PRODUCTION AND CHARACTERIZATION OF NATURAL DATE FRUIT POWDER (PHEONIX DACTYLIFERA L.)

Fayeza Hasan

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PRODUCTION AND CHARACTERIZATION OF NATURAL DATE FRUIT POWDER (PHEONIX DACTYLIFERA L.)

Fayeza Hasan

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

Under the Supervision of Professor Afaf Kamal Eldin

April 2021
Declaration of Original Work

I, Fayeza Hasan, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled “Production and Characterization of Natural Date Fruit Powder (Phoenix Dactylifera L.)”, hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor Afaf Kamal Eldin, in the College of Food and Agriculture at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

Student’s Signature:  Fayeza Hasan

Date: 11.03.2021
Advisory Committee

1) Advisor: Prof. Afaf Kamal Eldin
Title: Professor
Department of Food Science
College of Food and Agriculture

2) Co-advisor: Prof. Ali Al Marzouqi
Title: Professor
Department of Chemical and Petroleum Engineering
College of Engineering

3) Member: Dr. Bhawna Sobti
Title: Instructor
Department of Food Science
College of Food and Agriculture

4) Member: Dr. Akmal Nazir
Title: Assistant Professor
Department of Food Science
College of Food and Agriculture
Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): Prof. Afaf Kamal Eldin  
   Title: Professor  
   Department of Food Science  
   College of Food and Agriculture  
   Signature ___________ Date 11.06.2021

2) Member: Dr. Abdul Jaleel Cheruth  
   Title: Associate Professor  
   Department of Integrative Agriculture College of Food and Agriculture  
   Signature ___________ Date 11.06.2021

3) Member (External Examiner): Dr. Farah Saleena Taip  
   Title: Associate Professor  
   Department of Process and Food Engineering  
   Institution: Universiti Putra, Malaysia  
   Signature ___________________ Date 11.06.2021
This Master Thesis is accepted by:

Dean of the College of Food and Agriculture: Professor Bhanu Chowdhary

Signature ___________  Date  30/08/2021

Dean of the College of Graduate Studies: Professor Ali Al-Marzouqi

Signature ___________  Date  30/08/2021

Copy ____ of ____
The aim of this thesis was to study the possibilities for production and the characterization of powder from ripened date fruits (*Phoenix dactylifera* L.). Various techniques including tray drying, freeze drying, vacuum drying, microwave drying, convection drying were tested for their ability to dry the dates sufficiently to produce a date powder. Six varieties of dates namely Barhi and Khalas (soft varieties), Sagei and Sukari (semi-dry varieties), and Barakawi and Gundeila (dry varieties) were evaluated for their drying characteristics. The drying parameters and the physico-chemical characteristics were compared and a storage study for the date powder was conducted. It was observed that variations in moisture content existed within a variety. Only the convection drying technique of semi-dry and dry varieties were suitable to produce a powder. Sukkari and Barakawi were cabinet dried at 65, 70 and 75°C, after which the dates were milled. The most suitable temperature for drying was observed to be 70°C. Higher temperatures were associated with increased formation of hydroxymethylfurfural and darkness. Finer versions (<400µm) showed lower flowability, high compactibility and increased hygroscopicity compared to coarser counterparts. Storing the date powder for a month in a jar (one teaspoon was removed per day) showed that the moisture content increased from 2 to 8% during the storage period and hardness increased linearly upto 17 days.

