagging as a preharvest treatment to accelerate the fruit maturation process, as well as enhance the fruit quality of the soft date ‘Medjool’ cultivar, in the context of the Swartland regional climate in the Western Cape. In this paper, selected maturity and quality characteristics of date fruit subjected to the bunch bagging treatment, were recorded during one season. This was done in order to form future recommendations regarding the most suitable implementation time for the treatment, as well as the type of cover material, for the surrounding climate that may lead to an expedited ripening process and potentially enhanced fruit quality.

2. Materials and methods

2.1. Plant material and sampling. During the 2022 season, uniform date palm trees (*Phoenix dactylifera* L.) of the ‘Medjool’ variety were randomly selected in the commercial organic date palm orchard at Kleinplasie, which is located near Hermon (33.444°S 18.973°E, altitude 81 m above sea level), in the Western Cape province, South Africa. The date palms were established in 2012 with ‘Medjool’ offshoots and are intercropped with pecan trees of a similar age. The trees are grown at a planting distance of 8 m x 8 m in sandy clay soil on a low ridge and receive drip-irrigation and organic cultural practices. An annual winter cover crop is established in the work rows during autumn (April) and is terminated naturally at the end of spring (October).

Based on a sufficient fruit set (at least 50 dates per bunch, and at least six bunches), eleven ‘Medjool’ date palms were selected for the study. Bunches represented an experimental unit. Following a completely randomised design, fruit bunches arbitrarily received a treatment at two phenological stages during date fruit maturation, namely Khalal (early in maturation process) and Khimri (late in maturation process). Khalal refers to when the fruit achieves a status of physiologically mature, while Rutab refers to the fruit being semi-ripe (Yahia and Kader, 2011; Lobo *et al.,* 2014). The treatments are described in Table 1. The bunches were covered by bags with the assistance of workers and were tied at the top of the bunch. The blue bags were left open at the bottom, while the white bags were closed (Figure 1).

Early bagging treatments were performed on 17 February 2022, while late bagging treatments were performed on 31 March 2022. Commercial harvest commenced on 3 May 2022 and the treatments were terminated on 11 May 2022. This resulted in the early bagging treatments lasting for approximately 12 weeks (11 weeks and six days), while the later bagging treatments lasted for approximately six weeks (five weeks and six days). Each treatment was replicated six times.

Sampling of date fruit for evaluation was done by randomly selecting fruit of a similar size randomly in a bunch, in order to analyse fruit maturity and quality via its physiochemical and microbial characteristics. Fruit was sampled on three occasions: at the start of the early bagging treatments (February 2022), at the start of the late bagging treatments (31 March 2022), and at commercial harvest (11 May 2022). Five fruit per date palm were sampled randomly before the early bagging treatments, in order to record a baseline for fruit maturity and quality. The baseline measurements were not included in the analyses but will be discussed in comparison to treated measurements. During the late bagging treatments, as well as at harvest, five fruit per bunch were selected in order to compare its maturity and quality to its baseline measurements. After sampling, the fruit was transported under ambient conditions and stored at 4°C for seven days before physiochemical analysis, and 11 days before microbial analysis, at the Horticultural Science department of Stellenbosch University (Stellenbosch, Western Cape, South Africa). After harvest, an additional number of dates were randomly selected, and were stored at 21°C for 14 days, at the Horticulture department of Stellenbosch University (Stellenbosch, Western Cape, South Africa). This was done in order to conduct a postharvest analysis consisting of an evaluation of fruit ripening during storage, as well as a sensory evaluation. Additionally, fruit quality measurements were compared to the CODEX Standard for dates (FAO-WHO, 1985) in order to objectively assess and discuss fruit quality, when necessary.

2.2. Preharvest fruit analyses

2.2.1. Fruit weight and size. Fruit weight (g) was recorded with the Scout Pro electronic scale (Ohaus, Germany), while diameter (mm) and height (mm) were measured with the

Absolute Digimatic calliper (Mitutoyo Corporation, Japan). Measurements were recorded on individual fruit basis and presented as means per replicate.

2.2.2. Total soluble sugars, pH, and titratable acidity. A homogenous sample was prepared from each replicate for the determination of total soluble solids (TSS), acidity and pH. The dates were peeled and pitted, then mashed and blended using an Electrolux juice extractor (AEG, Germany). The extracted fruit juice was mixed with 30 ml distilled water and vortexed. The extract was centrifuged at 4000 rpm for 5 minutes, incubated at 4°C for 15 min and the supernatant was to be used for further analysis (Haider *et al.*, 2014; Mohammad *et al.*, 2015; Ahmed *et al.*, 2021).

A Palette PR-32∝ digital refractometer (Atago, Japan) was used to measure TSS as % Brix. Titratable acidity (TA: g/100 g of malic acid) was evaluated by titrating juice samples with 0.1 N sodium hydroxide to an endpoint of pH 8.2 with a Robotic Titration Soliprep (Metrohm AG, Switzerland) and the pH was determined with the same instrument, periodically calibrated with buffered solutions (pH 4.0 and 7.0).

2.2.3. Fruit surface colour. The colour was also recorded by measuring L, a, b values with a colorimeter (Konica Minolta, Japan). Two readings were taken on each replicate, on opposite sides of the fruit. Since there were three replicates, this resulted in a total of six readings for each treatment group. According to the CIELAB (Commission Internationale de l´Eclairage) colour spectrum (Figure 2), L* indicates brightness, a* indicates the red/green coordinate, and b* refers to the yellow/blue coordinate (Hasanaoui *et al.*, 2010; Pathare *et al.*, 2013).

2.3. Postharvest fruit analyses

2.3.1. Shelf-life potential. A visual evaluation was done in order to record the ripening of treated fruit under simulated storage conditions as an indication of shelf-life. Five to eight fruit per replicate was stored at 21ºC in small mesh net bags and its maturity status was indexed according to the percentage of each of the following categories: 1 – unripe, 2 – semi ripe, 3 – ripe (Figure 3). This was done every seven days for 14 days, whereafter visible signs of decay were observed.

2.3.2. Sensory analysis. Fourteen days after harvest, two ripe fruit per treatment was selected from storage to participate in an ad hoc, blind tasting panel in order to conduct a sensory evaluation of the harvested fruit based on literature about descriptive sensory analysis (Ismail *et al.*, 2001; Barrett *et al.*, 2010; Plotto *et al.*, 2016). Under sterile conditions, each date was cut into five pieces and placed onto a petri dish, in order to have five replicates. In total, eight groups of five petri dishes were prepared, each having two pieces of fruit from the same treatment group. Dates bought from either Woolworths or Checkers were included as a positive control and were included in the random design but will not be statistically analysed. Five participants who like and eat dates frequently (3 women and 2 men with ages ranging from 25 to 50 years), were recruited among students and staff of the Department of Horticultural Science, Stellenbosch University. Each participant was explained the procedure and ranking of the evaluation. The participants were given a store-bought date fruit as an example of a top score, whereafter they had to score the date fruit using a descriptive scale from 0 to 3 as follows: 0 = inedible, would not buy, 1 = edible, would not buy, 2 = tasty, would not buy, 3 = tasty, would buy. No palate cleanser was given to the participant between each tasting. Microbial evaluation of date samples was performed prior to taste evaluation to ensure microbial acceptance levels.

2.4. Climate data

During early bagging treatments, five Tinytag Plus 2 TGP-4500 (Gemini Data Loggers, United Kingdom) data loggers were installed inside the bagging treatment in order to record the internal hourly temperature (°C) and relative humidity (% RH). Two replicates per bagging treatment received a logger, and one logger was fitted on a control bunch. The data collected from the Tinytag loggers (temperature and relative humidity) was compared to data collected from the Landau weather station (33.578°S 18.968°E, altitude 127 m above sea level), that represents the Hermon region.

2.5. Statistical analysis

Fruit quality and maturity evaluations were statistically analysed using one-way analysis of variance (ANOVA) and the differences among the means were separated using least significant squares (LSD) test determined for significance at 5% level. When appropriate, means were separated by Fisher's Least Significant Difference (LSD) post hoc test for significance at 5% level.

Data collected for fruit surface colour was also found to follow a non-parametric distribution, where subsequently a Kruskal Wallis rank sum test was performed, and multiple comparison tests using the Dwass-Steel-Critchlow-Fligner procedure with significant differences at 5% level were executed. All statistical analyses were performed using the XLSTAT (version 2022.3.2, Addinsoft, New York, NY, USA) computer application in the Windows 10 Excel 16.0.15629 64-bit software.

3. Results

3.1. Fruit weight. The average fruit weight at Khalal and Rutab is summarised in Table 1. Significant differences ($p < 0.05$) between treatments were observed at both phenological stages.

When the bagging treatment was implemented later during the fruit ripening process i.e., March, both the blue (30.67 g; $p = 0.019$) and white bags (29.88 g; $p = 0.049$) produced significantly heavier fruit than the control (25.80 g) at Khalal. Additionally, the later blue bagging treatment at this point was significantly different to the earlier blue bagging treatment (26.73 g; $p = 0.020$), which was implemented in February.

Date fruit subjected to both earlier and later bagging treatments were statistically similar to the control at Rutab. However, the later blue bagging treatment (31.13 g; $p = 0.001$) produced significantly heavier fruit than the blue bag during the earlier treatment.

3.2. Fruit length and diameter. The average fruit sizes at Khalal and Rutab are also summarised in Table 1. While no significance difference was recorded for fruit length at either Khalal or Rutab, fruit diameter demonstrated significant differences ($p < 0.05$) between treatments during both phenological stages.

At Khalal, the blue (33.51 mm; $p = 0.001$) and white bags (32.93 mm; $p = 0.011$) applied later in the ripening process both produced fruit with significantly higher diameters than specifically the early blue bagging treatment (30.97 mm). Additionally, the earlier white bagging treatment (32.48 mm; $p = 0.048$) was also significantly different from its blue counterpart. No significant differences were found between the control and other bagging treatments.

The early blue (29.94 mm; $p = 0.017$) and white bagging treatments (30.4 mm; $p = 0.049$) produced fruit with significantly lower diameters than the control (32.47mm) at Rutab. No other treatment was found to have a significant difference when compared to the control. In contrast, the late blue treatment (32.2 mm) led to significantly higher diameters than both the early blue ($p = 0.009$) and white ($p = 0.036$) bagging treatments.

3.3. Fruit TSS, TA, pH. The biochemical characteristics of the treated date fruit is shown in Table 2. The bagging treatments had no significant effect on total soluble sugars at either phenological stage. Similarly, the bagging treatments had no significant effect on the TA or pH when compared to uncovered fruit bunches. Only values for the Khalal stage were recorded, as an adequate volume of fruit juice in which to accurately measure each parameter could not be obtained at Rutab.

3.4. Fruit surface colour. The surface colour of treated date fruit is quantitatively described in Table 3, which includes values for the average L* (brightness), a* (red/green) and b* (yellow/blue) coordinates. No significant differences were found between the treatments at Khalal. At Rutab, the early white treatment was found to produce significantly darker fruit than the early blue treatment (L* = 59.29; $p = 0.003$), as well as both the late blue (L* = 59.25; $p = 0.003$) and late white (L* = 58.48; $p = 0.009$) bagging treatments. However, no significant difference in the L* colour parameter was found between the treatments and control.

Furthermore, the early white treatment (a* = 7.55; $p = 0.002$) produced significantly greener fruit than the unbagged control (a* = 10.18) at Rutab. Fruit from the early white treatment was also significantly different from its blue counterpart (a* = 10.40; $p < 0.0001$). In addition, the early blue bagging treatment had significantly greener fruit than those produced by the late white bagging treatment (a* = 8.65; $p = 0.011$).

The earlier white bagging treatment (b* = 36.7; $p = 0.001$) had significantly less yellow fruit than the control (b* = 48.58) at Rutab. The former was also significantly less yellow than the fruit produced under the early blue bagging treatment (b* = 43.85; $p = 0.013$), as well as both the late blue (b* = 46.02; $p = 0.001$) and white treatments (b* = 45.44; $p = 0.013$).

3.5. Shelf-life potential. Fruit produced by the bunch bagging treatments were harvested at the Rutab stage, and the percentage of unripe, semi-ripe and ripened fruit were indexed after seven- and 14-days in storage at 21°C (Figure 4). After 7 days in storage, significant differences were found in the percentage of ripe, semi-ripe and unripe fruit after the application of bagging treatments, when compared to the control.

On day seven, the percentage of ripe fruit produced from the late blue bagging treatment (3.33%; $p = 0.025$) as well as the percentage of semi-ripe fruit produced from the early white bagging treatments (10%; 0.044), was significantly different to the percentage of unripe fruit from the unbagged control treatment.

The later blue bagging treatments (73.33%) produced the highest percentage of unripe fruits on day seven and was found to be significantly higher than the following treatments and indexes: ripe (16.67%; $p = 0.044$) and semi-ripe (16.67%; $p = 0.044$) from unbagged control, semi-ripe from the early white bagging treatment (10%; $p = 0.025$), as well as ripe fruit from the late blue bagging treatment (3.33%; $p = 0.014$). Furthermore, the percentage of unripe fruit produced by the early white bagging treatments (63.33%) was found to be significantly different from the percentage of ripe fruit produced by the late blue bagging treatment (3.33%; $p = 0.033$). By the end of the storage period at day 14, differences observed among treatments were not statistically significant.

3.6. Sensory analysis. Fruit samples sourced from each treatment group were scored from 0 to 3 in terms of taste, in an ad hoc, blind tasting. The average scores of each treatment group are presented in Figure 5. Fruit harvested from the early blue bagging treatments (2.2) scored significantly higher than the unbagged control (0.5; p = 0.000). Fruit sampled from the late white bagging treatment (1.4) also scored significantly higher than the control (p = 0.037). Furthermore, the earlier blue bagging treatment was significantly different to the earlier white treatment (1.3; p = 0.037), as well as the later blue treatments (1.2; p = 0.022).

3.7. Climatic data. High temperatures and a comparatively low relative humidity can be seen from the beginning of the experimental trial in February to the end of March in the Hermon region. Thereafter, a noticeable increase in the average relative humidity was recorded, which continued until the end of the experimental trial in May. The region had its hottest day in February with a temperature of 37.19°C, and its coldest in May at 8.99°C. Additionally, the relative humidity was at its highest in April at 96.36%, and at its lowest in March at 10.24% (Figure 6).

The average diurnal internal temperature and relative humidity of each bagging treatment can be seen in Figure 7. Also, the average internal hourly minimum and maximum temperature and relative humidity of the early bagging treatments is presented in Figure 8, while the late bagging treatments can be seen in Figure 9. During the early treatments, the average internal temperature across treatments was as follows: 25.96°C in February, 23.68°C during March, 18.99°C in April and 18.06°C in May. In addition, the average internal relative humidity was recorded as follows: 67.99% in February, 71.74% in March, 65.49% in April and 69.9% in May. Furthermore, the highest temperature across treatments was logged at 46.25°C in the blue bag during February, while the lowest temperature was 2.26°C from the control also during February. The relative humidity reached its lowest level of moisture at 12.87% in the control during April, and was at 100% several times during March, April and May in both the blue and white bags. During the late treatments, the temperature reached 43.07°C in the blue bag during April while the lowest temperature was recorded at 2.26°C in the control during May. The relative humidity reached its lowest recording at 12.30% in the blue bag during April and reached 100% multiple times in the blue and white bags at 12.30% in April and May.

4. Discussion

4.1. Fruit weight.

Changes in the weight and size of fruits are commonly used as maturity indices, as well as an indication of quality. In this study, late blue bagging treatments led to a significant increase in fruit diameter and weight at the Khalal and Rutab stages but had no effect on the fruit length at either stage.

Similar results have been found in a study by Al-Obeed and Harhash (2010), who performed bagging treatments on the ‘Succary’ and ‘Khalas’ date cultivars in Saudi Arabia. They found that bagging date palm fruit bunches with black, white, blue, and yellow polyethylene bags increased fruit weight, length, and diameter compared with the untreated control, effectively accelerated fruit maturity and ripening (Al-Obeed and Harhash, 2010). Additionally, Kassem *et al.* (2010) reported that blue polyethylene bags increased fruit weight, length, diameter, and shorter harvesting period of the ‘Zaghoul’ date cultivar at Khimri and Khalal in Egypt. This is after its implementation at pollination, and its removal at Hababouk (Kassem, *et al.*, 2010). Another Egyptian study also reported that bagging with blue and black polyethylene bags significantly increased fruit weight and flesh percentage of ‘Seewy’ date palms compared to other treatments, resulting in accelerated ripening and improved fruit quality when compared with the unbagged bunched (Mostafa *et al.*, 2014). This may be due to differences in the colour and material of bag used, ripening stage of fruit at the start of bagging, and the surrounding climate (Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014).

4.2. Fruit length and diameter.

An overall downwards trend in weight, length and diameter can be seen from Khalal to Rutab across the majority of treatments in Table 1. This confirms the typical progression of date fruit maturation during commercial production and favourable growth conditions (Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011; Siddiq and Greiby, 2014). Weight and size rapidly increase from the start of date fruit ripening until its maximum is reached at physiological maturity at the Khalal stage. Thereafter, a drop in fruit weight has been reported between the Khalal and Rutab ripening stages. This is due to a steadying loss in moisture as a result of the inversion of sucrose into reducing sugars, which continues until the last stage of maturation, Tamr. This leads to not only a decrease in weight, but also a decrease in the dimensions of the fruit (Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011; Lobo *et al.*, 2014).

As illustrated in Figure 8, the internal temperature during the early bagging treatments was the highest in the blue bags, followed by the control and then the white bag. This was similar to the late bagging treatments, where the internal temperature of the blue bags was higher than the white bags and the control (Figure 9). This means that the bagging treatment modified the microclimate of the fruit bunch by maintaining a higher internal temperature when compared to the ambient regional climate. While the early bagging treatments reached higher internal temperatures than the later treatments in general, it was the late blue bagging treatment that contained the highest internal temperature at harvest. Therefore, the increase of weight and diameter in the late blue bagging treatments could be attributed to the accumulated heat, which activates metabolic processes and growth regulation thereby improving fruit growth, accelerating fruit maturation, and increasing fruit quality (Awad, 2007; Mostafa *et al*., 2014). This phenomenon is similar to Omar *et al.,* (2014), who reported that bagging treatments on 'Zaghloul' fruit bunches tended to create a warmer microclimate for fruit development than those without the bag, resulting in increased flesh and fruit weight at harvest (Khalil Omar *et al*., 2014; Omar and El-Shemy, 2014). However, this result is in contrast to studies such as Awad (2007), who reported that black and blue polyethylene bags in particular accumulated higher heat units than the unbagged controls when implemented one month after pollination, leading to higher respiration rates. This would mean that another factor not within the scope of the study led to this particular deviation.

In the case of the unbagged control, the fruit was exposed to the fluctuating weather conditions of the Hermon region (Figure 8). In the Southern Hemisphere, pollination and the subsequent fruit set would typically occur in October. Since Rutab starts 27 weeks after pollination, the transition from Khalal to Rutab would roughly be at the beginning of May. According to Figure 8, which illustrates the average daily temperature and relative humidity of the Hermon region, the beginning of May experienced a cold front during the transition period from the Khalal to Rutab stage. Since high temperatures are crucial to the successful fruit ripening, any decrease could adversely impact the rate of ripening, leading to a delayed progression in fruit development. Additionally, the relative humidity increases during this time, which could lead to higher percentages of moisture around the fruit bunch and leading to a delay in its water loss (Awad, 2007; Ashraf and Hamidi-Esfahani, 2011).

The length, width, and weight of the 'Medjool' date fruit typically varies from 18 – 110 mm, 8 – 32 mm and 2 – 60 g, respectively (Fageria *et al*., 2000; Ashraf and Hamidi-Esfahani, 2011; Arafa *et al*., 2022). Therefore, the physical characteristics of fruit investigated in this study meet the standards of fruit maturity at harvest. Moreover, these dates may be characterised as high-quality fruit, since they are several times heavier and larger than the minimum requirement according to the CODEX standard of dates (FAO-WHO, 1985).

4.3. Biochemical fruit parameters.

Changes in the biochemical composition in fruit are also commonly used as maturity indices (Yahia and Kader, 2011; Lobo *et al*., 2014; Siddiq and Greiby, 2014). In this study, bunch bagging with different materials did not have an effect on the biochemical parameters of date fruit at either the Khalal or Rutab stage. Several studies have reported that total acidity was not significantly affected by bagging treatments. For instance, Kassem *et al.,* (2010) reported that 'Zaghloul' dates covered with dark polyethylene bags at the Khimri stage did not affect total acidity and total soluble solid content (Kassem *et al*., 2010). Similarly, Awad (2007) reported that bunch bagging on the ‘Helali’ date palm showed no negative impact on the overall quality characteristics of ripe fruit (Awad, 2007).

Total soluble solids (TSS) progressively rise during the stages of date fruit maturation. This increase of the sugar concentration is related to the decrease in the moisture content of date fruit during the ripening process, which reaches its maximum the fully ripe Tamr stage (Yahia and Kader, 2011; Siddiq and Greiby, 2014; Ali *et al.*, 2021). Generally, an upwards trend in TSS can be seen from Khalal to Rutab across all treatments. Furthermore, fruit subjected to the blue polyethylene applied later in the season had the highest TSS at Khalal, while fruit sampled from the uncovered control had the highest TSS at Rutab. This could be due to the accumulation of sugars during the transition from Khalal to Rutab, which is expected at this point of maturation (Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011; Lobo *et al.*, 2014). Overall, the TSS, TA and pH slightly increased from the Khimri to Khalal stage. This is to be expected for the natural progression of fruit maturation at this time (Yahia and Kader, 2011; Lobo *et al.*, 2014; Ali *et al.*, 2021).

Typical values for these biochemical parameters in ‘Medjool’ dates have been reported at a TSS of 18.83 – 55.5 °Brix, pH of 5.3 – 6.6, and a malic acid content of 0.11 – 0.21 g/100 g at harvest (Fageria *et al.*, 2000; Ghnimi *et al.*, 2018; Arafa *et al.*, 2022). The biochemical characteristics of fruit investigated in this study meet the standards of fruit maturity at harvest. However, at this point, the fruit are moderately sweet but slightly astringent, leading to a lower quality date fruit in terms of sensory quality (FAO-WHO, 1985).

4.4. Fruit surface colour.

Colour is an important parameter for maturity and market acceptability of foods, as the correlation between maturity level and colour allows consumers to determine ripeness by visually examining the colour of the fruit (Al-Hooti *et al.*, 1996; Lee *et al.*, 2008; Ali *et al.*, 2021). In this study, fruit surface colour was significantly affected by the bagging treatments at the Rutab stage, but not Khalal. The early white bagging treatment increased a* values of fruit colour, resulting in greener fruit than the control at Rutab. Additionally, the same bagging treatment showed a higher decrease in b* values than the control, indicating the production of a more yellow fruit. These results correspond to those reported by Serrano *et al.* (2004), who reported that bagging improved fruit coloration. Similarly, Madani *et al.* (2021) reported that bunch bagging the ‘Piyarom’ date cultivar reduced the lightness (L*) of the fruit compared to the control (Serrano *et al.*, 2004; Madani *et al.*, 2021).

Values for L* typically decline from Khalal to Rutab, as date fruit starts to darken as ripening progresses (Table 3). However, fruit sampled from the unbagged control showed a very little difference in L* values from Khalal to Rutab, suggesting that the fruit did not experience a noticeable change in colour. In the case of a* all values change from negative at Khalal to positive at Rutab. At Khalal, the date fruit had the same green colour across all treatments which changed to significantly less green colour at Rutab. Furthermore, values for b* generally increase from Khalal to Rutab, indicating that the fruit became more yellow and thus matured. However, fruit sampled from white bags applied later in the process increase in b* values, suggesting no measurable change in colour.