**Keywords:** Date fruits, *Phoenix dactylifera*, Drying, Date powder, Quality.
انتاج ودراسة خصائص مسحوق ثمار التمر

المقدمة
هدف هذه الورقة هو تحديد إمكانيات إنتاج مسحوق التمر ودراسة خصائصه. لقد تم تجريب عدة تقنيات واختبار كفاءتها على تجفيف التمور الناضجة وانتاج مسحوق التمر وهي التجفيف بالجمد، التجفيف بخفض الضغط، التجفيف بال써ير، والتجفيف الحراري. كما تم تقييم ودراسة خصائص التجفيف لستة أصناف من التمور وهي البرحي والخلاصة (تمور رطبة) والسكرى والصقعي (تمور شبه جافة) والبركاوي والدقيل (تمور جافة). وقد تم مقارنة معاملات التجفيف والخصائص الفيزيائية والكيميائية لمسحوق التمر بالإضافة إلى دراسة أثر تخزين الحبيبات. لوحظ وجود اختلافات في محتوى الرطوبة باختلاف الاصناف. كما وجد أن تقنية التجفيف الحراري للأصناف شبه الجافة والجافة مناسبة لإنتاج مسحوق التمر. تم التجفيف صنفى السكرى والبركاوي في عدة درجات حرارة (65 و 70 و 75 درجة مئوية)، وبعد ذلك تم طحن التمور الجافة. وقد لوحظ أن درجة الحرارة الأكثر ملاءمة للتجفيف هي 70 درجة مئوية حيث أن ارتفاع درجات الحرارة قد ارتبط بزيادة إنتاج مركب هايدروكسيد ميثيل الفرفرال واللون الداكن. أظهرت الحبيبات الناعمة (400 ميكرون) قابلية أقل للتحلل وصلابة عالية وزيادة في الرطوبة مقارنة بنظيراتها الخشنة. عند تخزين مسحوق التمر لمدة شهر وجد أن المحتوى الرطبي ازداد من 2 إلى 8% وأزدادت الصلابة طرديًا حتى 17 يومًا.

مبادئ البحث الرئيسية: تمر التمر، التجفيف، مسحوق التمر، الجودة.
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Dedication

To my beloved parents and family
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<tr>
<td>GAE</td>
<td>Gallic Acid Equivalents</td>
</tr>
<tr>
<td>HMF</td>
<td>Hydroxymethylfurfural</td>
</tr>
<tr>
<td>MENA</td>
<td>Middle East and North Africa</td>
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<td>UAE</td>
<td>United Arab Emirates</td>
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Chapter 1: Introduction

1.1 Overview

*Pheonix dactylifera*, L. (Palmaceae), commonly known as the ‘Date Palm’, is cultivated due to its ability to survive harsh weather conditions. The fruit of the date palm is commonly referred to as ‘Dates’. Date fruit is one of the crops that associate closely with Arab heritage and culture. Arab households are known for consuming dates regularly, irrespective of the season or time of the year. As per FAOSTAT (2018), the United Arab Emirates (UAE) annually produces around 345,119 metric tonnes of the fruit which is largely consumed unprocessed. A small proportion of the fruit is processed and used in the form of paste, syrup, additive in biscuits or in other traditional sweet dishes. Due to limited processing options coupled with inefficient marketing, the producers are unable to exploit their profit margins to the fullest potential nationally and internationally. Hence, there is still considerable scope for new product development.

Dates are a rich source of multiple vitamins, minerals, polyphenols (Nadeem et al., 2019), and fibre (Elleuch et al., 2008). They are very sweet in taste due to a 60 – 70% sugar content (Nadeem et al., 2019). One potential possibility of date processing is date sugar which could be used as an alternative to cane sugar. The nutrient content of 100 g of cane sugar is 387 kcal of energy, no fibre, 0.05 mg iron, 2 mg potassium, 0.01 mg zinc, and 0.007 mg copper while for the same quantity of dates, it is 282 kcal of energy, 8 g fiber, 1.02 mg iron, 656 mg potassium, 0.29 mg zinc and 0.206 mg copper (USDA, 2020). Thus, date sugar could serve as a sweetener with an added advantage
of being nutritionally more viable and potentially healthier compared to cane sugar. Date sugar would hence provide more than just calories.

Presently, the need to find viable and healthier alternatives to cane sugar are keenly sought. The primary reason for this is that sugar has been associated with an alarming rise of diabetes, obesity (regionally as well as globally), as well as high liver fat, visceral fat, triglycerides and total cholesterol (Bray & Popkin, 2014; Maersk et al., 2012). About 55 million people suffer from diabetes in Middle East and North Africa (MENA) regions and by 2045 this number is expected to rise to 108 million (IDF, 2020). In a recent study it has been shown that consumption of sugars added to tea, coffee and other sugar containing non-alcoholic beverages was associated with poor glycemia and an increase in inflammatory markers, while sugars from fruits and vegetables were not (O'Connor et al., 2018). The chances of date sugar increasing the glycemic index in individuals consuming them is expected to be much lower than that from cane sugar (Gourchala & Henchiri, 2013).

The industry has developed various alternatives like xylitol, saccharin, aspartame and stevia to meet the growing demands for sugar replacement. However, these ‘artificial sweeteners’ are also found to be associated with Type II diabetes, cardiovascular problems, hypertension, stroke besides blood glucose impairment and alteration of the gut microbiota (Swithers, 2015).

A successfully produced date powder would add value to the industry and the consumer by providing an alternative that is a ‘sweetener with health benefits’ which even in a nascent form will be revolutionary. Moreover, it would also support the date based revenue in MENA regions where millions of tonnes of dates are produced every season and a substantial proportion is triaged. Viewed from this perspective, it seems
reasonable and appropriate that the region's flagship fruit - the dates - also features on the country's development program so that the 'Mother' of Arab fruits is accorded due respect for its myriad medicinal values, and cultural importance. Therefore, producing and commercializing ‘date powder’ could be an avenue worthy of consideration both for better health and as a new source of business from dates.

1.2 Statement of the Problem

Date powder could be a beneficial alternative to cane sugar, be it from a nutritional or an economic viewpoint (for producers). However, producing a date powder is not an easy task primarily due to its high sugar content and associated hygroscopicity.

The research hypothesis is that date fruits have different water binding properties and drying kinetics. In addition, powders produced from different date varieties will have different properties such as moisture content/activity, solubility, flowability/compressibility, colour, phenolic content and Hydroxymethylfurfural (HMF).

Therefore, it will be necessary to determine the appropriate set of conditions for producing, storing and serving the powder.

The aims of this thesis were:

(i) To compare different drying processes to produce powder from date fruits (soft, semi-dry, and dry varieties).
(ii) To identify the best conditions for production of the powder and evaluate powder quality.
(iii) To study the sorption of powder during storage.
1.3 Literature Review

The date fruit and the Date palm tree are woven very intricately in Arab Culture (Ismail et al., 2006b). Dates represent a major staple in the diet. They are often consumed as snacks, with tea or coffee and as special servings for guests. Various competitions are held throughout the region in which the dates produced in personal farms are judged for various qualities like sweetness, appearance, taste, texture, etc. The date palm adorns various homes and the streets to give a sense of nationalism and pride. Exchanging dates as gifts during various occasions and making savory snacks from dates is a traditional practice in the region. The average individual date consumption in the UAE was estimated as 114 g per day (Ismail et al., 2006b). There are about a 100 million date palm trees globally of which 90% are in the MENA region (Ghnimi et al., 2017).

The overall development of the date fruit is classified into five stages namely, Hanabauk, Kimri, Khalal, Rutab and Tamr; however, it is only post the Kimri stage that the fruit is edible (Ghnimi et al., 2017). The texture of the fruit could be soft, semidry or dry. The texture is in part dependent on varying moisture content present in the date. At harvest, soft dates usually contain greater than 30% moisture, semi-dry varieties contain 20-30% moisture while dry varieties contain <20% moisture, respectively (Ghnimi et al., 2017). The soft date cultivars usually are richer in invert sugars (glucose and fructose) while the dry varieties have a higher contents of sucrose (Ghnimi et al., 2017). Hence, another way of classifying dates based on the composition of sugars is: i) invert sugar varieties containing glucose and fructose predominantly (e.g. Barhi and Saidi), ii) mixed sugar varieties (e.g. Khadrawy, Halawi), and iii) cane sugar variety containing sucrose as the predominant sugar (e.g.
Deglet Noor) (Ghnimi et al., 2017). Although moisture would play the role of being a primary factor in determining date softness, there could be other factors like date fibre content or physical properties of the date flesh. In a study conducted by Ismail et al. (2006a), it was observed that a high moisture content in the date did not correspond with low shear pressure. The common fibre constituents found in dates include cellulose, hemicellulosic components, lignin, and pectin (George et al., 2020).

For fine grinding of the dates to a powdery consistency, first the dates need to be completely dried. Traditionally in peak summer, the fruits are laid under the sun on a floor covered with palm leaves for drying purposes. The drying is performed at the Tamr stage, as at this stage the fruit is the sweetest and has the lowest moisture content (Ahmed et al., 1995). There is no one ‘golden method’ to decide whether the dates have sufficiently dried. Be it selling, buying or processing the fruit into a date powder, all is based on individual perception, preference and usage.