The change in colour during maturation is due to a combination of different pigments undergoing a series of biochemical changes. The changes in colour parameters in this study may be due to differences in the cultivar, climatic conditions, as well as the colour, material, and duration of bagging treatment (Yahia and Kader, 2011; Sharma *et al.*, 2014). The colour parameters investigated in this study followed the typical changes as described for the 'Medjool' date fruit, indicating a normal progression of fruit maturation, with deviations attributed to the type of bagging treatments, as well as the climatic conditions surrounding the fruit bunch.

In this study, the temperature in the control, early white treatment bags and early blue treatment bags were similar throughout the experimental trial until the end of March. Thereafter, the temperature was at its highest in the early blue treatment bags, then the unbagged control, and was lowest in the early white treatment bag until harvest. This difference may explain the variation in fruit colour (Figure 8). The colour of the bagging material acts as a filter of photosynthetically active radiation (PAR), which refers to the range of wavelengths that aid in photosynthesis. For instance, blue bags let in 73% of the wavelengths in the PAR, whereas transparent let in more than 90%. This means that blue bags are able to increase temperature without causing burns as it blocks UV rays, resulting in an adapted microclimate with favourable conditions for fruit development (Awad, 2007; Ashraf and Hamidi-Esfahani, 2011; Yahia and Kader, 2011). The values for fruit colour in 'Medjool' dates in this study are comparable to those presented in literature (Al-Hooti *et al.*, 1996; Fageria *et al.*, 2000; Mahawar *et al.*, 2017) with any deviations due to variations in cultivar and climatic conditions.

4.5. Postharvest fruit quality.

Postharvest fruit physiology and shelf-life are closely related, as the length of time fruit may be in storage while maintaining its quality depends on the degradation mechanisms of the fruit (Lobo *et al.*, 2014; Paul and Pandey, 2014; Ali *et al.*, 2021). In this study, the shelf-life potential of organic 'Medjool' date fruit picked at the Rutab stage was assessed by the proportion of ripeness after storage. The late blue treatment displayed the highest percentage of unripe fruits on day seven and was significantly different to the control. The early blue treatment had the highest percentage of semi-ripe fruit, and the late white treatment had the highest percentage of ripe fruit, but neither were significantly different from the control. On day

14, the unbagged control treatments had the highest percentage of unripe fruit, while the late blue treatment had the highest percentage of semi-ripe fruit. The early white treatment produced the highest percentage of ripe fruit. However, no significant difference was found when compared to the control. The difference in fruit ripeness across bagging treatments are most likely due to the duration of the treatment, as well as the type of bag. Blue polyethylene bags are more likely than the white bags to increase the internal temperature of the fruit bunch, leading to more favourable growth conditions and a subsequent enhanced rate of fruit growth (Figure 8). Bags implemented early in the season would have a longer period of time to modify and maintain the elevated temperature of the bunch microclimate. However, the blue bags were left open at the bottom of the bunch, while the white bag completely enclosed the fruit bunch. This isolation most likely led to a similar but more uniform effect of the modified fruit bunch microclimate when compared to the blue bag, causing an enhanced rate of ripening on a larger number of date fruit.

Morphological observations during the assessment indicated that a number of date fruit across bagging treatment groups had fruit with the beginning signs of shrivelling. While controlled storage conditions are known to cause a loss of moisture, these particular fruits had the characteristic yellow colour of Rutab dates but showed no signs of transitioning to a darker brown colour common to ripe ‘Medjool’ dates. It is hypothesised that shrivelling dates are parthenocarpic fruits, which were not pollinated but have developed without fertilisation. Consequently, they will not ripen further but rather rot (Yahia and Kader, 2011; Lobo *et al.*, 2014; Munir *et al.*, 2020). Furthermore, a common sign of harvest ready Rutab dates is a visible browning at the tip of the fruit. Typically, this would indicate the transition of Rutab dates maturing into Tamr dates. However, with parthenocarpic fruit, it is more likely due to a physiological abnormality where undesirable enzymatic and non-enzymatic browning occurs due to a loss in moisture. This occurs in dates that were exposed to periods of high relative humidity and temperature (Yahia and Kader, 2011; Al-Yahyai and Manickavasagan, 2013; Lobo *et al.*, 2014), which existed from time to time in the bagging treatments. Fruit flies were observed among fruit while in storage, which indicated the progression of decay or rot of the dates. Additionally, this fruit had a hard texture and remained greenish yellow in colour, even though the browning at the tip of the fruit spread to the middle of the fruit. This supports the hypotheses that these are parthenocarpic fruit, and that the browning was as a result of a physiological disorder at harvest.

In this study, bunch bagging treatments led to the improvement of postharvest ripening and shelf-life potential of Rutab dates compared to the control. However, a number of harvested fruits was found to be parthenocarpic fruit, and the storage temperature of 21°C was unsuitable for the storage of the highly perishable Rutab date. Kassem *et al.* (2011) found that bunch bagging the ‘Zaghloul’ date variety with blue polyethylene bags led to a high percentage of ripe Rutab fruit after 15 or 30 days in cold storage as compared to the unbagged control, in Egypt. However, these results were due to implementing the bunch bagging technique directly at pollination, and the bags were applied to the flower spathes (Kassem *et al.*, 2010; Khalil Omar *et al.*, 2014). In this study, 'Medjool' date fruit were stored at 21°C after the application of bunch bagging after fruit set and at the transition of colour in date fruit development. Therefore, the variation in results may be due to the difference in the duration of bagging treatments, cultivar-specific responses, and storage temperature.

Sensory perception is a recognized parameter of fruit quality and may refer to fruit appearance, texture, taste and/or aroma, all of which contribute to consumer satisfaction and market success (Myhara *et al.*, 2000; Ismail *et al.*, 2001; Noutfia *et al.*, 2019). In this study, bunch bagging had a significant effect on the taste of postharvest date fruit. More specifically, fruit harvested from the early blue treatment achieved the highest tasting score, closely followed by the late white treatment applied later in the season. The lowest score was given to fruit produced from the unbagged control treatment, which is an indication of the positive effect of the bagging treatments on taste. While several studies have investigated the organoleptic properties of date fruit cultivars, very few literature sources have assessed the effect of bagging treatments on the sensory properties, specifically taste, of fresh 'Medjool' date fruit with a similar scoring system and methodology as in the present study.

Studies have indicated that date fruit was considered higher in quality and sensory ability when it had a high TSS and low TA value at harvest (Myhara *et al.*, 2000; Singh *et al.*, 2015; Noutfia *et al.*, 2019). Additionally, eating quality parameters are affected by storage conditions and shelf life. In this study, the highest TSS was recorded in the control treatment at Rutab, while the lowest TA at Khalal was also seen in the control treatment (Table 2). This is in contrast to the sensory analysis, as the control treatment received the lowest score. However, this contradiction may be clarified in that the percentages of ripe fruit did not change from day seven to 14, implying little to no ripening of fruit produced from the control treatment. Additionally, it may be due to the low number of subjects used in the experiment. Meanwhile, the early blue and late white bagging treatment showed a high rate of fruit ripening during storage, which implies the occurrence of metabolic changes during storage, ultimately leading to sweeter, less acidic date fruit.

5. Conclusion

The purpose of this study was to assess fruit bunch bagging as a sustainable preharvest treatment to accelerate the fruit maturation process, as well as enhance the fruit quality of the soft date 'Medjool' cultivar, in the context of the Swartland regional climate in the Western Cape. Selected maturity and quality characteristics of date fruit were recorded during one season to make future recommendations regarding the most suitable implementation time for the treatment, as well as the type of cover material to address the late maturation of dates in this region.

As the adoption of organic agriculture slowly but steadily grows in South Africa, it has become increasingly important to develop techniques for improving fruit production, appearance, and quality with little to no use of chemical intervention. Preharvest fruit bunch bagging has been used extensively in many crops to provide a physical protection to the fruits, which helps in improving their external and internal quality as well as modifies the microclimate inside the bag for favourable growth and development. However, results are variable and depend on the covering type, fruit age at covering and cultivar response, as well as climatic conditions. The effect of fruit bunch bagging on the maturity and quality of organic date fruit was shown to accelerate fruit ripening and had a positive impact on fruit diameter, weight, and colour, as well as postharvest fruit quality. Furthermore, the technique showed no negative impact on the biochemical characteristics of ripe fruit. Generally, the late blue bagging treatment was the most effective treatment. Its preharvest impact includes increases in weight and diameter at both Khalal and Rutab and improving fruit colouration at Rutab. The early blue bagging treatment achieved the highest score in taste across all treatments, after the enhanced rate of fruit ripening seen during storage. Bunch bagging has also proven to be an environmentally sustainable approach suitable for use in organic farming systems, as the bags can be recycled or re-used after the end of the season.

Microclimate data for the early and late bagging treatments confirmed the modification of the internal temperature and relative humidity within the enclosed fruit bunch bag. This aided in the formation of optimal conditions for fruit growth and development. Although positive results were achieved with some bagging treatments, we need to standardise specifications for the type of bag to be used, the date of bagging, and the date of bag removal for growers to benefit from this technology.

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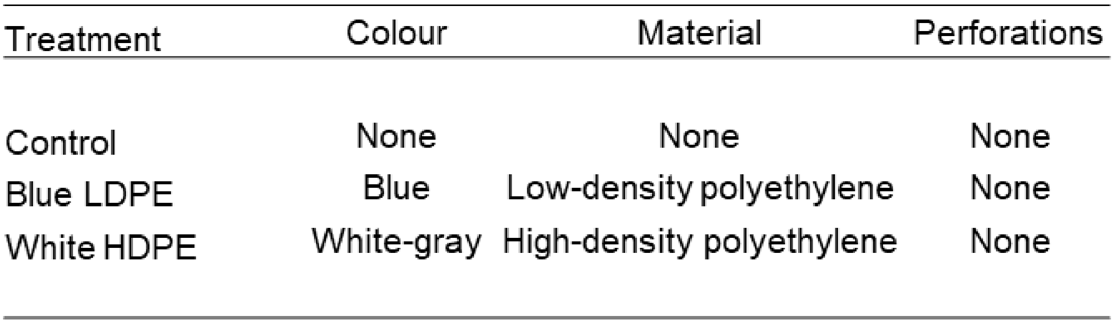


Treatment	Colour	Material	Perforations
Control	None	None	None
Blue LDPE	Blue	Low-density polyethylene	None
White HDPE	White-gray	High-density polyethylene	None

Table 1: A detailed description of treatments used in the experiment

Figure 1A. Experimental view of (A) control, (A) blue and (C) white bagging treatments on 17 February 2022 as seen on ‘Medjool’ date palm fruit bunches at Kleinplasie, Hermon. Photos by RJ Peddie (2022).

Figure 1.B. Experimental view of (a) control, (b) blue and (c) white bagging treatments on 31 March 2022 as seen on ‘Medjool’ date palm fruit bunches at Kleinplasie, Hermon. Photos by RJ Peddie (2022).

Figure 1C. Experimental view of (a) control, (b) blue and (c) white bagging treatments on 12 May 2022 as seen on ‘Medjool’ date palm fruit bunches at Kleinplasie, Hermon. Photos by RJ Peddie (2022).

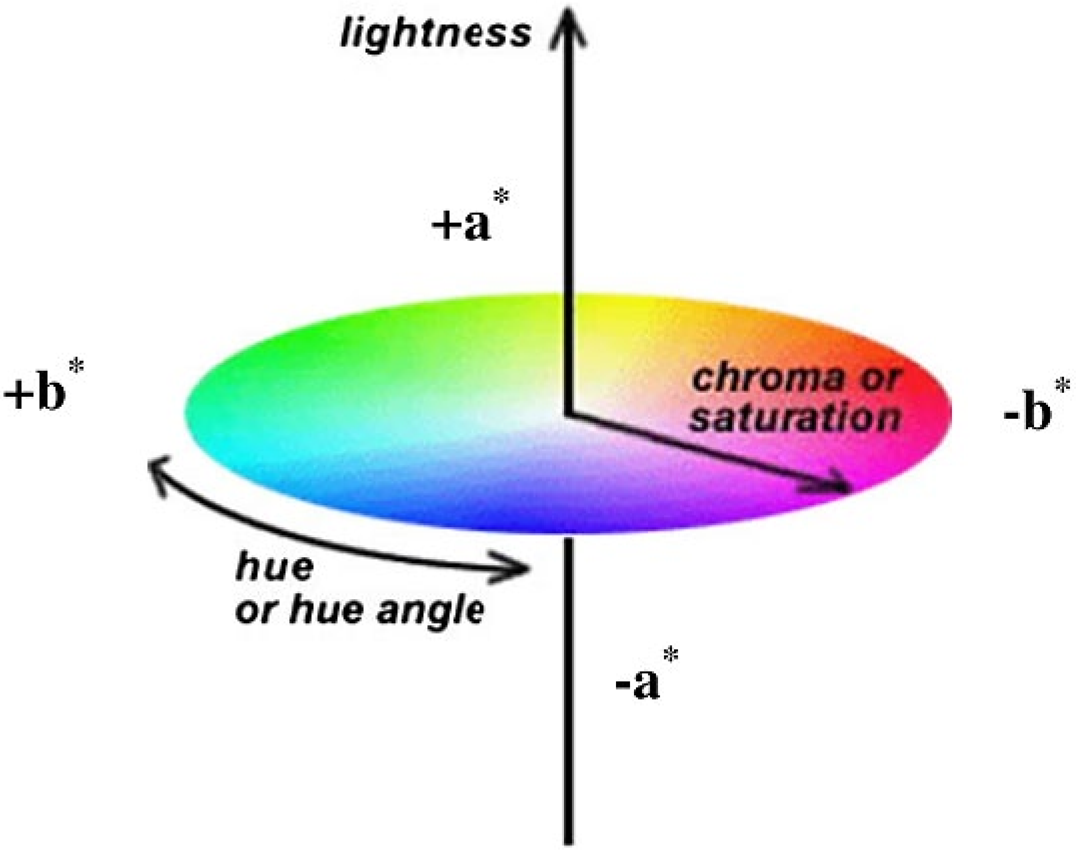
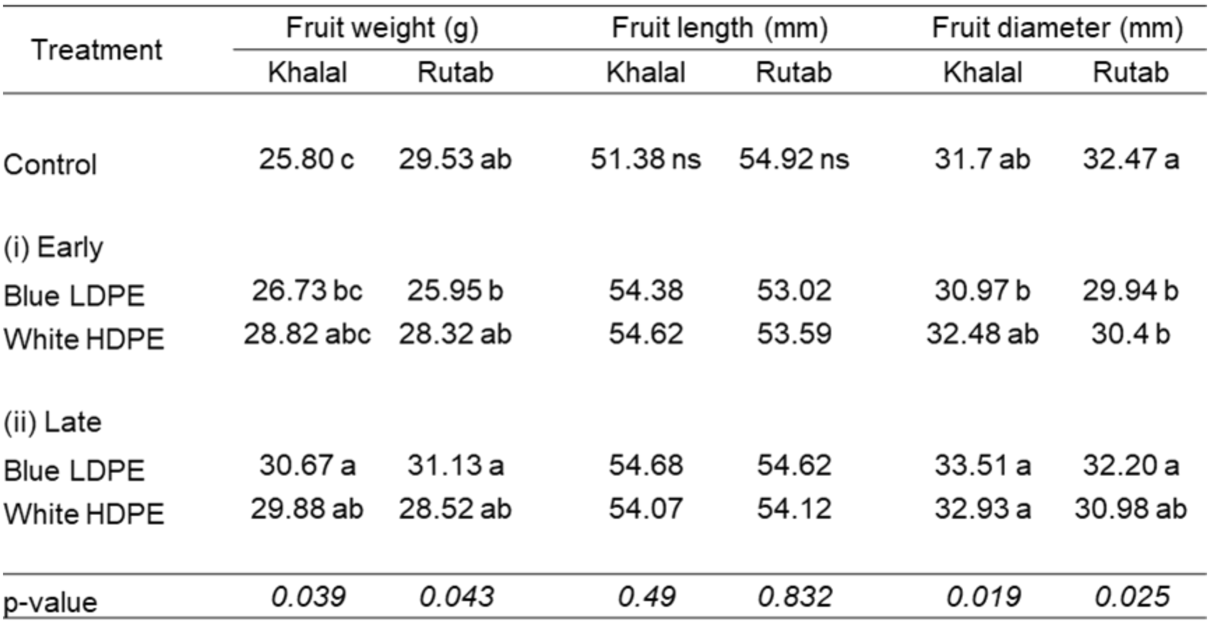


Figure 2. CIELAB colour spectrum and parameters, as adapted from (Pathare *et al.*, 2013)

Figure 3. Representative example of (a) unripe and (b) semi-ripe and (c) ripe ‘Medjool’ date fruits during the assessment of shelf-life potential. Photos by RJ Peddie (2022).

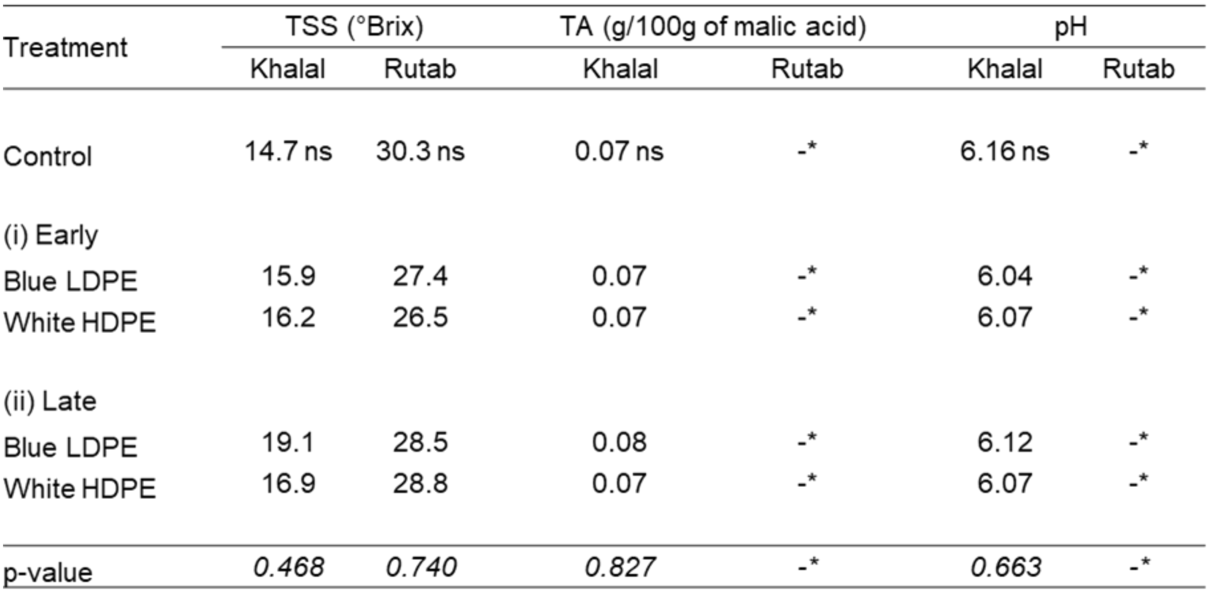
Table 2. Effect of preharvest treatments on ‘Medjool’ date fruit physical characteristics subjected to (i) early and (ii) late application during the Khalal and Rutab phenological stages, at Kleinplasie, Hermon, during 2022.



Treatment	Fruit weight (g)		Fruit length (mm)		Fruit diameter (mm)	
	Khalal	Rutab	Khalal	Rutab	Khalal	Rutab
Control	25.80 c	29.53 ab	51.38 ns	54.92 ns	31.7 ab	32.47 a
(i) Early						
Blue LDPE	26.73 bc	25.95 b	54.38	53.02	30.97 b	29.94 b
White HDPE	28.82 abc	28.32 ab	54.62	53.59	32.48 ab	30.4 b
(ii) Late						
Blue LDPE	30.67 a	31.13 a	54.68	54.62	33.51 a	32.20 a
White HDPE	29.88 ab	28.52 ab	54.07	54.12	32.93 a	30.98 ab
p-value	*0.039*	*0.043*	*0.49*	*0.832*	*0.019*	*0.025*

Means with different letters in the same column are significantly different at p > 0.05 using Tukey multiple comparison tests. LDPE = low density polyethylene, HDPE = high density polyethylene. ns = not significant.

Table 3. Effect of preharvest treatments on ‘Medjool’ date fruit biochemical characteristics subjected to (i) early and (ii) late application during the Khalal and Rutab phenological stages, at Kleinplasie, Hermon, during 2022.

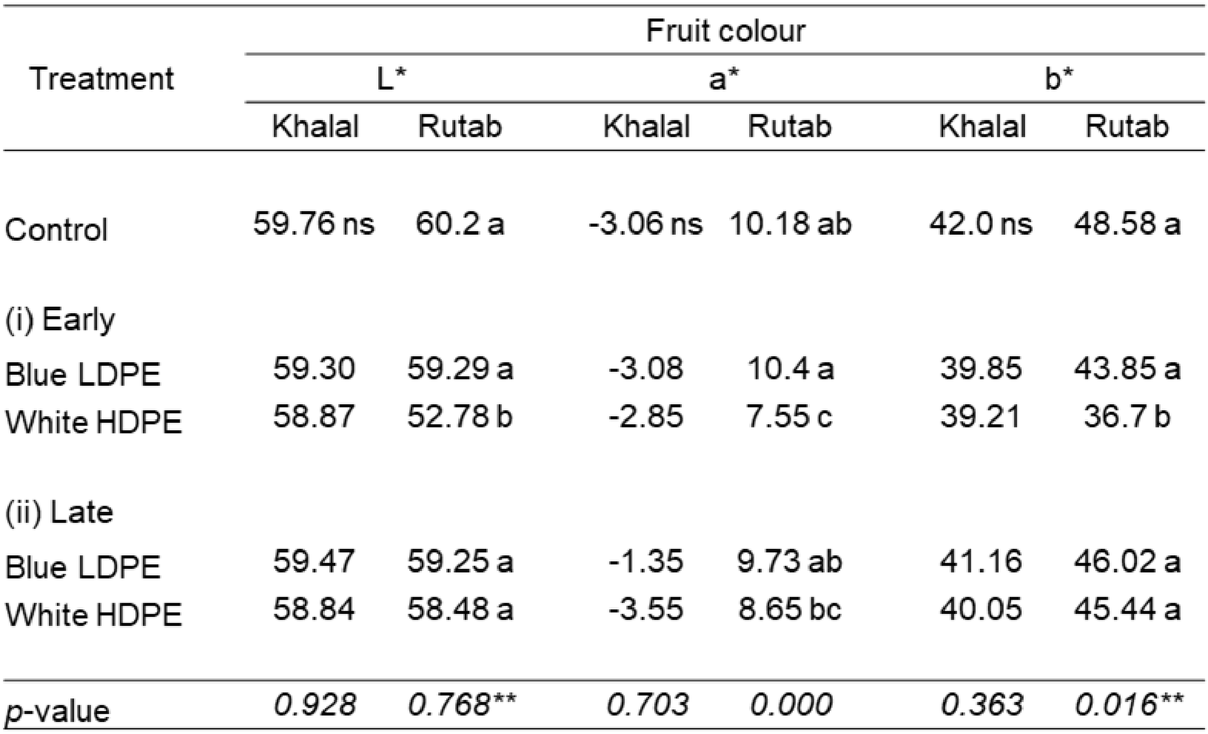


Treatment	TSS (°Brix)		TA (g/100g of malic acid)		pH	
	Khalal	Rutab	Khalal	Rutab	Khalal	Rutab
Control	14.7 ns	30.3 ns	0.07 ns	-*	6.16 ns	-*
(i) Early						
Blue LDPE	15.9	27.4	0.07	-*	6.04	-*
White HDPE	16.2	26.5	0.07	-*	6.07	-*
(ii) Late						
Blue LDPE	19.1	28.5	0.08	-*	6.12	-*
White HDPE	16.9	28.8	0.07	-*	6.07	-*
p-value	*0.468*	*0.740*	*0.827*	-*	*0.663*	-*

Means with different letters in the same column are significantly different at p > 0.05 using Tukey multiple comparison tests. TSS = total soluble solids. TA = titratable acidity. LDPE = low density polyethylene, HDPE = high density polyethylene. ns = not significant.