Different drying methods exist but each method is expected to have its own share of advantages and disadvantages. Oven drying compared to freeze drying has been associated with lower nitric oxide inhibiting capacity besides lower ascorbic acid levels (Abdul-Hamid et al., 2015). Ascorbic acid plays a role of an antioxidant in the body (Lykkesfeldt et al., 2014), while nitric oxide has been associated with diseases like Rheumatoid arthritis (Van't Hof et al., 2000). Thus, the drying method should be chosen wisely keeping the needs of the consumer in mind besides their advantages and disadvantages. A description of different drying methods and their effect on product quality is given below.
1.3.1 Drying Methods

1.3.1.1 Sun Drying

During sun drying, dates are spread out in the open and allowed to dry naturally under the sun (Saikiran et al., 2018). This is one of the cheapest and most natural ways of drying as it does not require any sophisticated equipment for drying. However, during sun drying, various parameters like temperature, humidity, air velocity etc. cannot be controlled and the drying process is highly dependent on the season (Hussain et al., 2014), with summer being the ideal season for drying. It is because of these attributes that neither the quality nor the production timing of the final product can be controlled. For instance, high humidity levels or unexpected rain spells could probably make the dates moist rather than drying them. All these setbacks would eventually translate to inconsistencies in powder production. Compared to fresh dates, it has been observed that sun dried dates have a higher total phenolic content but lower anthocyanin and carotenoid content (Al-Farsi et al., 2005).

1.3.1.2 Solar Drying

Unlike sun drying, solar drying involves the use of some basic equipment which could range from a cabinet to solar panels (Basunia et al., 2010). Solar drying can be classified into four major categories, direct, indirect, hybrid or mixed. Using direct rays of the sun to dry the fruit which is placed in a box or a cabinet is referred to as direct solar drying. If the air heated by the sun is used for drying the dates, the method is referred to as indirect solar drying. Sometimes heat generated thru biomass burning is used for drying besides the heat from the sun. Such a method of drying is referred to as mixed mode or hybrid type of drying (Patil & Gawande, 2016). The time required for drying varies based on the type of solar dryer used. For example, it was reported
that it took 22 hr, 11.5 hr and 2.5 hr to dry Deglet Nour variety of dates in a direct natural convective solar dryer, indirect convective solar dryer and indirect natural solar dryer, respectively (Chouicha et al., 2014). The maximum drying temperature in the indirect and direct solar dryers was reported to be 57 and 69°C, respectively (Chouicha et al., 2014). Each dryer has its own share of advantages and disadvantages, direct sun drying is the most cost effective, but the food placed in the dryer is prone to UV radiation which may act on certain light sensitive vitamins and destroy them. In indirect sun drying, the product would be safe from UV radiations, but the cost of the equipment needs to be borne by the producer. As for the mixed/hybrid method, faster drying times and lower dependency on the sun could be the advantages while fuel dependency could be the major disadvantage (Green & Schwarz, 2001). As mentioned earlier, the stage of the fruit and the varieties/breed would also influence the time taken for drying.

1.3.1.3 Vacuum Drying

In vacuum drying, as the dates would be placed in a vacuum, a difference in pressure is bound to develop and this is expected to force the water from the dates to its surface via diffusion (Dev & Raghavan, 2012). Further, the drying happens in the absence of oxygen and high temperatures are not needed. Thus, the technique allows lower oxidation which is associated lower losses in color, flavor and texture (Punathil & Basak, 2016). A reduction in moisture content from 14% to 6.5% in date flesh was reported using this method (60 - 100°C, 200 mbar vacuum) (Amellal & Benamara, 2008).
1.3.1.4 Convective Oven Drying

In this approach, an oven with an in built fan is used for circulating hot air in a closed chamber for drying the dates (Karam et al., 2016). Heat is transferred to the food material via conduction after which the moisture tends to move from the interior of the material towards the exterior thru diffusion. The moisture then evaporates from the food material via convection (Karam et al., 2016). The size of the dates, the amount of moisture in the fruit, texture, total heat inducted, etc. are factors that could influence the total time for drying. These aspects could also play a role in changing the color of the fruit during convection drying (Benamara & Chekroune, 2009). In a study conducted by Benamara and Chekroune (2009), the optimal drying conditions for 50 g of dates were determined to be 85°C for 60 min. Increasing the drying temperature/drying time unprecedently might char the dates (eventually affecting taste) besides increasing hydroxymethylfurfural (HMF) levels (Kowalski et al., 2013), and stickiness of the powder (Bhandari et al., 1997). Lower drying temperatures are expected to elongate drying times and might not be sufficient to extract moisture from the date - eventually hampering powder flow (İzli, 2017). It was also observed that increasing the temperature decreased the total phenolic content of the dates as well as their antioxidant capacity (İzli, 2017).