*Titratable acidity and pH values could not be measured at Rutab due to immaturity

Table 4. Effect of preharvest treatments on ‘Medjool’ date fruit surface colour characteristics subjected to (i) early and (ii) late application during the Khalal and Rutab phenological stages, at Kleinplasie, Hermon, during 2022.



Treatment	Fruit colour					
	L*		a*		b*	
	Khalal	Rutab	Khalal	Rutab	Khalal	Rutab
Control	59.76 ns	60.2 a	-3.06 ns	10.18 ab	42.0 ns	48.58 a
(i) Early						
Blue LDPE	59.30	59.29 a	-3.08	10.4 a	39.85	43.85 a
White HDPE	58.87	52.78 b	-2.85	7.55 c	39.21	36.7 b
(ii) Late						
Blue LDPE	59.47	59.25 a	-1.35	9.73 ab	41.16	46.02 a
White HDPE	58.84	58.48 a	-3.55	8.65 bc	40.05	45.44 a
p-value	*0.928*	*0.768***	*0.703*	*0.000*	*0.363*	*0.016***

Means with different letters in the same column are significantly different at p > 0.05 using Tukey multiple comparison tests. LDPE = low density polyethylene, HDPE = high density polyethylene. ns = not significant.

**p-value as calculated from Kruskal Wallis rank sum test

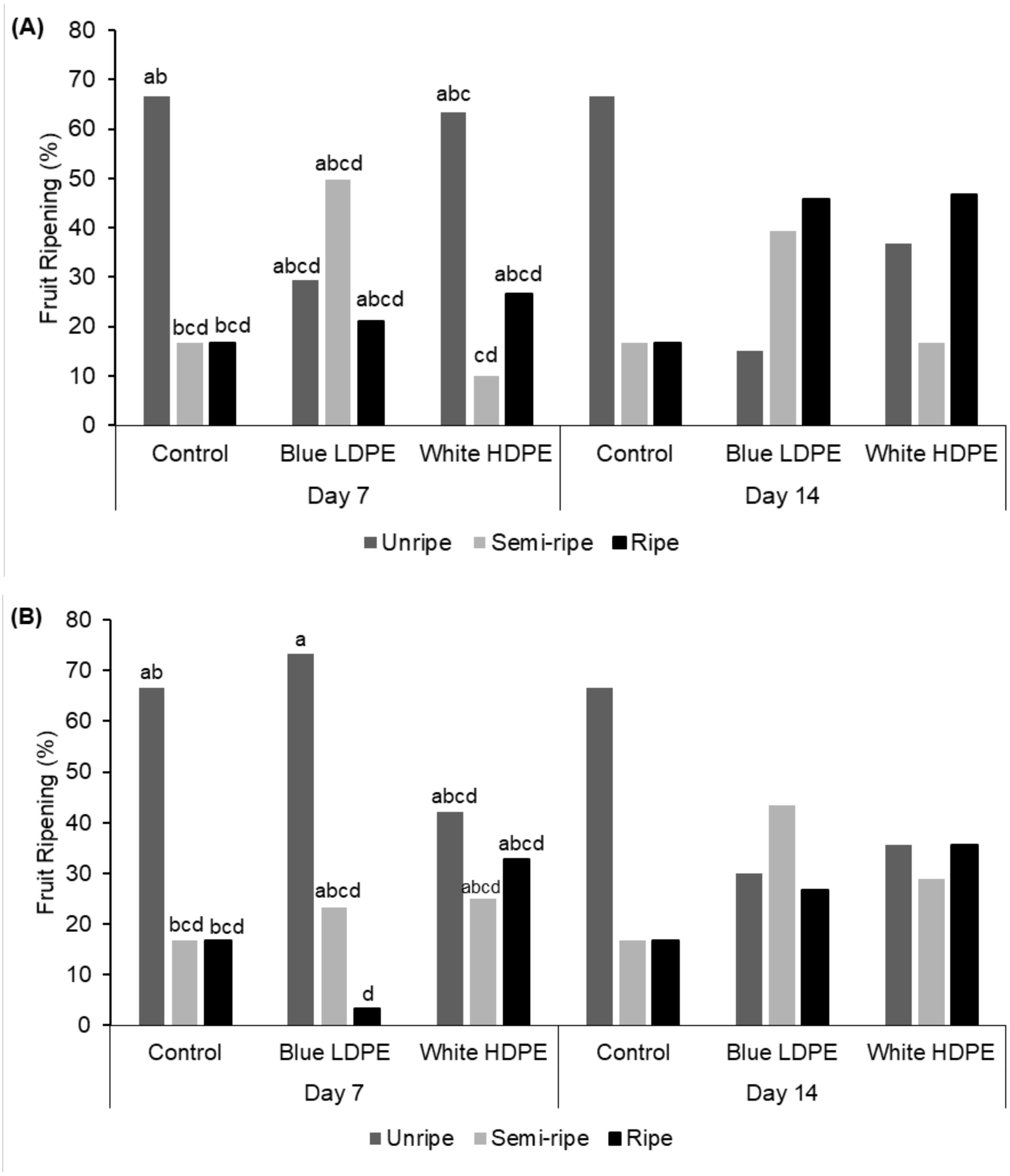


Figure 4. Effect of (A) early and (B) late bunch bagging treatments on postharvest ripening and shelf life over 14 days. Means with different letters are significantly different at $p > 0.05$ using Tukey multiple comparison tests. LDPE = low density polyethylene, HDPE = high density polyethylene

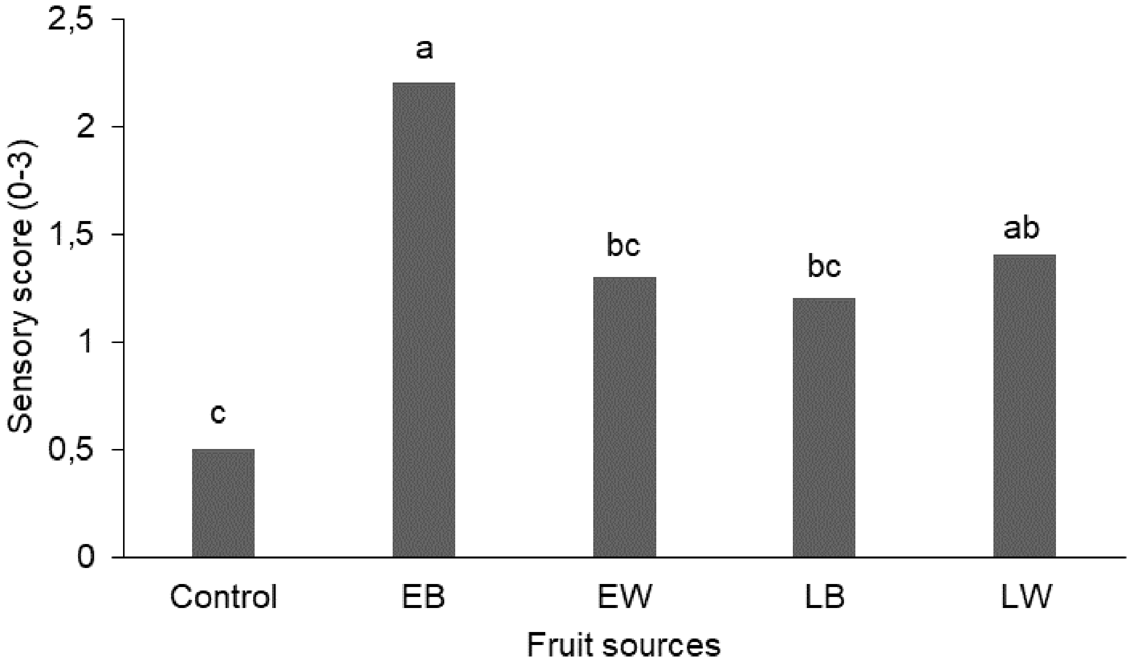


Figure 5. Organoleptic score of date fruit sourced from control, early blue (EB), early white (EW), late blue (LB) and late white (LW) bagging treatments. Tasting score ranked from 0 to 3: 0 = inedible, would not buy, 1 = edible, would not buy, 2 = tasty, would not buy, 3 = tasty. Means with different letters are significantly different at $p > 0.05$ using Tukey multiple comparison tests. LDPE = low density polyethylene, HDPE = high density polyethylene

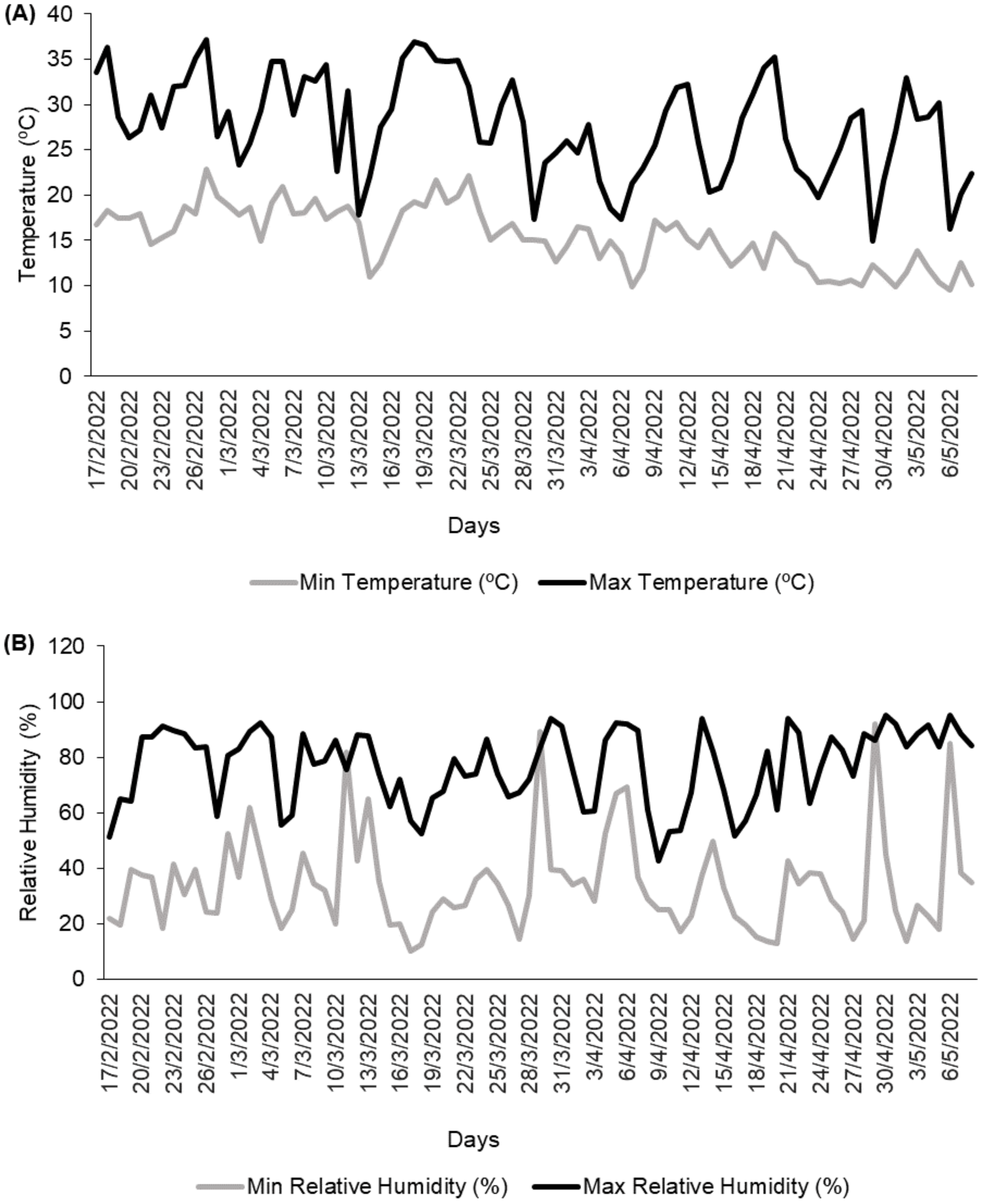


Figure 6. Average hourly minimum and maximum (A) temperature and (B) relative humidity of the Kleinplasie regional climate in Hermon during the experimental trial in 2022.

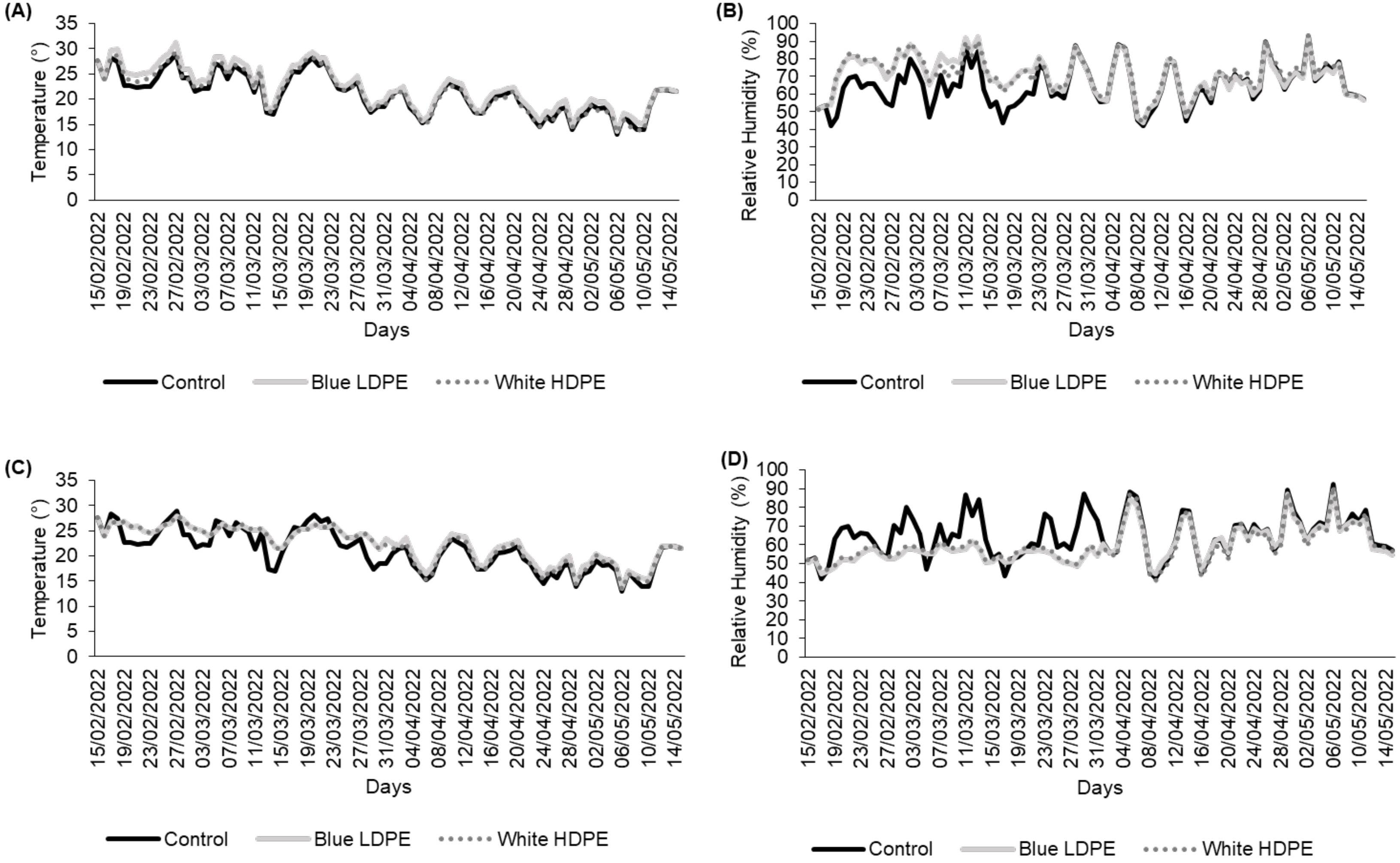


Figure 7. Average diurnal internal temperature and relative humidity of early (A, B) and late bagging treatments (C, D), as recorded with Tinytag loggers (Mitutoya Corporation, Japan) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene

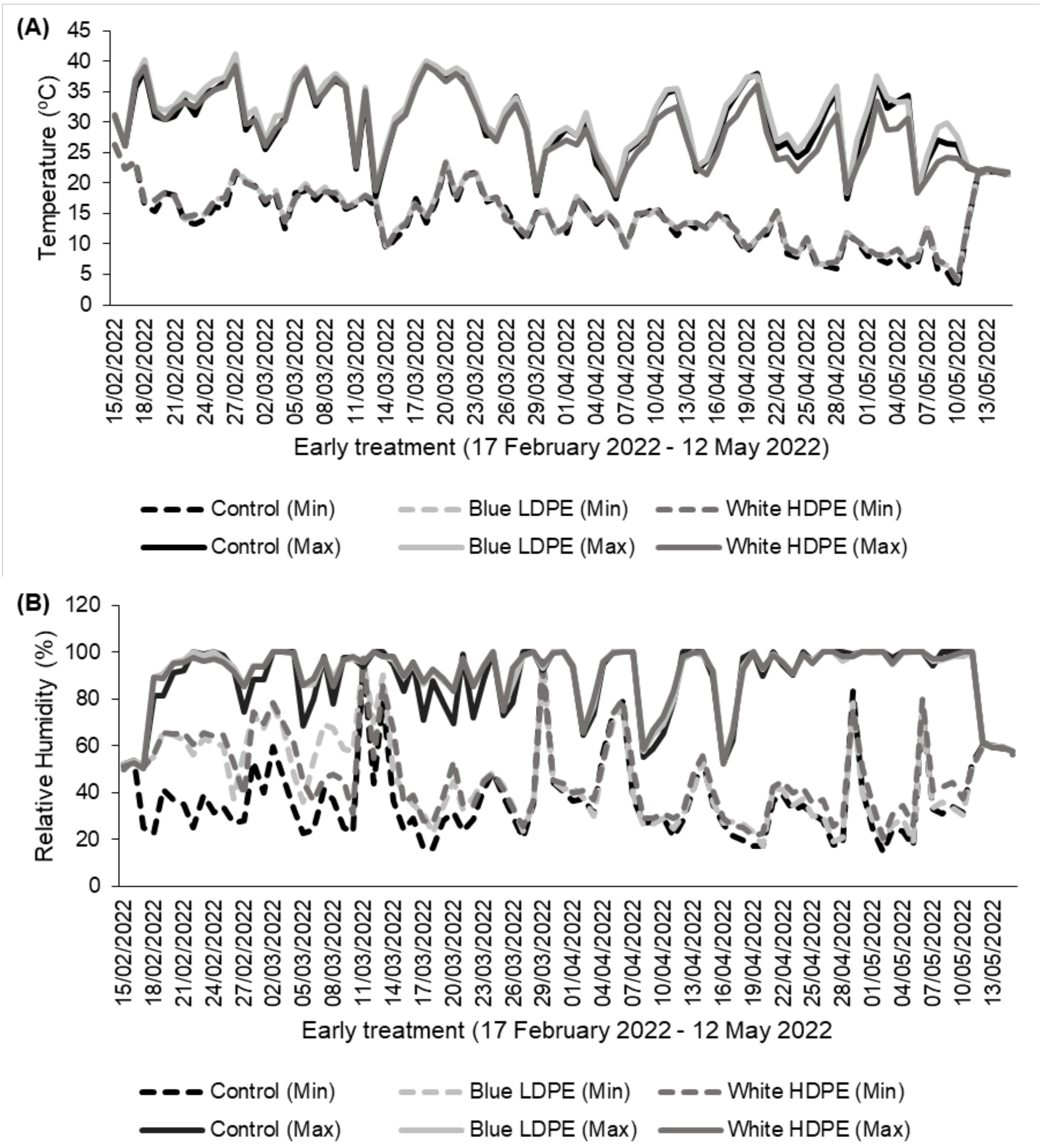


Figure 8: Average hourly internal (A) temperature and (B) relative humidity of early bagging treatments (17 February – 12 May) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene

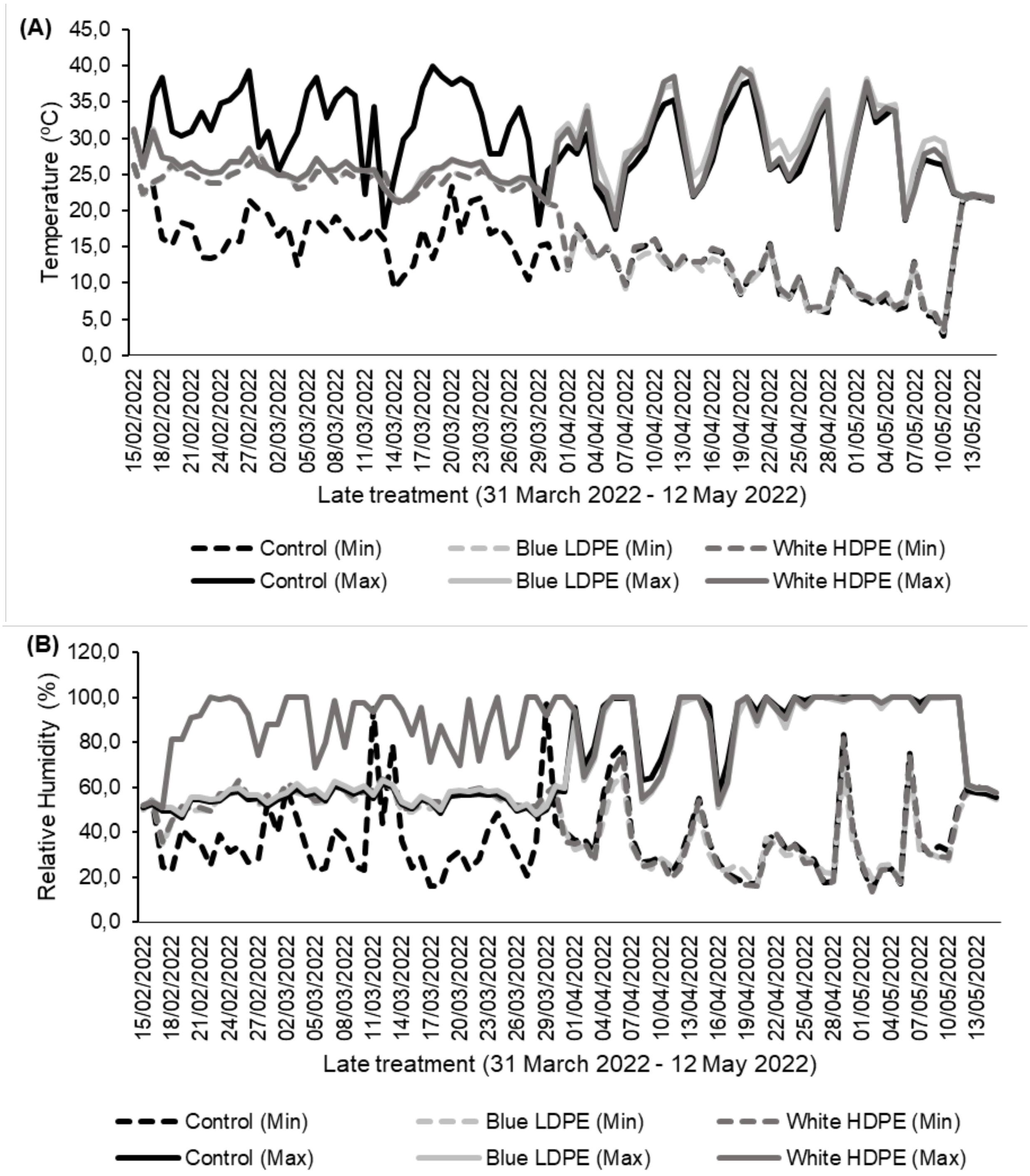
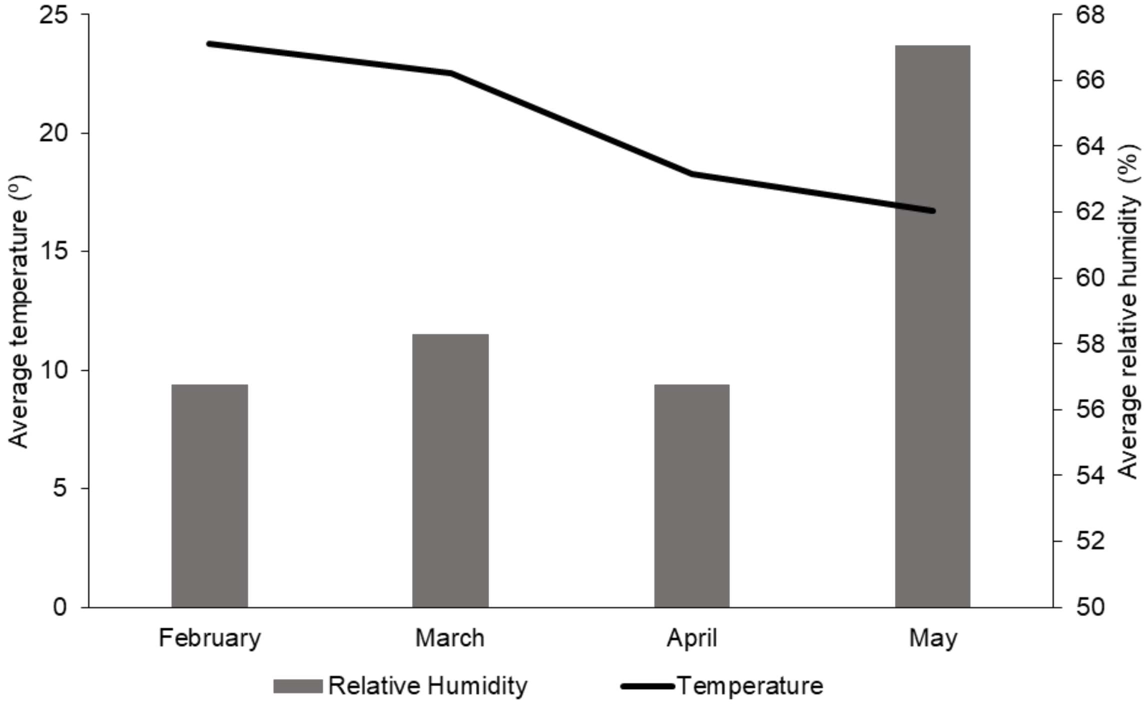
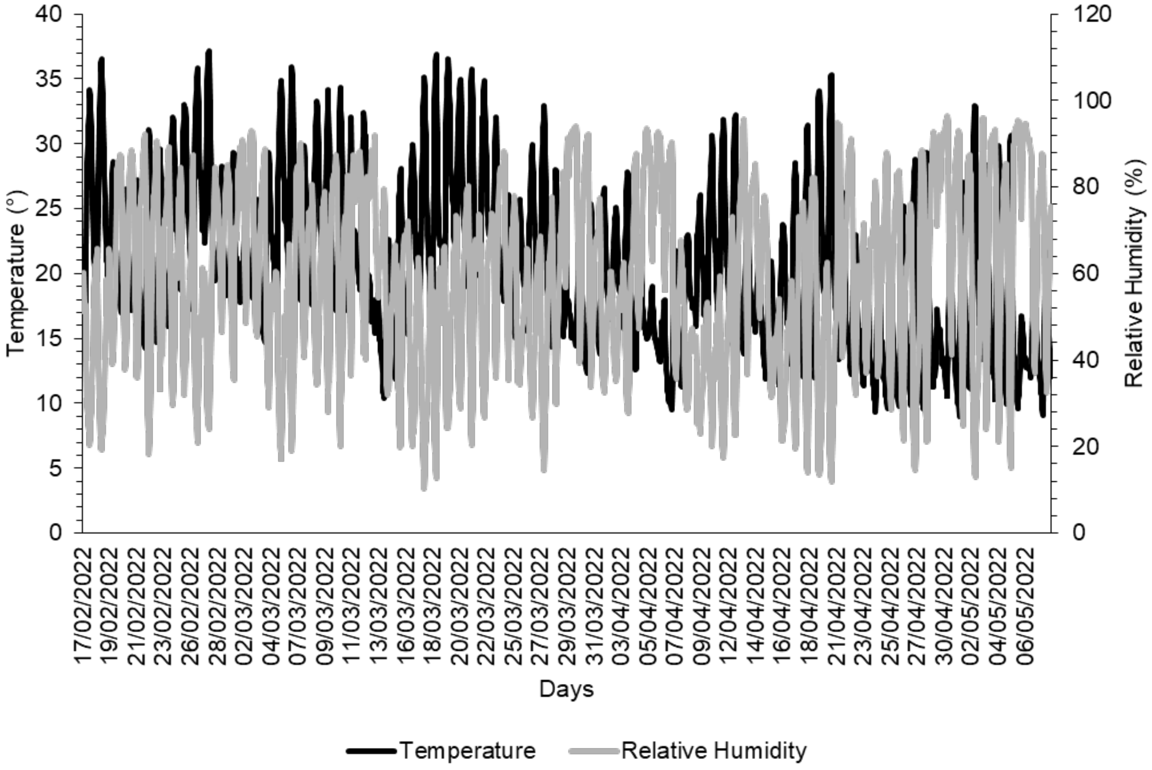


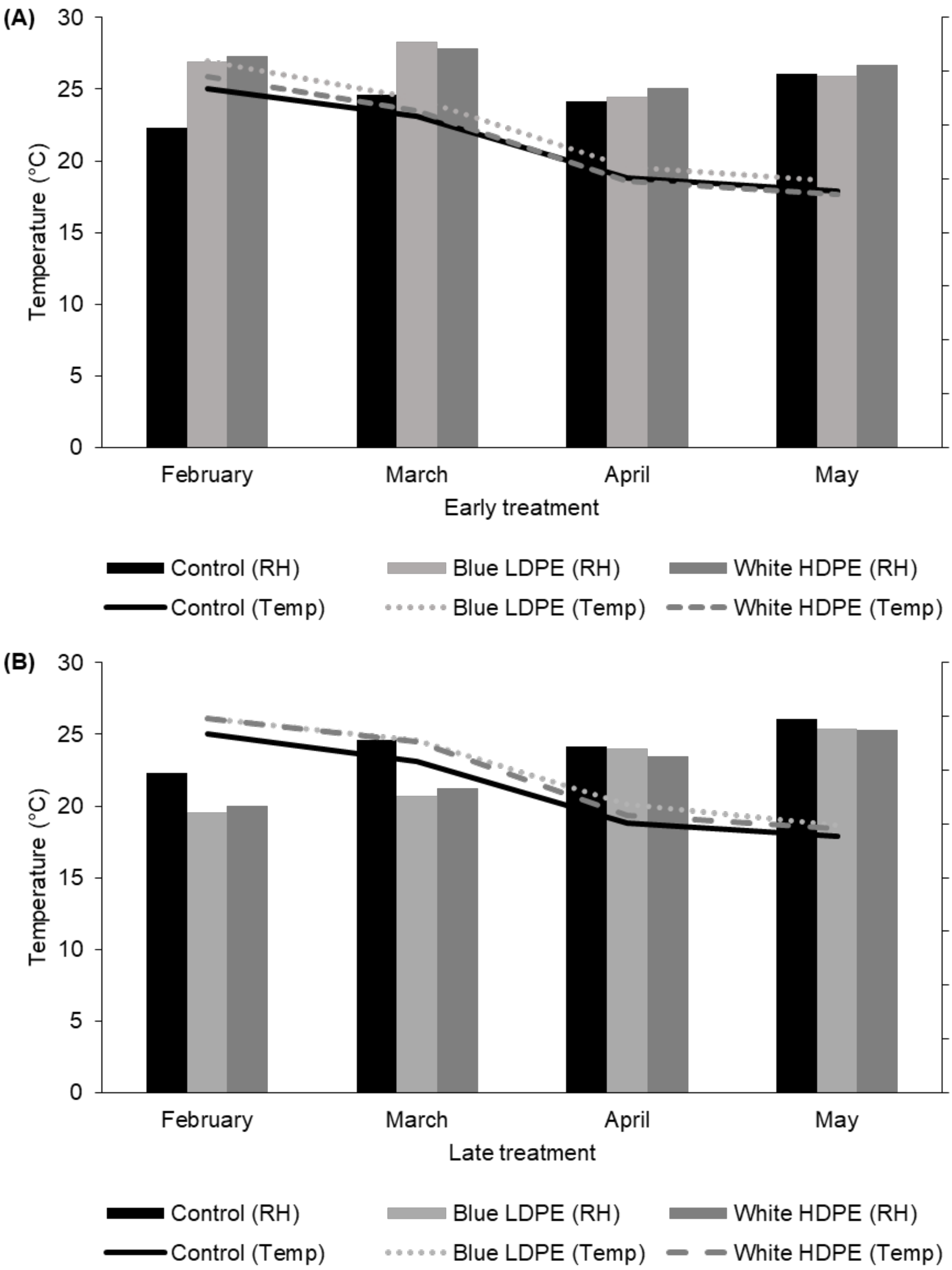
Figure 9. Average hourly internal (A) temperature and (B) relative humidity of late bagging treatments (31 March – 12 May) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene



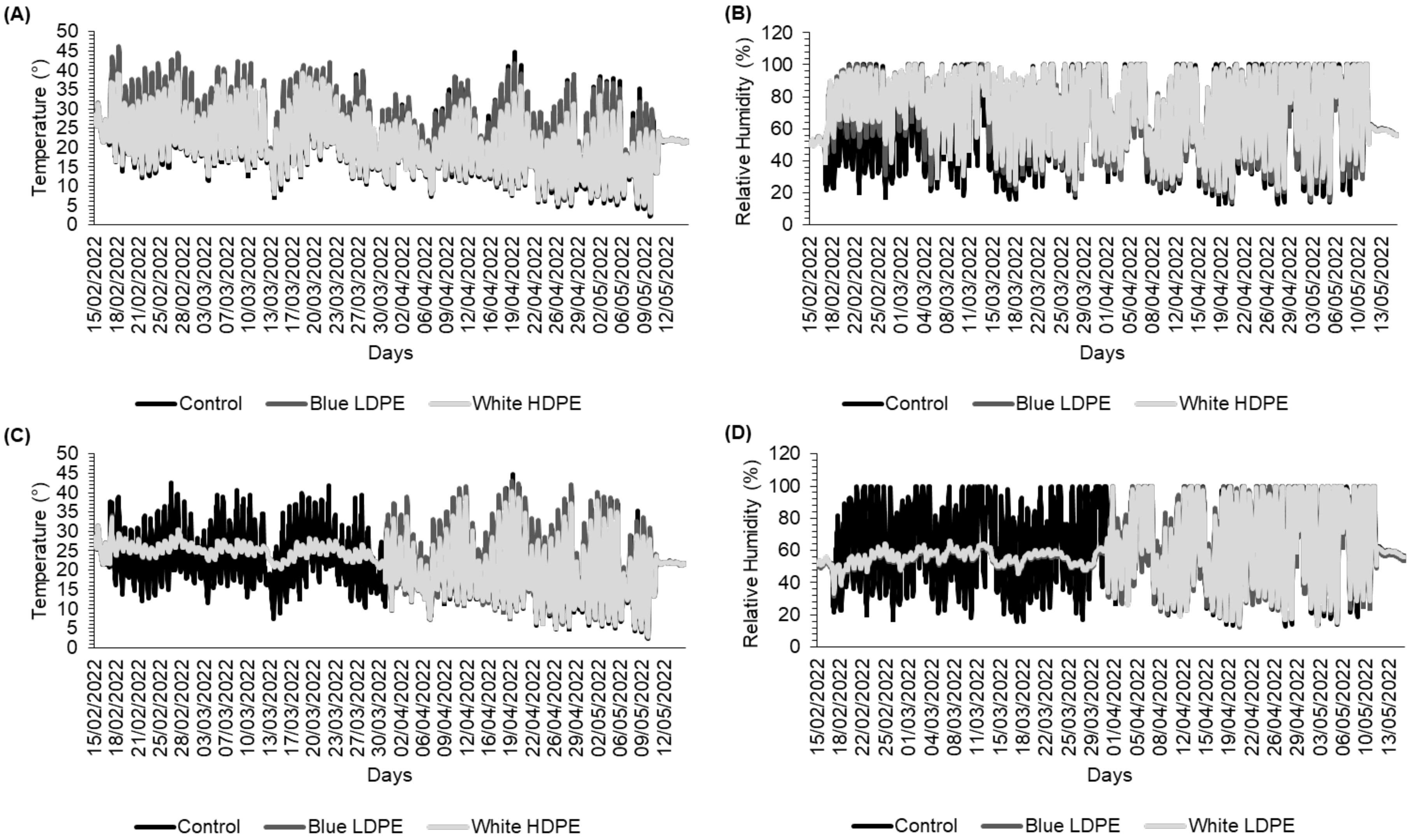
Appendix A.1. Average temperature and relative humidity of the Kleinplasie regional climate in Hermon over four months.



Appendix A.2. Average hourly temperature and relative humidity of the Kleinplasie regional climate in Hermon during the experimental trial.



Appendix A.3. Average internal (A) temperature and (B) relative humidity of the Kleinplasie regional climate in Hermon over four months.



Appendix A.4. Average hourly temperature and relative humidity of early (A, B) and late bagging treatments (C, D), as recorded with Tinytag loggers (Mitutoya Corporation, Japan) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene

Appendix A.5. Summary for the baseline measurements of 'Medjool' date fruit maturity characteristics recorded before the start of bagging treatments at Khimri on 17 February 2022 at Kleinplasie, Hermon

(A)	Fruit weight (mm)	Fruit length (mm)	Fruit diameter (mm)
Mean	20.53	45.58	29.54
Maximum	24.63	51.97	32.27
Minimum	16.46	38.27	25.95

(B)	Total soluble sugars (°Brix)	Titratable acidity (g/100g malic acid)	pH
Mean	9.07	0.027	5.8
Maximum	6.6	0.02	5.72
Minimum	10.5	0.03	5.86

(C)	L*	a*	b*
Mean	49.58	-13.1	27.4
Maximum	56.9	-7.84	35.67
Minimum	45.75	-16.41	21.54

Chapter 4: Paper 2

Evaluating the effect of bunch bagging treatments on the incidence and control of fungal infection on organic ‘Medjool’ date fruit at different phenological stages

Abstract

A commercial date orchard in the Western Cape province of South Africa has observed high levels of microbial contamination during its last harvest. Since the orchard is managed with organic cultivation practices, an environmentally sustainable approach is necessary to aid in preharvest disease control and ensure high quality fruit. In this study, the effect of preharvest fruit bunch bagging was investigated as a means of disease control in organic date fruit productions. The study was conducted from February to May of 2022. Three different bunch bagging treatments (blue low-density polyethylene, white high-density polyethylene, no bagging as control) were implemented at two different points during fruit maturation and removed at commercial harvest. The microbial load of date fruit was recorded at two phenological stages, viz. Khalal and Rutab. Additionally, the most prevalent fungal isolates at each stage were identified up to genus level. Results showed that bunch bagging had no effect at Khalal but increased the microbial load of the blue bagging treatments at Rutab. This is supported by the climatic data illustrating high temperature and high relative humidity in the modified fruit bunch microclimate before harvest, which are optimal conditions for the proliferation of spoilage microorganisms. Furthermore, the most commonly isolated pathogens throughout the treatment period were identified as *Penicillium spp., Alternaria spp., Aspergillus spp.* and *Alternaria spp*. *Cladosporium spp.* was the predominant fungi at Khalal, while *Alternaria spp.* dominated at Rutab. Overall, the early white bagging treatment was found to be the most promising in the control of spoilage organisms.

Key words: *Alternaria. Aspergillus, Cladosporium,* Mediterranean climate, *Penicillium*

1. Introduction

Date palm (*Phoenix dactylifera* L.) is one of the oldest domesticated fruit crops in history and is traditionally grown in the arid and semi-arid regions of the Middle East and North Africa (Johnson, 2010; Zaid and Piesik, 2021). Ideally, date palm is cultivated in climates with long hot summers and rainy winters, with temperatures ranging between 25°C and 32°C, < 12 mm rainfall and very low humidity (40% - 50%) during the flowering and fruit ripening stages of growth and development (E. M. Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014). However, date palms have a broad range of pests and diseases associated with its commercial cultivation (Chao and Krueger, 2007; Abo-El-Saad and El-Shafie, 2014; El-Shafie, 2019). Furthermore, a variety of fungal diseases have been known to infect the date palm throughout the fruit maturation process and harvest seasons, during cultural practices in the orchard, as well as at postharvest processing and storage conditions. Date palms are at particularly high risk for Bayoud disease, as caused by *Fusarium oxysporum* (Chao and Krueger, 2007; El-Shafie, 2019; Zaid and Piesik, 2021).

Fusarium species are known to infect a wide range of host plants. This group of soil-borne filamentous fungi is economically important as many are the causal agents of vascular wilt, root rot or fruit rot in agricultural and ornamental crops worldwide (Hafizi *et al.*, 2013; Dongzhen *et al.*, 2020; Khan *et al.*, 2021). Bayoud is one of the most destructive fungal diseases of date palm. It is a vascular wilt caused by *Fusarium oxysporum* f. sp. albedinis, causing heavy yield losses, as well as the eventual death of the entire palm tree. First recorded in Morocco around 1870, this disease destroyed more than ten million palm trees, wiping out the local cultivars with high production potential and good fruit quality. The symptoms of Bayoud include an ash gray discoloration on palm fronds and offshoots of the middle crown, whereafter withering symptoms progress to the leafstalk (Sedra and Zhar, 2010; Yahia and Kader, 2011; Moujaoui *et al.*, 2021).

Currently, numerous concerns about environmental contamination and human health risks associated with fungicide residues may lead to regulatory reviews, restrictions, or even terminations of synthetic pesticides. Furthermore, the widespread and continuous use of these synthetic compounds has led to pathogens developing a resistance toward active ingredients, which ultimately compromises the effectiveness of conventional disease control. Additionally, the demand for organically grown produce is rising and becoming more commonplace worldwide (Tilman *et al.*, 2011; FAO, 2014; El-Shafie, 2019). Since organic farming excludes the use of synthetic agrochemicals during cultivation, it is necessary to investigate sustainable approaches to pest, pathogen, and disease control, while maintaining high quality fruit production. While preventative strategies such as proper cultural management is oftentimes satisfactory, occasionally curative methods such as biocontrol, biopesticides and postharvest treatments are also necessary (Wakil *et al.*, 2015; Mahanty *et al.*, 2017; El-Shafie, 2019). A preharvest technique that may be applied in an organic farming system, reduce the input of synthetic pesticides, as well as improve fruit quality is bunch bagging. Fruit bunch bagging provides a physical barrier that prevents mechanical damage from pests. This approach creates a modified microclimate around the covered fruit bunches, which controls and maintains the internal light, temperature, and humidity, leading to conditions optimal to fruit growth and development (Yahia and Kader, 2011; Sharma *et al.*, 2014; Buthelezi *et al.*, 2020). Bunch bagging also prevents pathogens from reaching the developing fruit, which protects them from several diseases that can cause major losses. However, the type and material of the cover, the ripening stage at which the technique is applied, and the duration of this application are critical to the effectiveness of bunch bagging. Ineffective bunch covers may damage the fruit physiologically due to overheating, rotting, and premature ripening. Furthermore, the use of biodegradable or recyclable cover material may be costly, and the practice itself is labour intensive. Thus, fruit bunch bagging can be a beneficial practice for producing higher quality fruit, without or with less use of chemicals to control microbial diseases (Ashraf and Hamidi-Esfahani, 2011; Sharma *et al.*, 2014; Buthelezi *et al.*, 2020).

Recently, an organic 'Medjool' date orchard was established in the Western Cape province of South Africa. While the orchard may be located in a hot and dry area, the province has a Mediterranean climate, with the cold season coinciding with the last stage of date fruit maturation and its harvest. Since the soft 'Medjool' date is particularly sensitive to fluctuating weather conditions and susceptible to microbial spoilage during its ripening, these conditions led to the fruit experiencing severe fungal infections. While fruit bunch bagging on dates has been shown to increase the rate and uniformity of fruit maturation and ripening, little research has been done on its efficacy in Mediterranean climates such in the Western Cape. Furthermore, bunch bagging on dates has been shown to physically protect the fruit from insect pests and birds, as well as against adverse weather conditions. However, research shows varying results regarding the efficacy of bunch bagging against fungal infection, particularly fruit rots and moulds (McCubbin, 2007; Yahia and Kader, 2011; Siddiq and Greiby, 2014). For instance, bunch bagging has been found to reduce the incidence of stem-end rot in mango, as well as decrease cases of fruit rot in loquat and guava fruits. However, several Japanese pear and apple orchards have reported cases where black spot (*Trichothecium roseum*) has been associated with fruit bagging (Sharma et al., 2014; Buthelezi et al., 2020; Ali et al., 2021).

Therefore, the aim of this study was to evaluate preharvest fruit bunch bagging as a means of disease control suitable for organic farming systems, specifically of fungal pathogens leading to fruit rot on the soft 'Medjool' date cultivar, in the context of the Swartland regional climate in the Western Cape. In this paper, the microbial load and incidence of date fruit subjected to the bunch bagging treatment, were recorded at different phenological stages, during one season. This was done in order to form future recommendations regarding the most suitable implementation time for the treatment, as well as the type of cover material, for the surrounding climate that may lead to the control of fungal disease incidence and severity, thereby potentially enhancing the fruit quality.

2. Materials and methods

2.1. Plant material and sampling. During the 2022, uniform date palm trees (*Phoenix dactylifera* L.) of the 'Medjool' variety were randomly selected in the commercial organic date palm orchard at Kleinplasie, which is located near Hermon (33.444°S 18.973°E, altitude 81 m above sea level), in the Western Cape province, South Africa. A full description of the study site has previously been provided in Chapter 3, Paper 1.