An attempt to produce date powder using oven drying was made (Sablani et al., 2008). The date powder was produced by heating dates up to 70°C. Initially, a date puree was prepared using pitted dates to which maltodextrin was added in varying ratios (35:65, 40:60, 45:55 and 50:50 w/w), after which the mixture was placed in the oven for about 18 hours. It was observed that 50:50 ratio of maltodextrin and date paste resulted in the best powder which was non sticky and free flowing. Using higher concentrations
of maltodextrin was associated with higher ‘L’ (lightness) and lower ‘A’ (redness) values on the colour scale besides a decrease in drying time, hygroscopicity and an increase in the glass transition temperature. It was reported that an equal ratio of 50:50 (w/w) resulted in a powder which was free flowing even after storage at room temperature for a year (Sablani et al., 2008).

1.3.1.5 Microwave Drying

Microwaves produce electromagnetic radiations which are absorbed by the polar molecules present in the food item. During the process, these molecules tend to rotate to align themselves to the alternating magnetic field of the microwave causing friction between them, eventually leading to heat being dissipated (Anwar et al., 2011; Vadivambal & Jayas, 2007). The advantage of microwave drying over conventional oven drying is that the heat is directly transferred to the food material (in conventional drying, the environment is first heated and then the heat is transferred to the food material via conduction). Thus, if the food material does not possess good conduction properties as in majority of solid foods, such methods would prolong the drying process (Puligundla et al., 2013). In contrast, microwaves heat the food in a ‘volumetric’ manner, due to which microwave drying is more efficient. In volumetric heating, the moisture in the food material is converted to water vapors, eventually resulting in a pressure gradient that forces the moisture out of the food material. In conventional heating, such a scenario is not observed because the surface shrinks and hardens preventing any further loss of moisture from the food material (Bouraoui et al., 1994; Punathil & Basak, 2016).

It was observed that microwave dried dates had a higher antioxidant content and a shorter drying period compared to convective and freeze drying (İzli, 2017). Drying
using a microwave has its own share of disadvantages too such as ‘scorching’ of food materials especially towards the end of drying (Zhang et al., 2006), uneven distribution of heating (Drouzas et al., 1999), high initial investment of setup and specific shape and size requirements of the food material (dates) for efficient drying (Orsat et al., 2006). Furthermore, the weight of the dates, size, power of the microwave and the total time of drying are all parameters which have shown to influence the color of the date post drying (Benamara & Chekroune, 2009). Comparing various drying methods for dates, the most efficient method was found to be microwave, followed by oven, vacuum and the solar dryer (Elsharnouby et al., 2007).

1.3.1.6 Freeze Drying

In this method, the food material is placed in a specialized chamber in which the temperature is brought to freezing and the pressure is reduced. The combination results in sublimation of the moisture present in the food material (Parikh, 2015). It has been observed that stickiness increases as the temperature increases beyond 10 – 20°C of the glass transition temperature (Adhikari et al., 2005). Hence, in context of dates and their characteristics, reduced temperatures used in freeze drying would prevent an increase beyond glass transition temperatures and thus produce a free flowing powder. Another benefit of freeze drying reported was that freeze dried products tend to have faster rehydration properties compared to other drying techniques (Karam et al., 2016). This characteristic would make it easy for the powder to be dissolved in aqueous media like water or milk. Some of the key disadvantages of freeze drying include high initial costs of setup and prolonged drying time (Ratti, 2001; Thirupathi et al., 2017b). On a comparative note, the total processing time for freeze drying (−50°C, 48 Pa) was noted to be 1800 min versus 16 min needed by microwave (120 W) drying (İzli, 2017).
Freeze drying was also experimented to produce date powder (Thirupathi et al., 2017a), wherein an attempt to reduce the drying time involved introducing a foaming technique. The foam increased the surface area and hence reduced the drying time.