Eleven 'Medjool' date palms were selected for the experimental treatment, based on a sufficient fruit set of at least six bunches, with 50 date fruit per bunch. Following a completely randomised design, date fruit bunches were randomly allocated a bagging treatment at two phenological stages during the process of date fruit ripening, specifically Khalal (earlier in ripening process) and Khimri (later in ripening process). Khalal refers to when the fruit achieves a status of physiologically mature, while Rutab refers to the fruit being semi-ripe (Yahia and Kader, 2011; Lobo et al., 2014). The bagging treatments are described in Table 1. The bunches were covered by bags with the assistance of workers and were bound with zip ties at the top of the bunch, close to the fruit stalk. The blue bags were left open at the bottom, while the white bags completely enclosed the bunch (Figure 1).

Early bagging treatments were performed on 17 February 2022, while late bagging treatments were performed on 31 March 2022. Commercial harvest commenced on 3 May 2022 and the treatments were terminated on 11 May 2022. This resulted in the early bagging treatments lasting for approximately 12 weeks (11 weeks and six days), while the later bagging treatments lasted for approximately six weeks (five weeks and six days). Each treatment was repeated six times.

Fruit was sampled on three occasions: at the start of the early bagging treatments (February 2022), at the start of the late bagging treatments (31 March 2022), and at commercial harvest (11 May 2022). Five fruit per date palm were sampled randomly before the early bagging treatments, in order to record a baseline for microbial load. Thereafter, five fruit per bunch were selected at the Khalal and Rutab stage in order to compare the microbial load found in bagged treatments to the unbagged control treatment. After each sampling event, the fruit was stored at 4°C for 11 days before its analysis, at the Microbiology department of Stellenbosch University (Stellenbosch, Western Cape, South Africa).

2.2. Microbiological analysis

2.2.1. Whole date incubation. One fruit per replicate was placed onto an empty 90 mm Petri dish under aseptic conditions and closed with parafilm. The sample was incubated at 26°C for eight days or until growth was observed. Thereafter, subcultures were made of each plate with visible growth under aseptic conditions in order to obtain pure cultures. The tip of a flame-sterilised needle was used to take a small sample of the fungal colony and place it onto a Petri dish containing Potato Dextrose Agar (PDA) (Biolab Millipore, # HG00C100.500). The plate was then inverted and incubated at 26°C for eight days. Streptomycin and chloramphenicol were added to the PDA at 500 µl per 500 ml of medium in order to prevent the potential growth of bacteria. The subculture was done every eight days until a pure colony of the fungal isolate was obtained (Saito *et al.*, 2016; Kahramanoğlu and Usanmaz, 2019).

2.2.2. Pour plating. One fruit per replicate was placed into an Erlenmeyer flask containing 100 ml sterilised dH_2O, vigorously vortexed and serially diluted to 10^{-2}. Using the pour plating technique, a 1 ml sample from each dilution was pipetted onto the middle of a sterile 90 mm Petri dish under aseptic conditions. Approximately 20 ml molten cooled PDA with added antibiotics (streptomycin and chloramphenicol) was poured into the Petri dish and mixed well. Thereafter, the plates were inverted and incubated at 26°C for eight days. The number of colonies within the countable range (25 – 250) was recorded at the end of the incubation time and calculations were performed using colony forming unit (CFU) per g of fresh weight (CFU/g) in order to determine total fungal/mould count (Saito *et al.*, 2016; Kahramanoğlu and Usanmaz, 2019). Thereafter, subcultures were made of the most prevalent fungal colony in each plate, according to the description in paragraph 2.2.1.

2.2.3. Colony morphology and microscopy. Prevalent colonies were selected from both whole date incubation and pour plating techniques, and pure cultures were obtained. Thereafter, the macroscopic and microscopic characteristics of the most common organisms found across all sampling events and treatments were recorded in order to identify them to genus level (Pitt and Hocking, 2009; Bensch *et al.*, 2012). The macroscopic examination was based on descriptive features of colony morphology described in Table 2. Photos of the plates were captured with a PowerShot SX260 HS digital camera (Canon, 2016). The microscopic examination was carried out by suspending a small sample of the fungus in a drop of distilled water on a microscope slide and covering it with a cover slip in order to visualise cell components under Eclipse E800 light microscope (Nikon, 2003). The microscopic observation was based on features of the identified fungal structures as described in Table 2. Photos of these structures were captured with the Nikon Imaging Software Elements 3.2 64-bit (Nikon, 2016).

2.5. Climate data. During the early bagging treatments, five Tinytag Plus 2 TGP-4500 (Gemini Data Loggers, United Kingdom) data loggers were installed in order to record the internal hourly temperature (°C) and relative humidity (%). Two replicates per bagging treatment received a logger, and one logger was fitted on an unbagged control bunch. Data was also collected from the Landau weather station (33.578°S 18.968°E, altitude 127m above sea level), which represents the Hermon region.

2.6. Statistical analysis. Data collected for microbial analysis followed a non-parametric distribution. After a log10 transformation, a Kruskal Wallis rank sum test was performed. Where necessary, multiple comparison tests using the Dwass-Steel-Critchlow-Fligner test with significant differences at 5% level were executed. All statistical analyses were performed using the XLSTAT (version 2022.3.2, Addinsoft, New York, NY, USA) computer application (Windows 10 Excel 16.0.15629 64-bit).

3. Results

3.1. Microbial load.

Bunch bagging had a significant effect on the microbial load at Rutab, but not Khalal (Figure 2). At Khalal, fruit from the control treatment contained the highest microbial load (3.979 logCFU/g), while the late blue bagging treatment had the lowest microbial load on the fruit (3.703 logCFU/g), but the difference was not found to be significant ($p = 0.052$). Fruit from all other treatments had similar microbial loads to the control. At Rutab, significant differences in microbial load were found among bagged treatments. The early white bagging treatment (3.779 logCFU/g; $p = 0.006$) had a significantly lower microbial load than its blue counterpart (4.126 logCFU/g). Additionally, the earlier white bagging treatment contained a significantly lower microbial load than the late blue bagging treatment (4.046 logCFU/g; $p = 0.034$).

3.2. Morphological identification. Pure cultures were made of prevalent colonies across all sampling events and were grouped according to its general appearance whereafter a total of six representative groups were formed from the fungal isolates.

Macroscopically, the first group displayed surface colours ranging from olive green to grey to brown and a green to grey regular margin, while the reverse colour ranged from dark green to smoky grey with a distinct white to grey border. The texture of the isolates was mainly velvety and villose and had dense mycelia mats that rarely grow from the surface of the colony (Figure 3A). Microscopically, structures identified as vegetative hyphae, conidia and conidiophores were observed (Figure 3B) The mycelium was septate, branched, sub-hyaline with a mustard yellow to olive green to brown tint, and had smooth to rough-walled hyphae. Conidiophores were septate, and would arise laterally from hyphae, and may be unbranched or branched only in the apical region, with geniculate sympodial elongation. Brown to olive green ellipsoidal conidia were present in branched acropetal chains and had a distinct dark hilum. Structures thought to be ramoconidia were visible at the apical end of the hyphal branch. These are short branches of a conidiophore which function as conidia, and often give rise to branched or unbranched conidia (Crous *et al.*, 2007; Bensch *et al.*, 2012). These morphological observations are characteristic of the *Cladosporium* genus and were isolated from bagging treatments at both Khalal and Rutab.

The second group comprised colonies with surface colours ranging from white to light grey to olive green to brown and would often contain with black or grey sclerotia in the middle of the colony (Figure 4A). The reverse colour ranged from yellow, green or brown to bright orange red. The overall texture was floccose to cottony and had an irregular form with a margin ranging from filiform to filling the entire surface. Hyphae, conidiophores, and conidia were observed under the microscope (Figure 4B). Generally, the fungal structures were light to dark brown in colour and septate. Conidia were long and relatively small in size, with an ellipsoidal to pear-shaped form. Chain branching along the chlamydospore was observed occurring in a sympodial manner through the elongation of secondary conidiophores from distal terminal conidial cells. These morphological observations are characteristic of the *Alternaria* genus and were isolated from bagging treatments at both Khalal and Rutab.

The third group had two distinct types of colonies with similar powdery granular texture, irregular shape, and a light brown to yellow reverse colouration with a violet middle and sometimes had radial fissures in the agar (Figure 5A). One type displayed colonies had greenish yellow surface colours, with white grey sclerotia in the middle and a grey filamentous margin. The other type had dark brown to black surface colours with abundant black aerial mycelium, and a light brown middle with sparse aerial mycelium, as well as a white to grey to yellow irregular margin. Microscopically, conidiophores and conidia were observed (Figure 5B). Conidiophores were long, smooth-walled, and had a dark brown to black globose vesicle. The conidia were round to ellipsoidal in shape, and were arranged in dry, upright abundant chain. These observations are characteristic of species from the *Aspergillus* genus and were isolated from bagging treatments at both Khalal and Rutab. The variation displayed across the isolates were due to the amount of sporulation at that specific stage of development.

The fourth group exhibited flat, filamentous colonies that were velvety to floccose to cottony in texture. The margin was oftentimes irregular, with smooth to lobate edge and white to grey in colour. The surface colour varied from blue green, grey green, olive grey, and yellow, sometimes with golden exudates in the middle. The plate reverse was usually pale to yellowish (Figure 6A). Microscopically, the hyphae, conidiophores, metulae, phialides, and conidia were observed. The hyphae were septate and subhyaline. Conidiophores were irregularly branched, and consisted of short stipes with a few metulae, which carried flask-shaped phialides that ultimately formed a brush-like clustered arrangement. The conidia were unicellular, round, and present in unbranching chains at the tips of the phialides (Figure 6B). These observations are indicative of species from the *Penicillium* genus, which were isolated from bagging treatments at both Khalal and Rutab.

The fifth group appeared to have isolates that had the appearance of a filamentous mould, and that of a yeast (Figure 7A). The filamentous fungi isolate had a white to grey surface colour, and a yellow to light brown reverse, as well as a purple to red middle. The texture was floccose to cottony and had sparse to abundant aerial mycelium in an irregular shape. When the isolates were examined under a microscope, typical structures such as hypha, conidiophores and conidia were observed. The mycelium was sub-hyaline to yellow-green in colour and rough-walled. Complex conidiophores were dichotomously branched, and had sickle shaped septate conidia with oval tapering. The yeast isolates appeared as a smooth cream colony with a regular margin and surrounded by red exudate which was embedded into the agar. The reverse was white to pink to red in colour. Under the microscope, a mass of mycelium and conidia was observed. The mycelium was similar to the above filamentous fungal isolate, while the conidia were oval to ellipsoid shaped, had an apical tapering and septate. These conidia were arranged in a chain of chlamydospores (Figure 7B). These descriptions were characteristic of the *Fusarium* genus, which was isolated from bagging treatments at Khalal as well as Rutab.

The last group comprised colonies with a white to dark grey surface colour in the middle and dark brown to black colour on the edge, as well as a light yellow to brown reverse. The texture was cottony in the middle of the colony but became floccose and granular toward the edge. Abundant aerial mycelium was found throughout the colony. Microscopically, hyphae, conidiophores and conidia were observed. The hyphae were branched and septate. Conidia were unicellular, hyaline and had a round to slightly ellipsoidal shape. Furthermore, the conidia were present on the tips of freely branched conidiophores. These morphological observations are characteristic of the *Botrytis* genus and were only isolated from the late blue bagging treatment at Rutab (Figure 8).

3.3. Climatic data.

High temperatures and a comparatively low relative humidity can be seen from the beginning of the experimental trial in February to the end of March. Thereafter, a noticeable increase in relative humidity was recorded, which continued until the end of the experimental trial in May (Figure 8). This resulted in a period of high temperature and high relative humidity from the end of March to approximately the end of April, which coincides with the transition from the Khalal to Rutab maturation stage. The Hermon region experienced temperatures ranging from 9.58°C to 37.19°C throughout the experimental trial, while the relative humidity ranged from 10.24% to 95.29% (Figure 9).

During the early treatments, the highest temperature across treatments was logged at 46.25 °C in the blue bag during February, while the lowest temperature was 2.26°C from the control also during February. The relative humidity reached its lowest level of moisture at

12.87% in the control during April, and was at 100% several times during March, April, and May in both the blue and white bags (Figure 10).

During the late treatments, the temperature reached 43.07°C in the blue bag during April while the lowest temperature was recorded at 2.26°C in the control during May. The relative humidity reached its lowest recording at 12.30% in the blue bag during April and reached 100% multiple times in the blue and white bags at 12.30% in April and May (Figure 11).

4. Discussion

4.1. Microbial load

The microbiological quality of date fruit may be assessed by its microbial load, which refers to the number of microorganisms present in a sample. Microbial load on date fruit is affected by internal factors such as sugar content, moisture content and pH, as well as external conditions such as temperature, relative humidity, and rainfall (Yahia and Kader, 2011; Jdaini *et al.*, 2022). In this study, bunch bagging had no effect on the microbial load of date fruit at the Khalal phenological stage but showed significant differences between the bagged treatments at the Rutab stage. The early white bagging treatments showed significantly lower microbial loads than the early blue and late blue bagging treatments. However, no significant differences were found between the unbagged control treatment and the bagged treatments at either Khalal or Rutab. Similar findings have been reported by El Assar (2009), who investigated date bunch covering treatments on the fruit quality of Zaghloul dates in Egypt. They found that the treatments (tissue, polyethylene) led to an increase in fruit spoilage due to the high temp in bags (El Assar, 2009). However, they reasoned that the spoilage was due to physiological and not fungal reasons. Similarly, Dai *et al.*, (2019) confirmed that *Trichothecium* black spot is a disease associated with the fruit bagging and hypothesized that high relative humidity within bags is a key factor promoting *T. roseum* infection of bagged apple fruits in China (Dai *et al.*, 2019). The authors have hypothesized that the high relative humidity created and maintained within bags could be a key factor promoting infection of bagged fruits.

Overall, the microbial load of date fruit in this study increased from Khalal to Rutab across all treatments. It can be observed that the number of microorganisms almost doubled in every instance, except in the control and early white treatments. The control decreased in its number of microorganisms from Khalal to Rutab, while the early white bagging treatments showed an incremental increase in microbial load compared to the other bagged treatments. This pattern could be due to the date fruit maturation stage, the type of bagging treatment, and the surrounding climatic conditions.

The composition of the date fruit microbiome fluctuates throughout ripening and maturation due to changes in moisture content and physiochemical composition. For instance, high microbial counts are usually found during the Khimri and Khalal ripening stages, due to its high moisture and sugar content, as well as low acidity (Ashraf and Hamidi-Esfahani, 2011; Haider *et al*., 2014; Piombo *et al*., 2020). According to morphological observations during the early bagging treatments at Khalal (Figure 13), the fungal composition in the unbagged control treatment was made up of 41.67% *Cladosporium*, 25% *Aspergillus* and *Alternaria*, and 8.33% *Penicillium*. In the blue bagging treatment, 36% *Cladosporium* and *Aspergillus*, 16% *Alternaria* and 12% *Penicillium* were found. In the white bagging treatment, 44% *Aspergillus* was found, along with 32% *Cladosporium*, 20% *Penicillium* and 4% *Alternaria*. The fungal composition was similar during the late bagging treatments, where the blue bagging bag was made up of 38.5% *Cladosporium*, 23% *Penicillium* and *Alternaria*, 12,8% *Aspergillus* and 2.5% *Fusarium*. The white bagging treatment contained 48.8% *Cladosporium*, 28.6% *Alternaria*, 14.3% *Fusarium* and 8.6% *Penicillium*. The unbagged control treatment contained 66.67% *Cladosporium* and 33.33% *Fusarium*. Rutab is particularly susceptible to microbial spoilages, and the highest microbial counts are usually recorded during this stage, because the fruit undergoes a substantial increase in sugar concentration, as well as decrease in acidic substances and softer tissues. This leads to rapidly rising microbial counts, as the fruit provides a favourable medium for the proliferation of a wide range of microorganisms, particularly fungi. This was confirmed with results for total soluble sugars (TSS) in Chapter 3. The late blue bagging treatment had the highest microbial load and TSS (Shenasi *et al*., 2002; Ashraf and Hamidi-Esfahani, 2011; Teena *et al*., 2014). During the early bagging treatments at Rutab, the unbagged control treatment comprised 31.3% *Cladosporium* and *Alternaria*, 25% *Penicillium* and 6.3% *Fusarium* and *Aspergillus*. In the blue bagging treatment, 37% *Alternaria* and *Aspergillus* was found, along with 8.6% *Cladosporium*, *Penicillium* and *Fusarium*. The white bagging treatment was composed of 33.3% *Alternaria*, 22.2% *Cladosporium*, 20% *Penicillium*, 17.8% *Fusarium* and 6.7% *Aspergillus*. Similarly, the late bagging treatments had 33.33% *Alternaria*, *Penicillium* and *Fusarium* in the unbagged control treatment, while the blue bagging treatment was composed of 29% *Alternaria* and *Cladosporium*, 20% *Fusarium* and 11% *Penicillium* and *Aspergillus*. The later white bagging treatment was composed of 36% *Alternaria*, 28% *Cladosporium*, 24% *Fusarium*, 10% *Penicillium* and 2% *Aspergillus* (Figure 13). In Chapter 3, where the effect of bunch bagging treatments at different phenological stages on the development of organic ‘Medjool’ date fruit maturity and quality characteristics was assessed, it was concluded that the bagging treatments were successful in its acceleration of fruit ripening at Rutab, when compared to the control. This was supported by increases in fruit weight, diameter, TSS, as well as an improvement in fruit colour, resulting from the modification of the temperature and relative humidity inside the bags, leading to ideal conditions for fruit growth and development. This also may explain the significant increase in microbial load at the Rutab stage, which is seen across all bagging treatments. In this study, the increase in microbial load from Khalal to Rutab followed the typical changes as described for the date fruit microbiome during fruit maturation, but the extent to which the load was increased, and the wide variation of fungal pathogens may have been influenced by the bagging treatments.

The deviations found in the control and early white bagging treatment may be attributed to the bag material, as well as the climatic conditions surrounding the fruit bunch. In the present study, bunches were covered with blue low-density polyethylene (LDPE) and white high-density polyethylene (HDPE) bags that were not perforated. In the absence of perforations, a high relative humidity as well as a high temperature may be maintained in the modified microclimate, which jointly contribute to the ideal conditions for the proliferation of microorganisms (Omamor and Hamza, 2007; Hussain *et al.*, 2020; Wu and Wong, 2022).

The early and late blue bagging treatments in this study showed the highest microbial loads at harvest, due to the combination of high temperature and high relative humidity created in the fruit bunch microclimate, as seen in Figure 12. Additionally, these conditions are ideal for the proliferation of a wide range of fungal pathogens such as *Cladosporium spp*., *Alternaria spp.*, and *Aspergillus spp.*, which were found in high incidence in these bagging treatments. In contrast, the white bagging treatments showed the lowest microbial loads at harvest. In the case of the unbagged control, the decrease in microbial load from Khalal to Rutab reflects the regional climatic conditions and exposure to the surrounding crops. Overall, the region experienced high temperatures and a low relative humidity from February to April (Figure 10). This corresponds to the development of the Khalal maturity stage, wherein a high sugar and moisture content may lead to the proliferation of microorganisms. However, the beginning of May experienced colder temperatures during the transition period from the Khalal to Rutab stage. Although these conditions are unfavourable for further fungal growth, inoculum could persist to the following season and then germinate and grow rapidly under favourable conditions (Cochrane, 1974; Verhoeff, 1974; Brunet *et al.*, 2018).

In this study, the microbial load was determined to range from 5.04 x 10^3 CFU/g to 9.53 x 10^3 CFU/g at Khalal, as well as 6 x 10^3 CFU/g to 1.34 x 10^4 CFU/g at Rutab. Similar values have been reported by Shenasi *et al*. (2002), who reported that the total viable count for date varieties in the United Arab Emirates examined at Khimri ranged from 10 to 12 600 CFU/g (Shenasi *et al.*, 2002). Similarly, Orole *et al*. (2017) determined that the fungal load of date fruit collected from Nigerian markets ranged from 2 800 to 12 500 CFU/g (Orole *et al.*, 2017). However, these results are outside the range of microbial tolerance according to the

CODEX standards for date fruit. Although no instances of *Salmonella sp., Escherichia coli* or *Listeria monocytogenes* were identified and the fruit are deemed safe to eat, the microbial load at harvest was much higher than the limit set for yeast and moulds (1 000 CFU/g), resulting in a low fruit quality (FAO-WHO, 1985; Dag, 2020).

4.2. Morphological identification and microbial incidence

The most prevalent microorganisms isolated from date fruit at Khalal and Rutab were identified up to genus level. At Khalal, the most commonly isolated fungi during the early treatments were *Cladosporium spp., Penicillium spp., Alternaria spp*. and *Aspergillus spp*. The incidence of prevalent genera in the late bagging treatments were similar, but with the addition of *Fusarium spp.* (Figure 13). Overall, species from the *Cladosporium* genus was the predominant microorganism isolated from bagging treatments at Khalal. At Khalal, the early and late bagging treatments were found to have a temperature ranging from approximately 15 to 40°C and a relative humidity of 50 to 100%. Additionally, the pH was evaluated to range from 5.3 to 6.6. These conditions are most favourable to the luxuriant growth of *Cladosporium spp*. confirming the findings of Piombo *et al.,* (2020). At Rutab, the most commonly isolated fungi during both the early and late bagging treatments were *Cladosporium spp.*, *Penicillium spp.*, *Fusarium spp.*, *Alternaria spp.* and *Aspergillus spp.* (Figure 13). Furthermore, *Alternaria spp.* was observed to be the dominant genus at Rutab. At Rutab, the early and late bagging treatment maintained temperatures ranging from approximately 20 to 40°C, and a relative humidity from 60 to 100% (Figure 10). These conditions are most favourable to the abundant growth of *Alternaria spp*. Brown (1920) from the USA asserts that it is probable that it is the primary cause of rot and mummification of the ‘Deglet Nour’ date fruit which is typically accompanied by the species from *Aspergillus* and *Penicillium*. Al-Sheikh (2009) in Saudi Arabia also reported that *Alternaria alternata* was the predominant species in seed-borne and fruit spoilage fungi, followed by *Aspergillus flavus*, and *Fusarium*. Similarly, Abass (2016) reported that the most abundant genus isolated from date palm fruit rot in Iraq was *Alternaria*, followed by *Cladosporium* (Al-Sheikh, 2009; Abass, 2016). However, these studies are the exceptions to the norm, which is that fungi from the *Aspergillus* genus is typically found at Rutab and Tamr (Al Hazzani *et al.*, 2014; Ahmed *et al.*, 2016; Alsohaili and Bani-Hasan, 2018).

In Figure 13, the microbial incidence of the unbagged control treatment contains *Alternaria, Fusarium* and *Penicillium* in comparable measures at Rutab. This means that the deviation in the most prominent species at harvest could be due to the naturally occurring microbial population and the local environmental conditions of the orchard (Omamor and Hamza, 2007; Palou *et al.*, 2016; Hussain *et al.*, 2020).

In this study, the influence of temperature and moisture can be observed in the high microbial load present on fruit produced by the early blue bagging treatment, which had a longer period of time to create favourable conditions for disease development than its counterpart (Omamor and Hamza, 2007; Teena *et al.*, 2014; Abass, 2016).

Interestingly, several instances of *Botrytis* isolates were found at Rutab, in particular from the late blue bagging treatment. However, *Botrytis* species are mostly associated with inflorescence rot and considered of minor importance in date fruit, especially concerning the 'Medjool' variety (Manzelat, 2019), although an Egyptian study reported *Botrytis cinerea* in 'Barhee' dates (El-Sersawy *et al.*, 2019). Thus, the presence of *Botrytis sp.* in this study is most likely due to inoculum from the pecan nut trees in the orchard or adjacent vineyards.

5. Conclusion

The purpose of this study was to investigate fruit bunch bagging as a sustainable approach to control pre-harvest fungal infection of organic date fruit, in the Western Cape. The number and type of fungi of date fruit were recorded at the Khalal and Rutab maturation stages, during one season. The goal of this experiment was to formulate a recommendation regarding the start and duration of the bunch bagging technique, as well as a suggestion for the colour and material of the bag itself, that is most befitting for the surrounding regional climate. Its implementation would ideally result in a reduction in the microbial spoilage of pre- and postharvest date fruit, as well as improving the overall fruit quality and safety.

According to the findings reported in the study, bunch bagging with a white high density polyethylene bag applied earlier in the ripening process at Khimri was the most promising treatment in the control of fungal infection. Although the microbial load nearly doubled from Khalal to Rutab across all bagging treatments, the early white bagging treatment still had the lowest incidence. This indicates a potential control against fungal infections that should be investigated further, such as adding desiccants to reduce the relative humidity.

Bunch bagging has proven to be an environmentally sustainable approach suitable for use in organic farming systems, as no harmful impact on the date palm tree or its surrounding environment was observed during the study, and the blue and white bags can be recycled or reused respectively, after the end of the season.

Further research is necessary regarding the effect of bunch bagging on agriculturally important pathogens, such as *Fusarium sp.*, *Alternaria sp.* and *Botrytis sp.*

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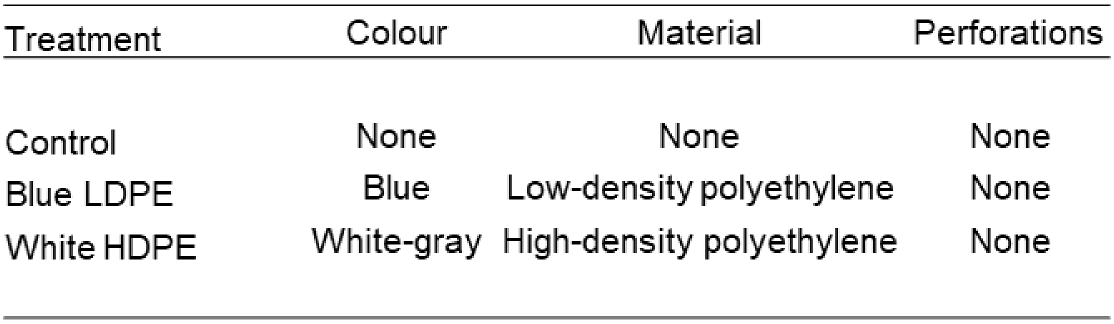
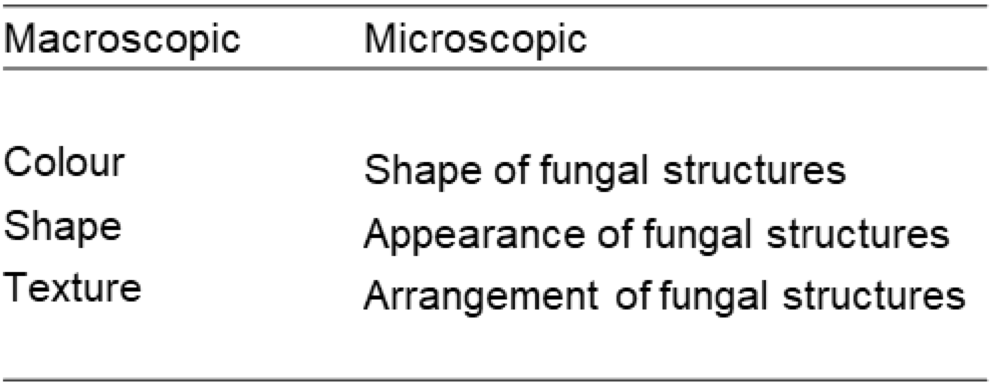


Treatment	Colour	Material	Perforations
Control	None	None	None
Blue LDPE	Blue	Low-density polyethylene	None
White HDPE	White-gray	High-density polyethylene	None

Table 1. Details of bagging treatments used in the experiment.

Figure 1. Experimental view of bagging treatments as seen on date palm fruit bunches at Kleinplasie, Hermon. Photos by RJ Peddie (2022).



Macroscopic	Microscopic
Colour	Shape of fungal structures
Shape	Appearance of fungal structures
Texture	Arrangement of fungal structures

Table 2. Description of macroscopic and microscopic characteristics used in the identification of prevalent fungi up to genus level.

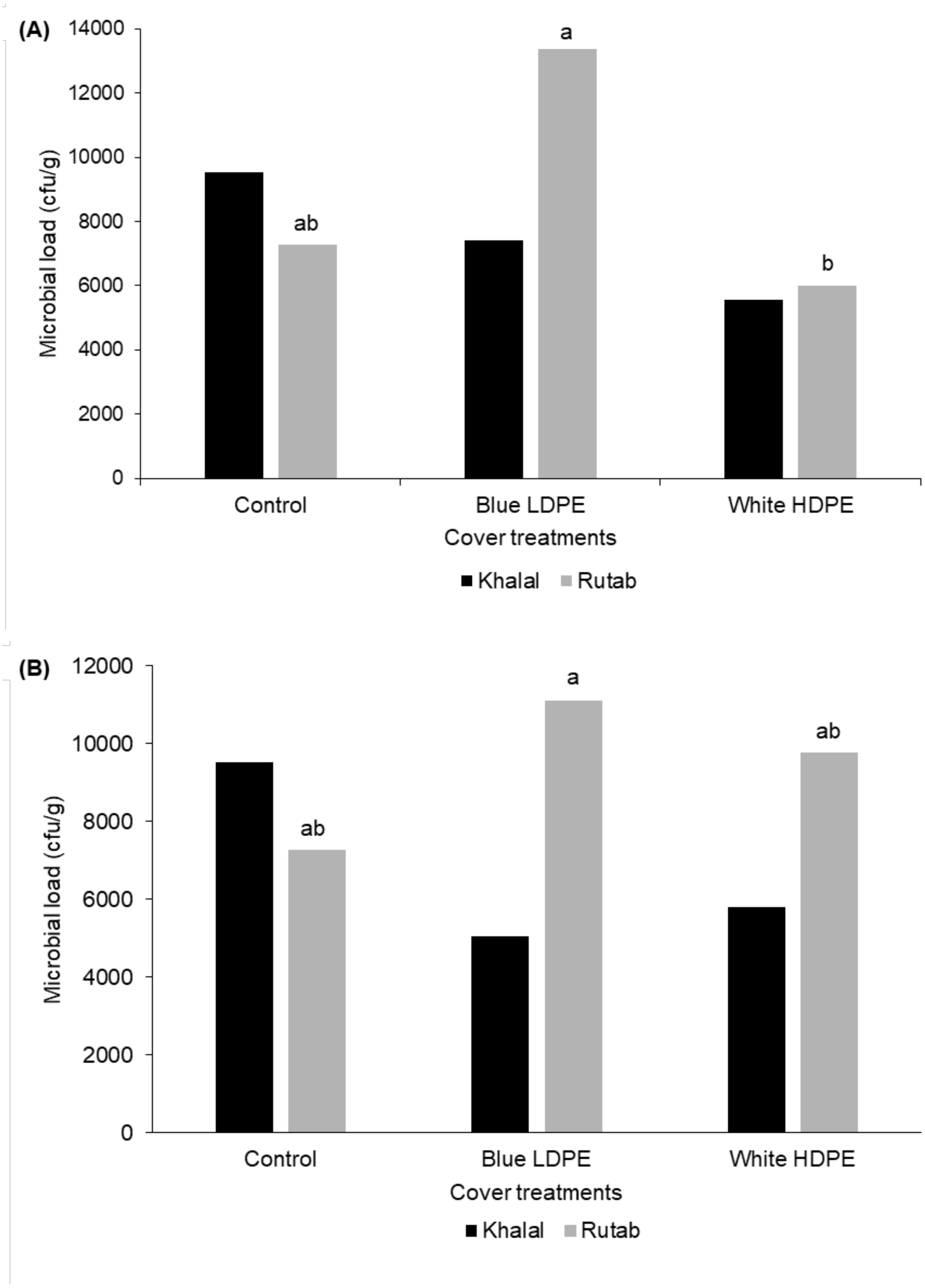


Figure 2. Effect of different pre-harvest treatments on ‘Medjool’ date fruit microbial load subjected to (A) early and (B) late bagging treatments during the Khalal and Rutab phenological stages, at Kleinplasie, Hermon, during 2022. Means with different letters are significantly different at $p < 0.05$ using multiple comparison tests. LDPE = low density polyethylene, HDPE = high density polyethylene. CFU/g = colony forming unit per 1 ml of culture

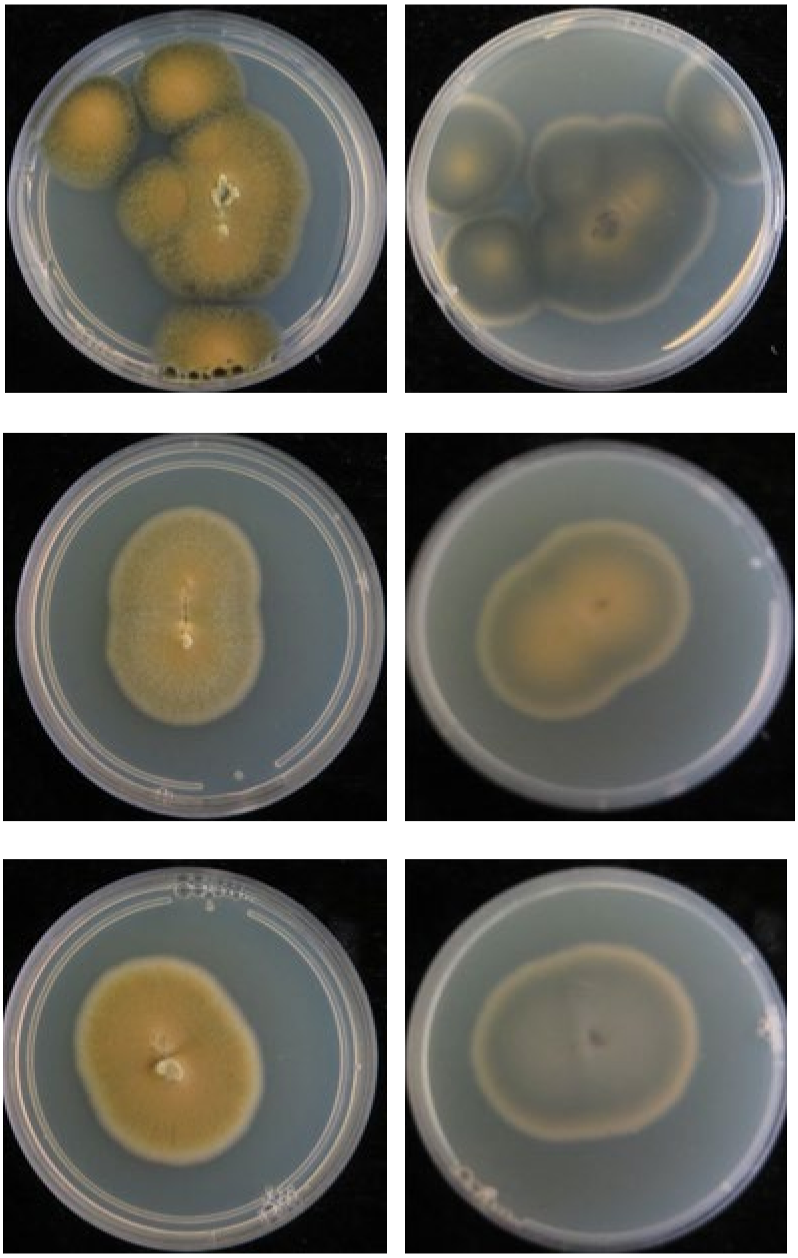


Figure 3.A. Representative images of *Cladosporium spp.* isolates viewed from above (left) and below (right) on PDA.

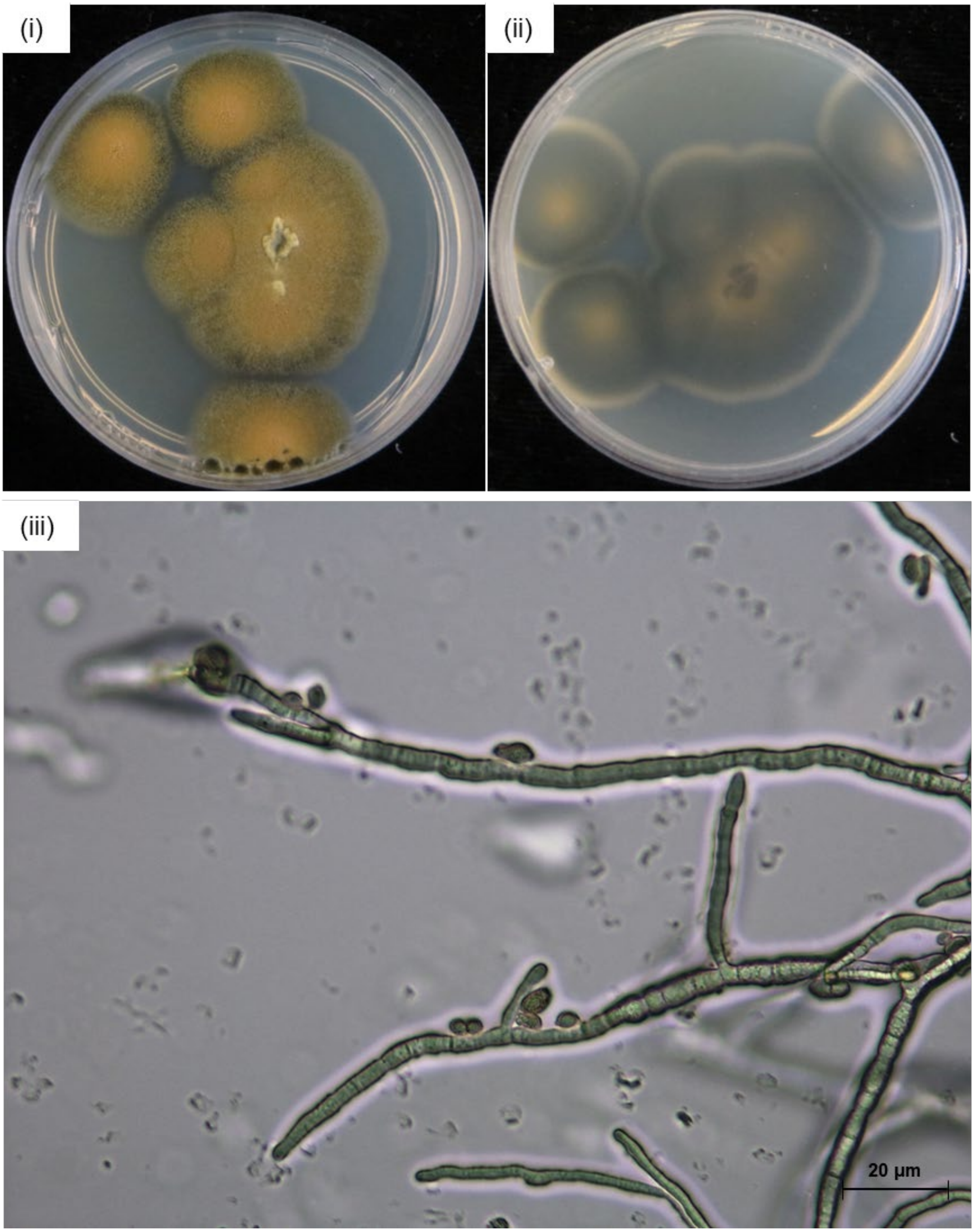


Figure 3.B. Representative images of *Cladosporium spp.* isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

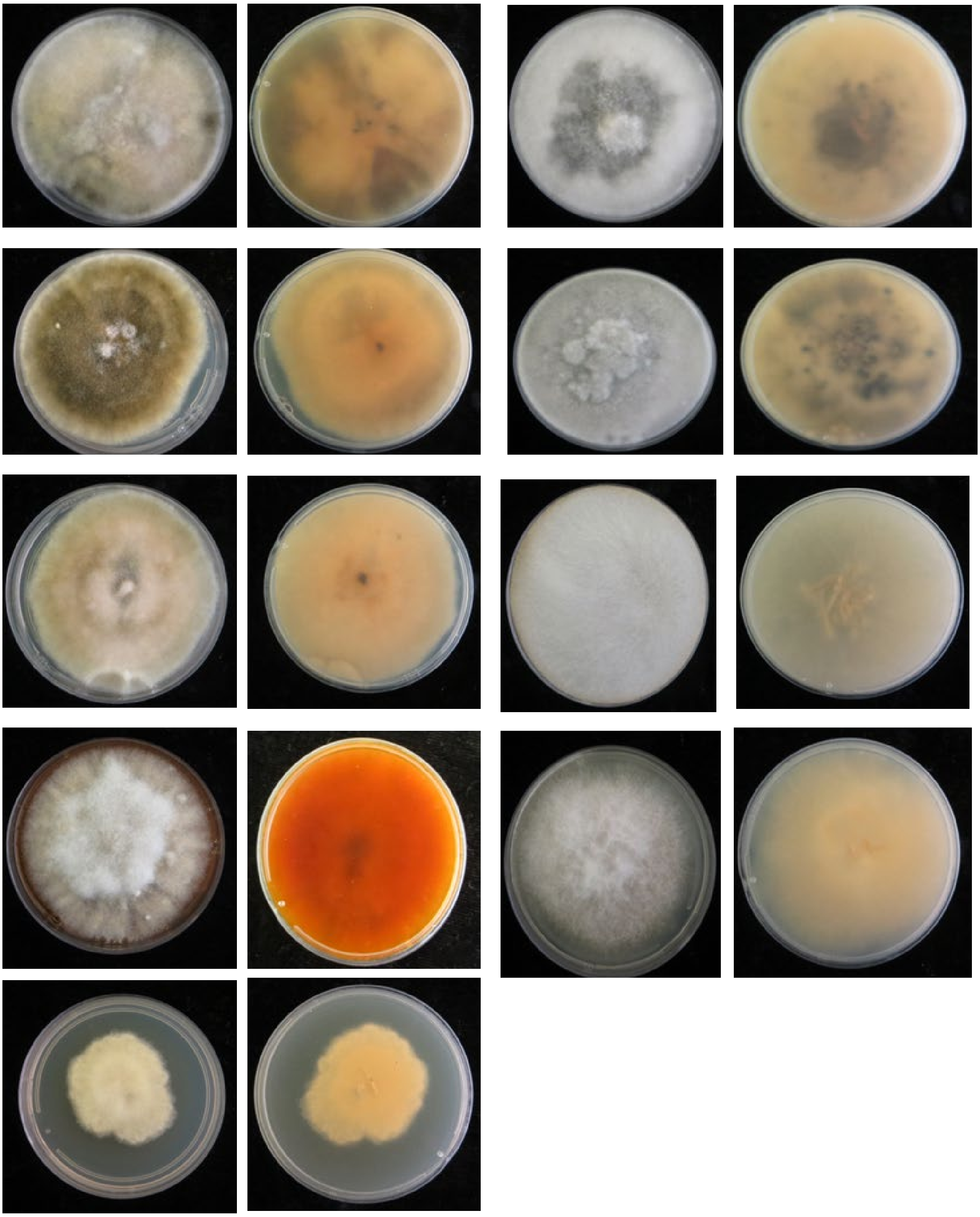


Figure 4.A. Representative images of *Alternaria spp*. isolates viewed from above (left) and below (right) on PDA.

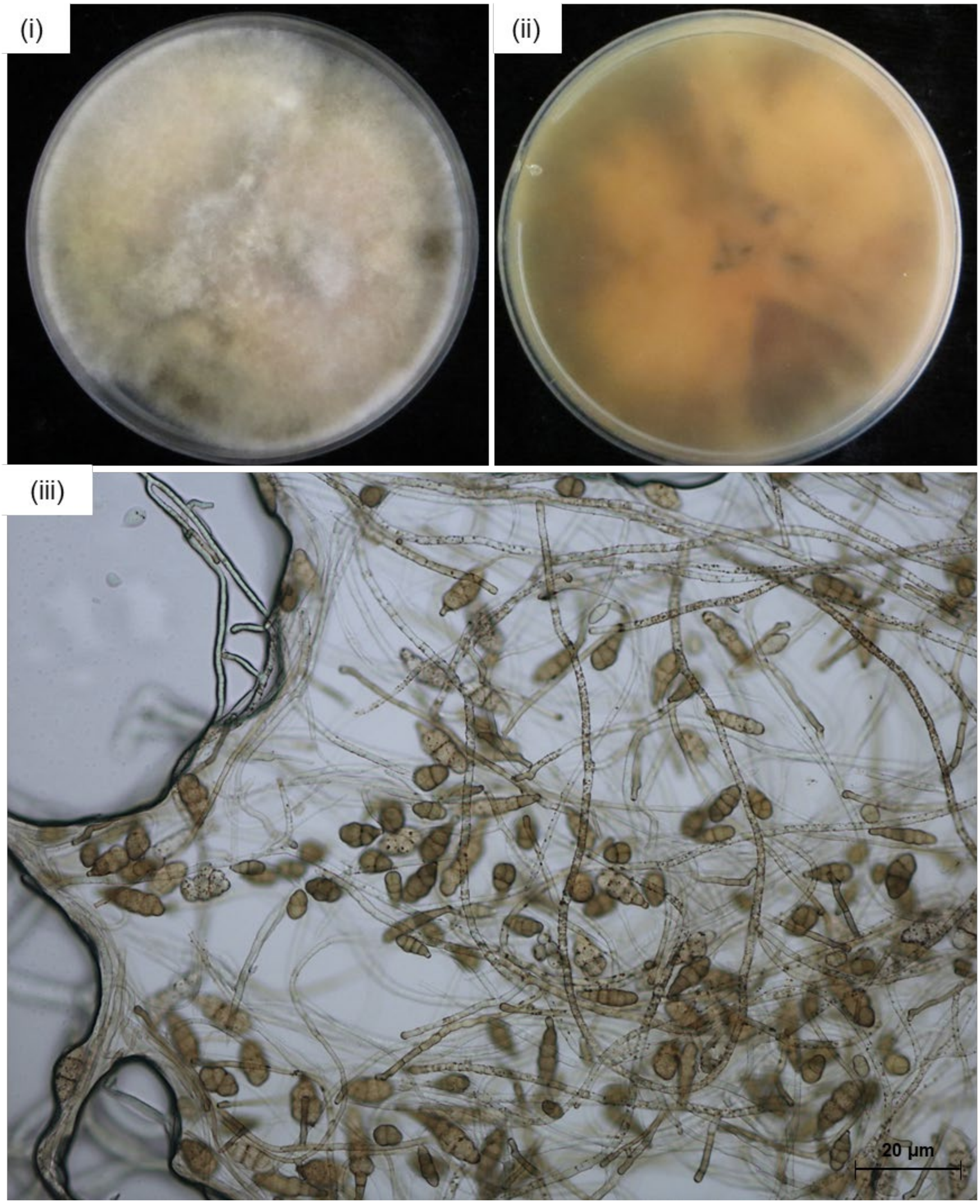


Figure 4.B. Representative images of *Alternaria spp*. isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

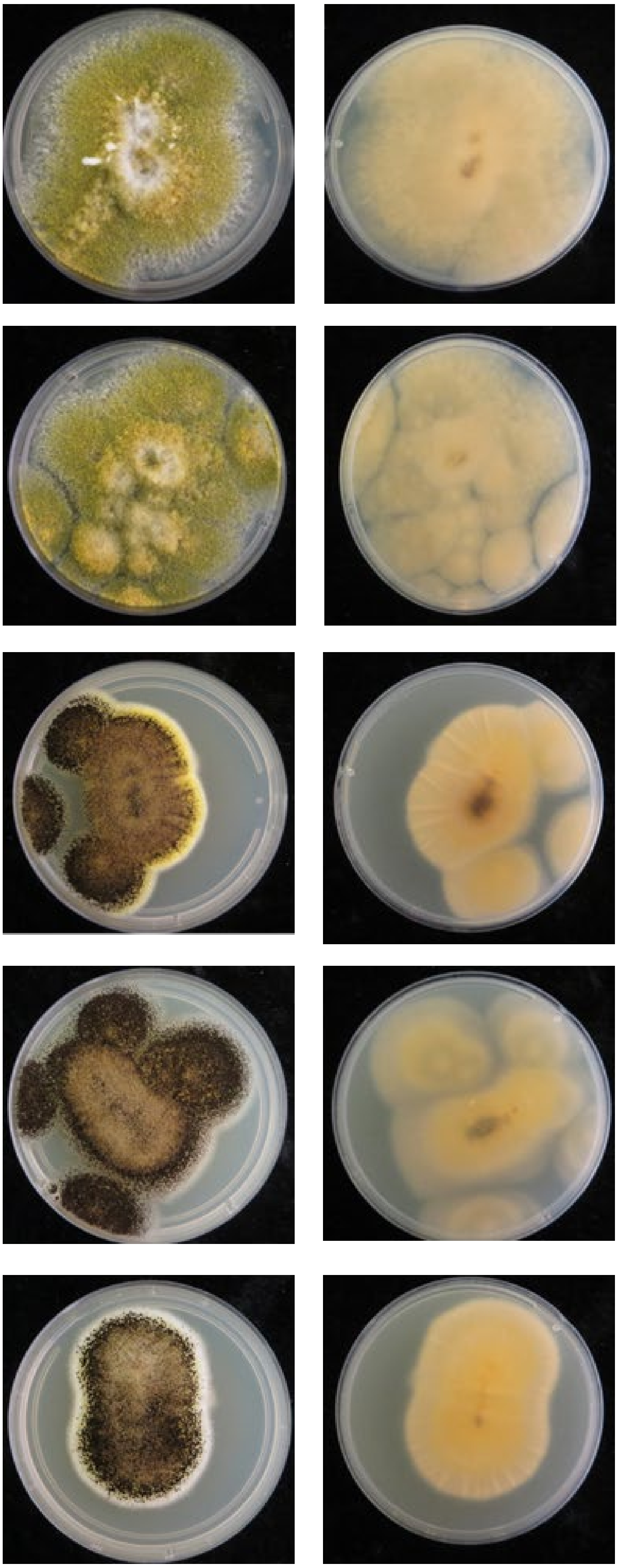


Figure 5.A. Representative images of *Aspergillus spp*. isolates viewed from above (left) and below (right) on PDA.