Two foam stabilizing agents were chosen, guar gum and xanthan gum at 0.5, 1, 2% (dry weight basis of date flesh). The dates were de-seeded, soaked in warm water at 50°C for 10 min at 1:1 ratio and were later blended with two carrier agents, maltodextrin and gum arabic at (40-50%) besides the foam stabilizing agents. The mixture was then freeze-dried at 42 Pa, -40°C for 72 hours after which it was grinded to produce a date powder. Maltodextrin constituted powders were reported to have significantly higher water activity, moisture, angle of repose, hausner ratio, carr index and were observed to have larger particles under an electron microscope compared to gum arabic powders. Studies conducted by Thirupathi et al. (2017b) at Kalal, Rutab and the Tamr stage of the fruit showed that the tamr powder had significantly higher hygroscopicity followed by rutab and khalal stage powders. Adding carrier agents maltodextrin and gum arabic was reported to decrease overall caking and increase ‘solubility’.

1.3.1.7 Spray Drying

Spray drying is a technique in which a liquid solution of the product that needs to be dried is sprayed onto a heated drying chamber. The solution upon contact with heat loses water, leaving behind a dried product (Engmann, 2013). Using spray drying to produce date powder is not very feasible due to the stickiness and high sugar content of the dates which can potentially block the nozzle of the spray dryer (Thirupathi et al., 2017b). However, Spray drying as a means for date powder production was
previously attempted by multiple authors (Manickavasagan et al., 2015; Nortuy et al.,
2018; Raza et al., 2019; Thirupathi et al., 2017b).

Despite various approaches available and attempts for producing date powder, there is
still not an ideal approach presently available for optimal production. It is evident that
the dates need to be dried to a degree such that a free-flowing powder could be made.
However, this cannot not come at the cost of extensive heating times as this would
potentially increase HMF levels in the powder besides increasing production costs
(Kowalski et al., 2013). Many authors attempted to produce a free flowing date powder
albeit adding to it various anti-caking agents like maltodextrin, gum arabic
(Manickavasagan et al., 2015), silicon dioxide (Farahnaky et al., 2016), that prevented
clumping or caking of the material. However, adding such anticaking agents dilutes
the claim that the product is ‘100% natural’ which is a major selling point for this
powder. The converse challenge is that a product produced without such anticaking
agents has as yet not allowed production of quality powder. Other factors like change
in consistency of the powder upon moisture absorption due to exposure to surrounding
air also require a detailed study in order to produce a viable product. Increasing the
storage period of bael (Aegle marmelos) fruit powder, was found to increase the
moisture content and bulk and tapped densities of the powder (Sornsomboonsuk et al.,
2019). Moreover, powder solubility, flowability, wettability were reported to decrease
with increased storage period (Chauhan & Patil, 2013). In guava powder, higher
storage temperatures enhanced water activity, glass transition temperature, and caking
(Shishir et al., 2017).
1.3.2 Incorporation of Date Powder in Food Items

Date sugar as a substituent in food products has been studied previously, cane sugar in bread was substituted with date powder, it was observed that the date powder substituted bread increased the nutritional quality of the bread; the protein, crude fiber content increased by 15.2 - 19.4%, 1.6 - 4.4%, respectively depending on the level of substitution (Nwanekezi et al., 2015). In cookies, it was reported that a substitution of date powder in place of cane sugar (upto 50%) was considered to be acceptable in terms of sensory evaluation (Alsenaien et al., 2015). An attempt to produce date chocolate using date powder was also made (Erukainure et al., 2010).

Date powder was incorporated in biscuits (Dhankhar et al., 2019), it was observed that the fibre content increased upon incorporation. The sugar content in the biscuits could be decreased by upto 60% without effecting the sensory qualities. Besides this, the water absorption capacity of the biscuits also decreased (Dhankhar et al., 2019). Date pops (breakfast cereal) produced using date powder enhanced the profiles of flavor and potassium content (Alruqaie & Al Ghamidi, 2013).

1.3.3 Potential Health Benefits of Date Powder

Although no study has been conducted pertaining to the health benefits of date powder, a successfully produced date powder is potentially expected to impart various health benefits. Dates are a rich source of vitamins like C, B1, thiamine, riboflavin, niacin and A (Al-Shahib & Marshall, 2003), in addition to being a rich source of minerals like potassium, calcium, phosphorus, magnesium, iron and manganese (Parvin et al., 2015). They are also a good source of fiber (Al-Farsi & Lee, 2008), and polyphenols that have strong antioxidant properties (Nematallah et al., 2018; Rosenblat et al.,
dates have also been reported to exert anti-inflammatory (El Abed et al., 2018), cardioprotective (Alhaider et al., 2017), neuro protective (Pujari et al., 2014), hepatoprotective and anti-cancerous properties (Al-Sayyed et al., 2014). Thus, date powder too could possibly impart these benefits.