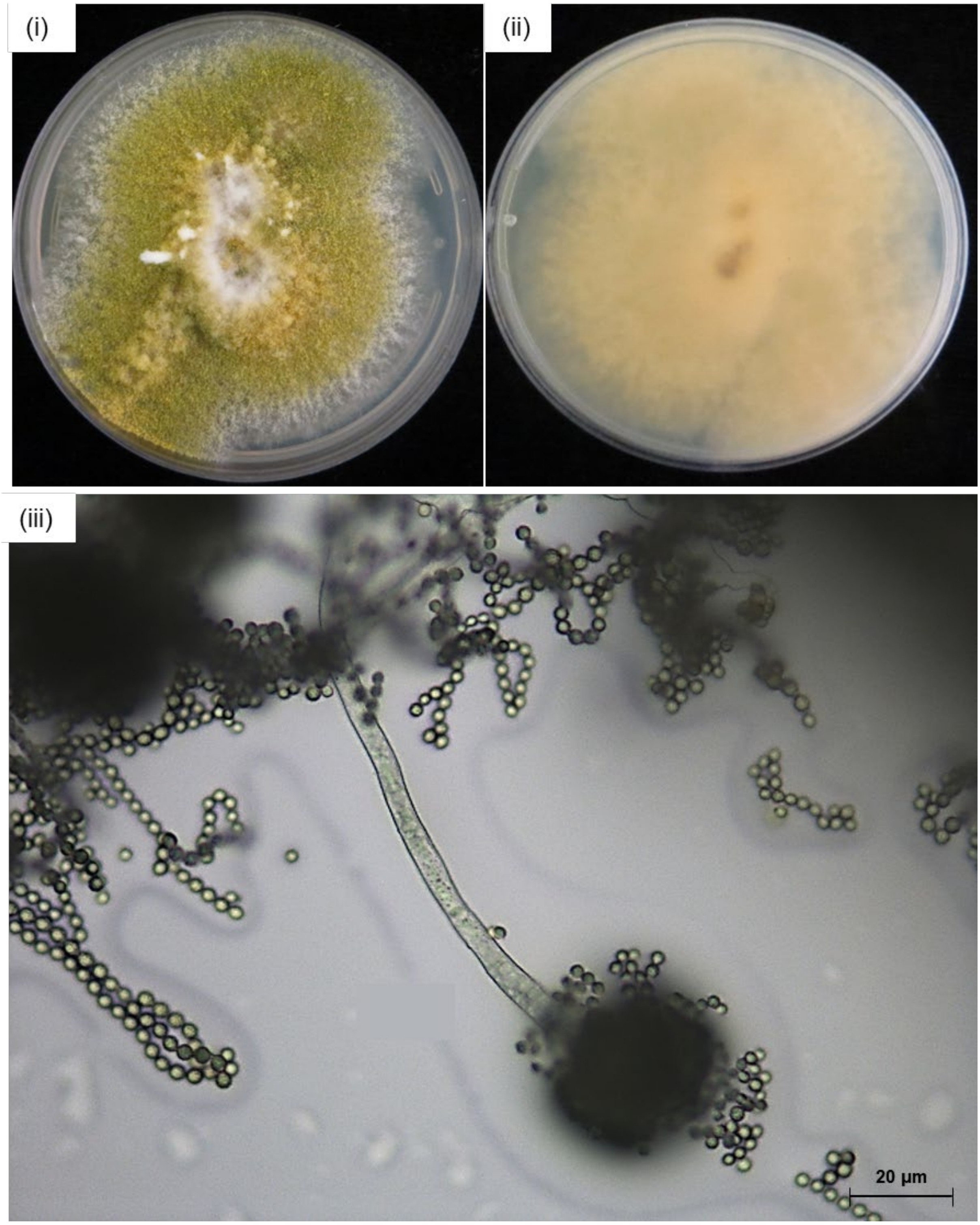


Figure 5.B. Representative images of *Aspergillus spp*. isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

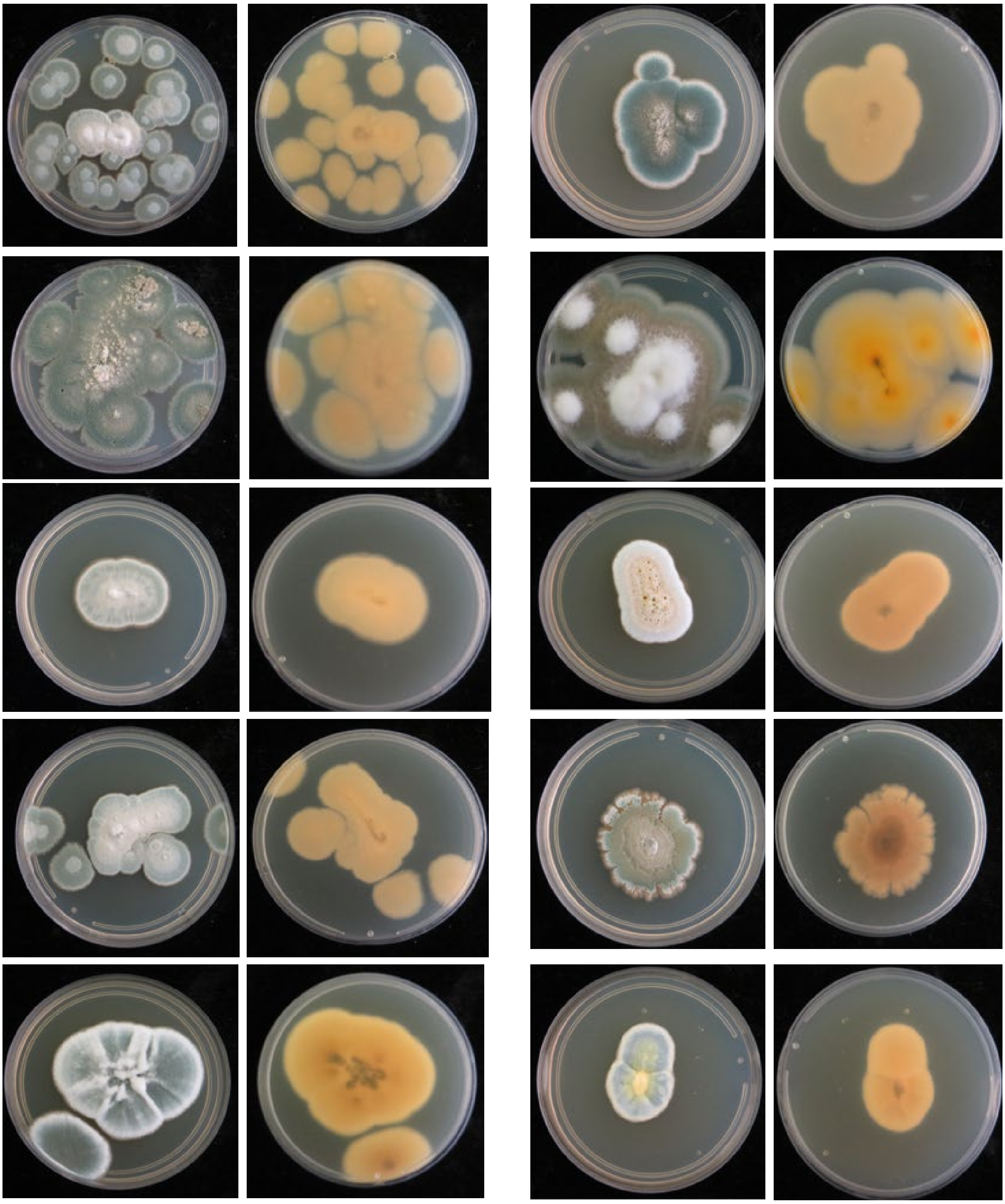


Figure 6.A. Representative images of *Penicillium spp*. isolates viewed from above (left) and below (right) on PDA.

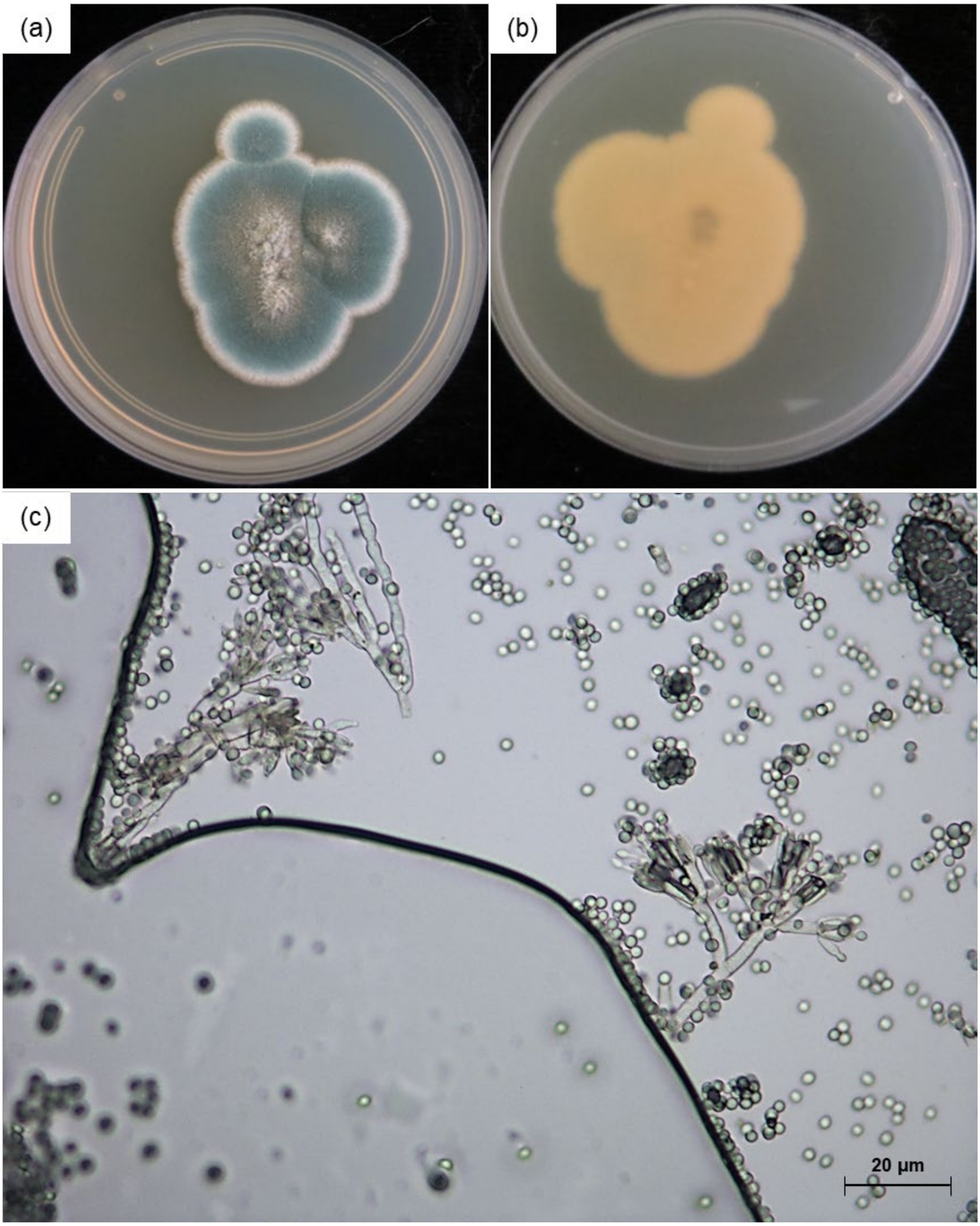


Figure 6.B. Representative images of *Penicillium spp*. isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

Figure 7.A. Representative images of *Fusarium spp*. isolates viewed from above (left) and below (right) on PDA.

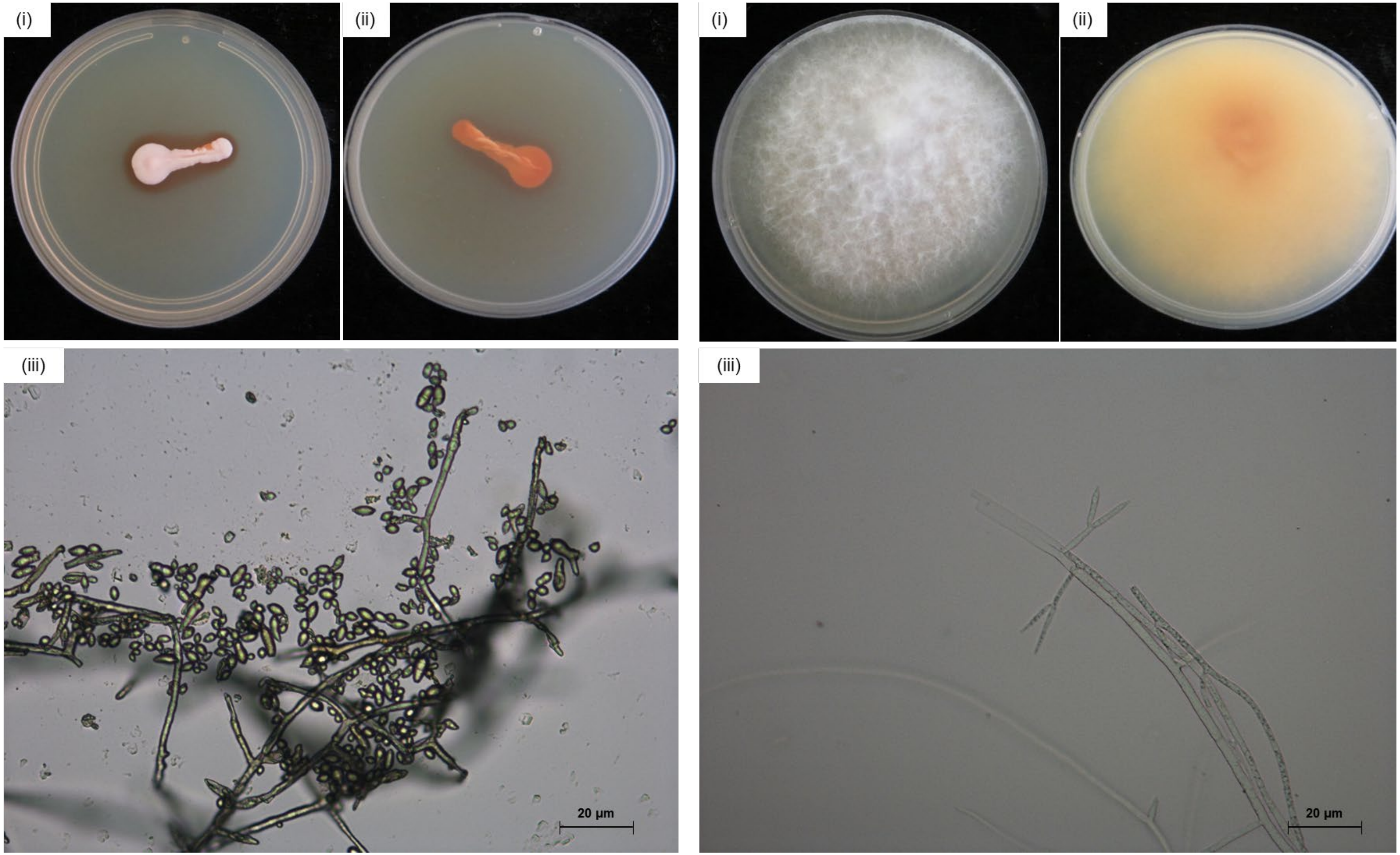


Figure 7.B. Representative images of *Fusarium spp.* isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

Figure 8. Representative images of *Botrytis spp*. isolates illustrating (i) top and (ii) reverse colony and (iii) conidial morphological characteristics on PDA.

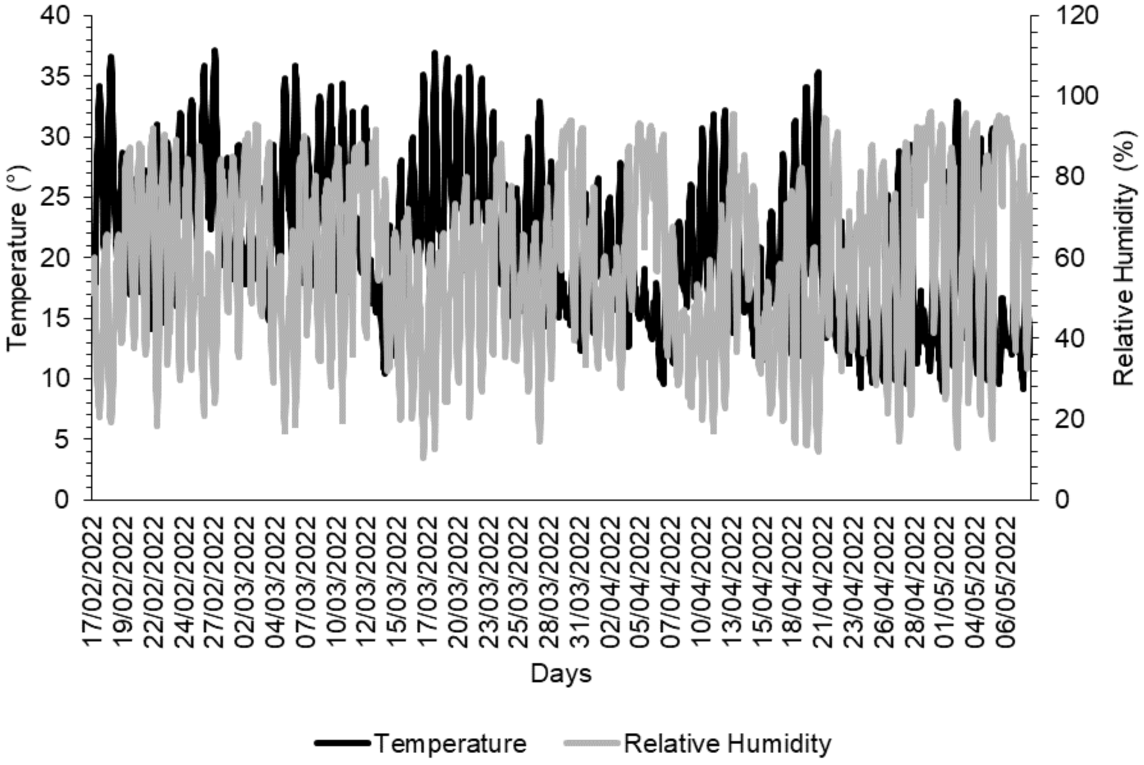


Figure 9. Average hourly (A) temperature and (B) relative humidity of Kleinplasie, Hermon in 2022.

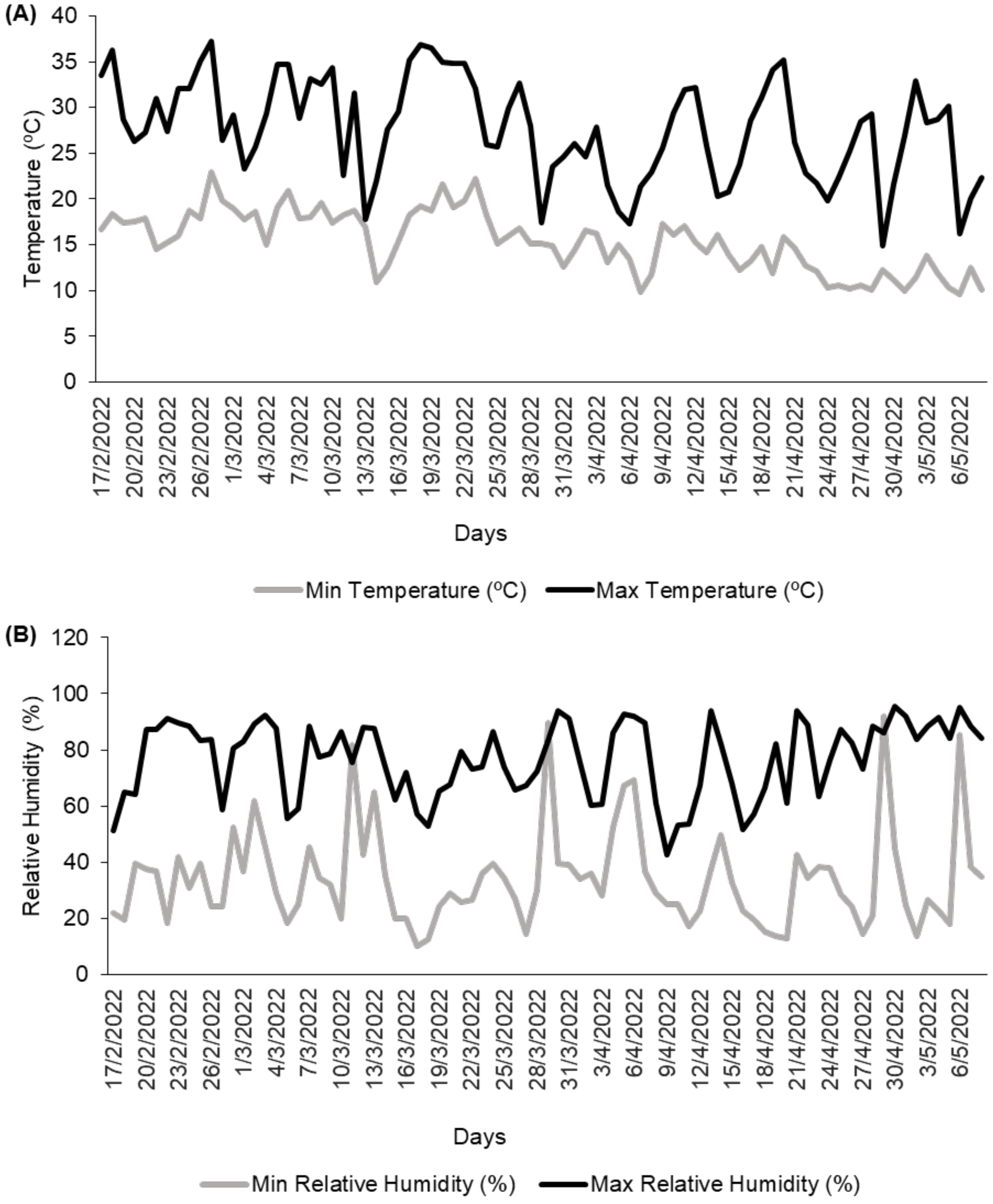


Figure 10. Average minimum and maximum (A) temperature and (B) relative humidity of Kleinplasie, Hermon in 2022.

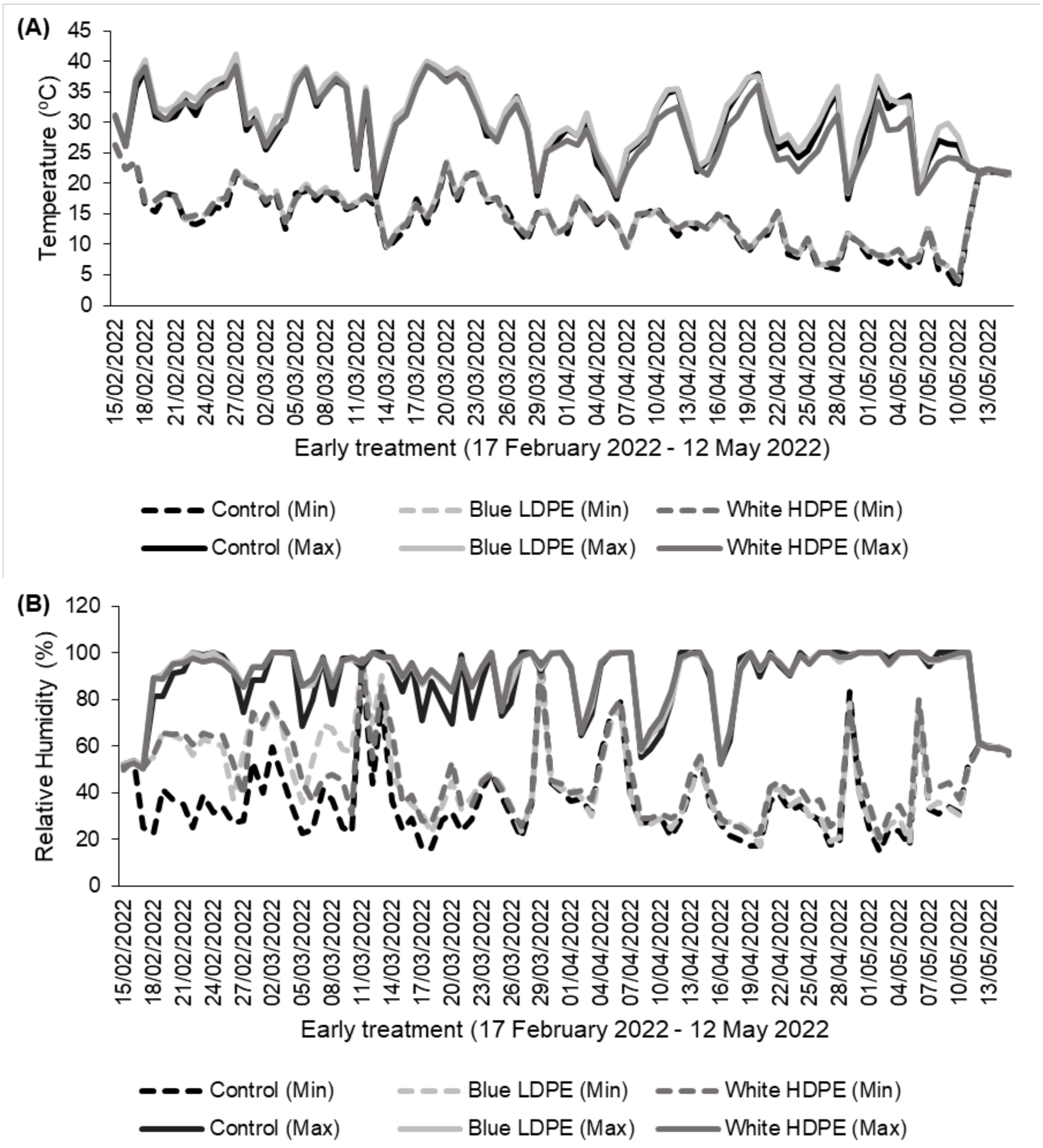


Figure 11. Average hourly internal (A) temperature and (B) relative humidity of early bagging treatments as recorded with Tinytag loggers (Mitutoya Corporation, Japan) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene.

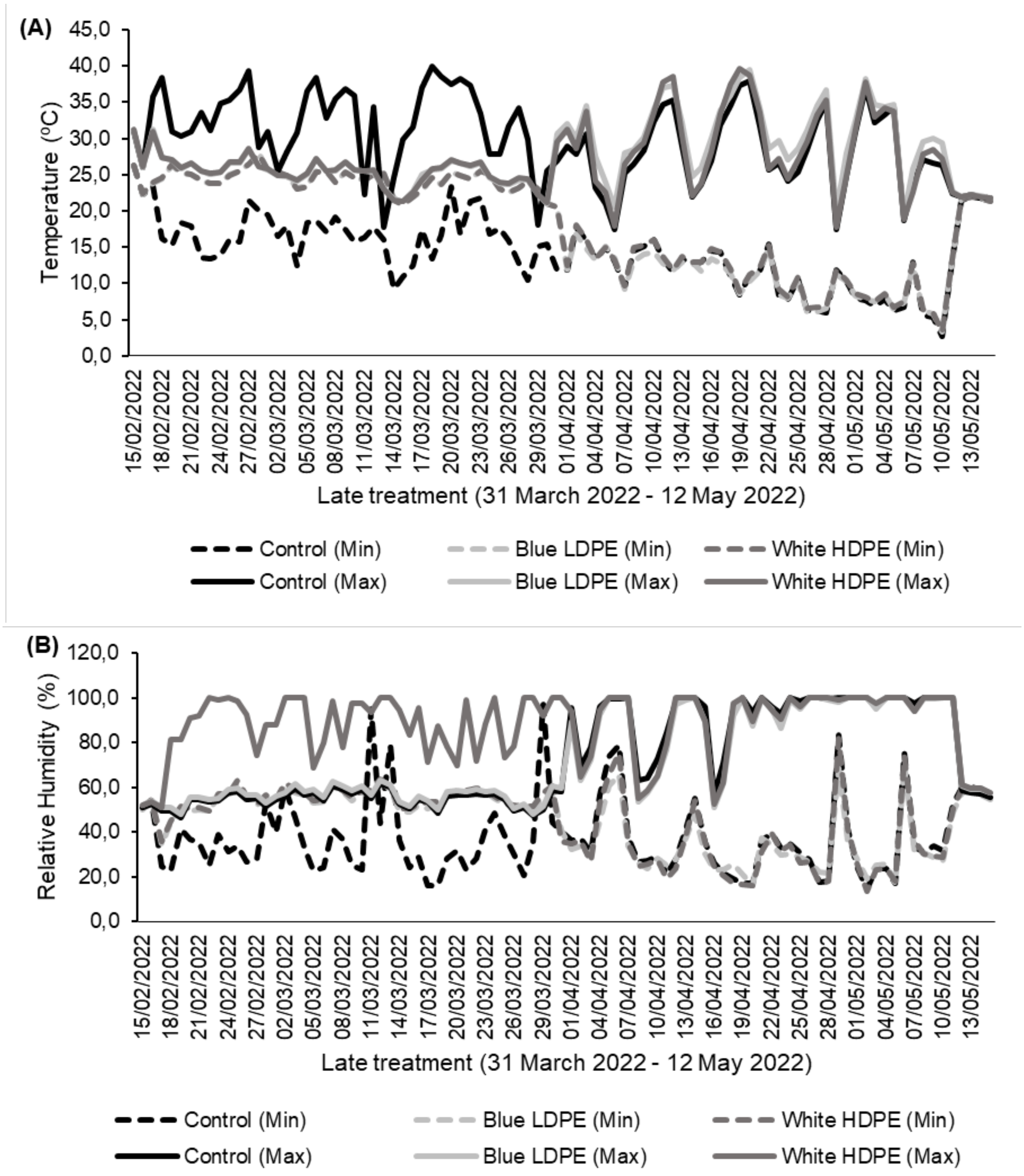


Figure 12. Average hourly internal (A) temperature and (B) relative humidity of late bagging treatments as recorded with Tinytag loggers (Mitutoya Corporation, Japan) at Kleinplasie, Hermon in 2022. Control = no treatment, LDPE = low density polyethylene, HDPE = high density polyethylene

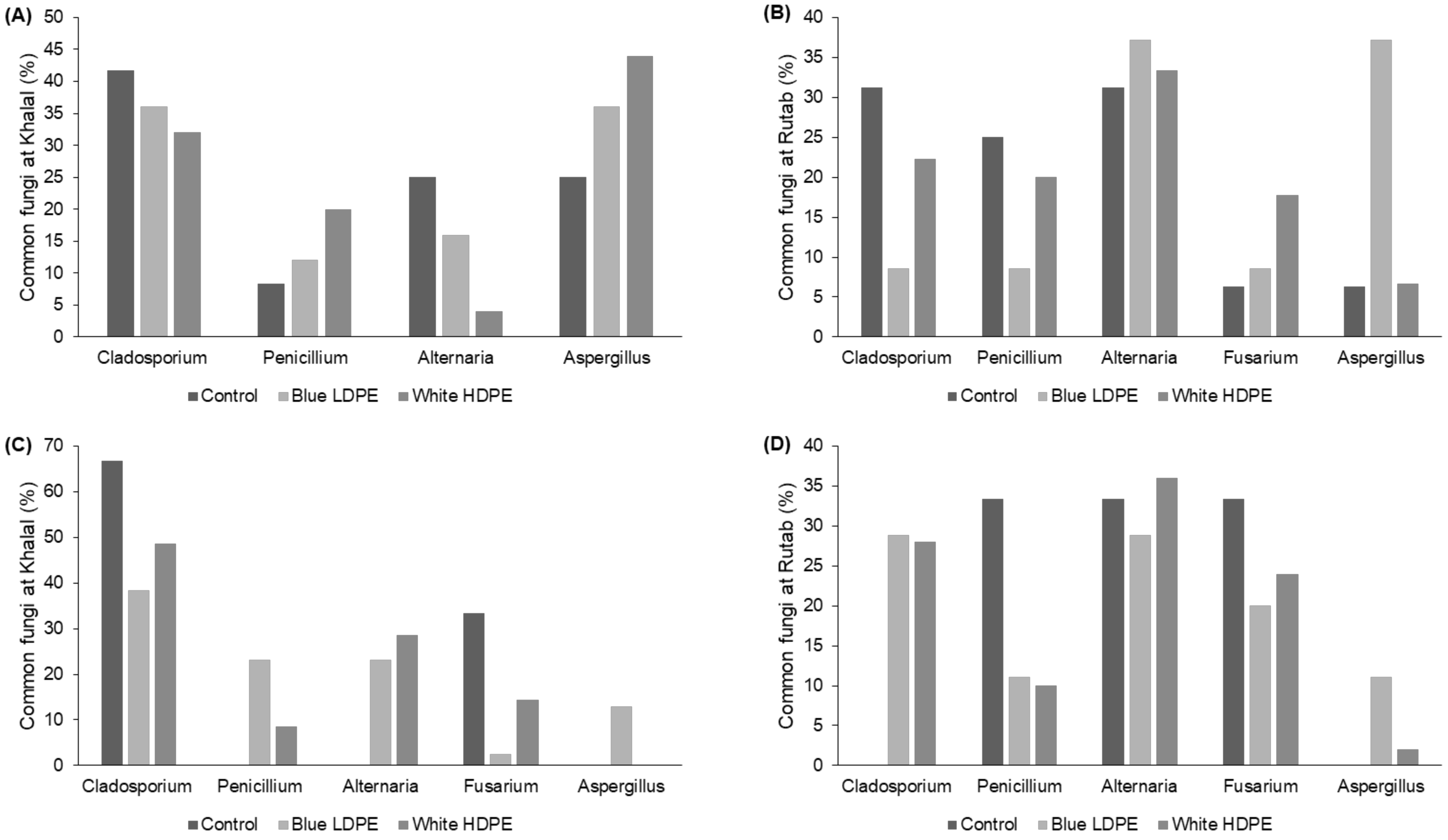
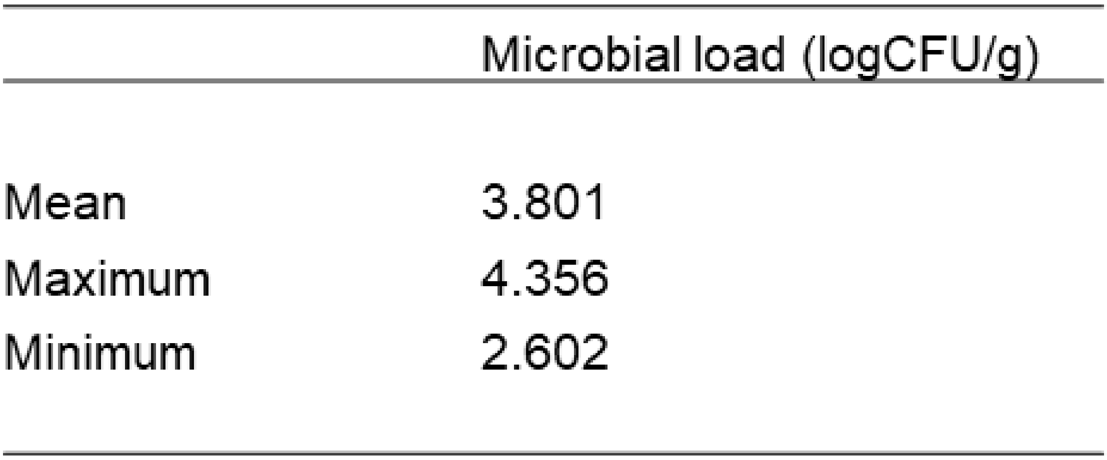


Figure 13. Values indicate the incidence of the most common microorganisms present in (A, B) early and (C, D) late bagging treatments during each phenological stage. LDPE = low density polyethylene, HDPE = high density polyethylene.

Appendix B.1. Summary of the baseline measurements of date fruit microbial load recorded before the start of bagging treatments at Khimri on 17 February 2022 at Kleinplasie, Hermon



	Microbial load (logCFU/g)
Mean	3.801
Maximum	4.356
Minimum	2.602

Chapter 5: General Discussion and Conclusion

Date palm production has the potential to be a resilient farming system in the face of climate change due to its high nutritional and economic value, climate adaptation and cultural significance, particularly when cultivated using organic agriculture (Kristiansen *et al.*, 2005; Ashraf and Hamidi-Esfahani, 2011; Eyhorn *et al.*, 2019). In this way, it aids in the promotion of sustainable agriculture. In the present study, it was demonstrated that fruit bunch bagging was effective in the acceleration of the irregular ripening of 'Medjool' date fruit in an organic orchard in the Western Cape province of South Africa. However, this approach was not effective in the incidence or control of fungi causing fruit rot and decay.

Preharvest analyses revealed that the effect of bunch bagging was significant on fruit weight, diameter, colour, and microbial load at the Rutab phenological stage, when compared to the control. Furthermore, bunch bagging from different materials did not have an effect on the biochemical parameters of date fruit at either the Khalal or Rutab stage. Postharvest analyses demonstrated that bunch bagging treatments led to the improvement of postharvest ripening and shelf-life potential of Rutab dates when compared to the control. Interestingly, a number of harvested dates was found to be parthenocarpic fruit, and the storage temperature of 21°C was unsuitable for the storage of the highly perishable Rutab date. Furthermore, bunch bagging had a significant effect on the taste of postharvest date fruit. More specifically, fruit from the early blue treatment achieved the highest tasting score, closely followed by the late white treatment. The lowest score was given to fruit produced from the unbagged control treatment, which is an indication of the positive effect of the bagging treatments on taste. Overall, the most prevalent microorganisms isolated from date fruit at Khalal and Rutab were identified as *Cladosporium spp., Penicillium spp., Alternaria spp*., *Aspergillus spp*. and *Fusarium spp.* Species from the *Cladosporium* genus was the predominant microorganism isolated at Khalal, while *Alternaria spp.* was observed to be the dominant genus at Rutab.

Climate data for the Hermon region confirmed the suitability of local environmental conditions for the successful cultivation of the 'Medjool' date cultivar, providing fruit maturity can be enhanced before the onset of winter rains. Similarly, the microclimate data for the early and late bagging treatments confirmed the modification of the internal environmental conditions, in which the blue and white bags increased in temperature compared to ambient conditions (control). In addition, the blue bag had a higher temperature than the white bags until the end of March, whereafter it was similar. The blue and white bags also increased its relative humidity compared to the control. These conditions assisted in the formation of optimal conditions for fruit growth and development (Yahia and Kader, 2011; Lobo *et al.*, 2014; Siddiq and Greiby, 2014). However, these same internal conditions are conducive to the proliferation of fungal disease, as the blue bag was found to contain a higher microbial load than the control, as well as the white bag, at harvest (Omamor and Hamza, 2007; Hussain *et al.*, 2020).

Sustainability in agriculture can be defined as the efficient and effective long-term management of natural and human resources, in a manner that is environmentally non-degrading, economically viable and socially acceptable (Kristiansen *et al.*, 2005; Eyhorn *et al.*, 2019). However, in this study, only the aspect of environmental sustainability was included in the scope. Bunch bagging has proven to be an environmentally sustainable approach suitable for use in organic farming systems, as it was effective in the acceleration of the fruit ripening process and showed promise in the control of pathogens causing fungal infection. Furthermore, no harmful impact on the date palm tree or its surrounding environment was observed during the study. and the bunch bag itself was found to be recyclable or reusable, depending on its conditions after the end of the season. Only when the bags were damaged irreparably, were they disposed of. This means that these bags were merely wiped down after each season and used again.

Another interesting finding of the study was the effect of bunch bagging on the quality of harvested date fruit, which was assessed according to the CODEX standard of dates (FAO-WHO, 1985; Aleid *et al.*, 2014; Dag, 2020). The date fruit investigated in this study may be characterised as high-quality fruit in terms of physical appearance, since they are several times heavier and larger than the minimum requirement, as well as developing a uniform dark brown colour characteristic of the 'Medjool' date variety. However, the fruit was found to be moderately sweet but slightly astringent, leading to a lower quality date fruit in terms of sensory quality, compared to fresh dates sold in the supermarket. Furthermore, although the fruit was deemed safe to eat, the microbial load at harvest was much higher than the limit set for yeast and moulds, resulting in a low fruit quality prone to spoilage during processing and storage.

According to the findings reported in the study, implementing a blue low density polyethylene bag later in the ripening process at Khalal until harvest resulted in the accelerated ripening of date fruit, while applying a white high density polyethylene bag applied earlier at Khimri was the most promising treatment in the control of fungal infection. Thus, while the fruit may undergo a more rapid ripening process, it would also contain a higher number and wider range of pathogenic fungi causing fruit rot and decay, particularly if harvested early and stored under ambient conditions.

The results of the present study may contribute to new and support existing knowledge about the effect of the bunch bagging technique on the 'Medjool' date variety, during different stages of fruit ripening with different types of bags, its effectiveness in the climate of the Western Cape, its modification of the internal environmental conditions inside the bag, as well as its positioning as a sustainable approach suitable for organic productions. This knowledge may be relevant to both industry and academia, in terms of providing recommendations on the type and duration of bunch bagging in Mediterranean and other temperate climates, as well as providing a foundation for further research in the fields of horticulture, microbiology, engineering, and sustainable agriculture.

Some limitations associated with the present study include a small sample size due to the unavailability of resources, a limited scope, as well as minor flaws in the methodology. During the inspection of the study site, the development of a low fruit set (< 50%) following pollination was confirmed. This led to a smaller number of available fruit bunches to be used as experimental units, thereby diminishing the sample size of date fruit to be evaluated. Additionally, the study focused on the effect of only bunch bagging on date fruit, whereas its production is also influenced by irrigation, fertilisation, fruit thinning, leaf pruning as well as pest and disease control, which limits the scope considerably. Also, the tensile and thermal properties of the bunch bag material could not be fully analysed and incorporated into the study. The climatic data recorded temperature and relative humidity but did not take into consideration information on the regional patterns of rainfall, which was relevant to ripening and fungal infection. Furthermore, chemical parameters at Rutab could not be analysed accurately because of difficulties in the sample preparation process, resulting in missing values and speculation. Also, while the study based its recommendation on the data of one season, at least three seasons would be necessary in order to make a reliable conclusion.

It is clear that in the future research of bunch bagging on date palm in South Africa, it would be wise to standardise specifications for the type of bag to be used, the date of bagging, and the date of bag removal for local growers to benefit from this technology. For instance, the use of more colours of the polyethylene bag, such as yellow, green, or black bags. Or the use of different materials, such as paper or cloth. Furthermore, the naturally occurring microflora on date fruit at different stages of maturation should be investigated in order to predict and control the occurrence of fungal infection. Bunch bagging could also be investigated in conjunction with other cultural techniques primed for the preharvest enhancement of fruit. This includes fruit thinning, the application of green manure and compost as a fertilisation strategy, as well as cover- and/or intercropping. In addition, new materials to be used as bunch bags could be investigated or could be altered in order to enhance its desired properties. This could be tensile strength, water absorption, UV resistance or biodegradability. Other preharvest measures besides bunch bagging could be investigated in the field. This may include improving air ventilation of the fruit bunch by inserting different sizes of wire, or selective pruning of fruit strands in order to reduce the moisture levels of the fruit bunch (Brown, 1920; Djerbi, 1983; Palou *et al.*, 2016).

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