Date powder due to its contents, could also be of great benefit to diabetic patients who could use it as a substitute for cane sugar in tea, coffee, desserts etc. It has been shown that consuming about 50 g dates (7 – 10 pieces) did not result in any significant increase in post prandial glucose levels (Alkaabi et al., 2011). Further, the date powder could also be added to milk/tea/coffee and be given to patients for better wound healing (Hasson et al., 2018). This would give the patients, especially those who are used to consuming dates, a taste which they are familiar with, probably improving their overall food intake. Moreover, because the powder could be dissolved in liquids, it would create ease for patients with swallowing and chewing difficulties to consume.

A successfully produced date powder would also prove useful for health conscious people and sportspersons as dates have shown to provide high energy and carbohydrates but low fats (Sohail et al., 2018). The energy, fiber, fat, protein and mineral content found in date powder was reported to be 311 Kcal, 7.3%, 2.1%, 2.6%, and 2.2%, respectively (Sohail et al., 2018). The fibre content ranges from 5.2 – 18.4% depending on the variety (Elleuch et al., 2008; George et al., 2020). Sportspersons need carbohydrate sources while performing their activity/sport or during training to replenish the energy lost during various activities including training. The high content of potassium could replenish the mineral lost during sweating while the fibre content would prevent constipation (Mao et al., 2001; Parvin et al., 2015).

Thus, conversion of dried dates to powder will be an innovative way to utilize this
nutritionally rich and largely underutilized resource for various purposes supporting health. The use of the powder specially as a substitute for cane sugar has the potential of being rather beneficial for the overall wellbeing of individuals particularly in the Middle East or MENA regions; where dates grow abundantly and where non-communicable chronic metabolic diseases, among which diabetes is prominent, are rampant. Comparative analysis of dates and cane sugar presented earlier, further testify to this premise.

In the first section of this work, different techniques and varieties of dates were evaluated to produce a date powder with good flow properties. The second section dealt with analyzing the various physicochemical properties of the resultant powder. Additionally, a storage study was conducted to analyze the viability of the powder for usage.
Chapter 2: Materials and Methods

2.1 Chemicals and Reagents

Carrez Solution I (Potassium ferrocyanide trihydrate) (15 g/100 ml), Carrez Solution II (Zinc acetate dihydrate) (30 g/100 ml), Folin – Ciocalteu reagent (dilution 1:10), Sodium bicarbonate (60 g/L), Sodium Bisulfite (0.2%), Sodium Chloride, Toluene (Sigma – Aldrich®, St. Louis, USA), Silica for desiccator (Supelco®, Bellefonte, USA), Gallic acid (1 – 100 mg/100 ml distilled water) (EMD millipore®, Burlington, USA).

2.2 Date Fruit Samples

Four varieties of dates i.e. Barhee, Khalas, Sagei, and Sukkari were purchased from a local date market in Dubai, UAE. Two varieties, Barakawi and Gundeila were purchased from a local market in Sudan. Another batch of Sukkari at the Tamr stage was kindly donated by Liwa Factory, Abu Dhabi.

2.3 Sample Preparation

The dates upon arrival to the laboratory were transferred into sealable plastic bags with each plastic bag having about 200 g of dates. The dates were then stored in a freezer at -18 °C until use. Prior to the experiment, the dates were removed from the freezer, equilibrated to room temperature, de-seeded and cut into four longitudinal sections.
2.4 Drying

2.4.1 Drying Using Multiple Techniques

A pilot study was conducted initially to compare different techniques that can be used for drying dates. The Sukkari variety which was used for this purpose was prewashed, dried and exhumated at the factory. About 25 g of dates were weighed, de-seeded, cut into small pieces (about 3 cm in length, 1 cm in breadth) and placed on labelled glass petri dishes (9 cm). They were then subjected to various drying techniques as recorded in Table 1. Moisture loss was measured as difference in weight post drying and a subsequent trend was developed based on heating time. Moisture content and charring were the two main decisive factors kept into perspective while drying.

Table 1: Applied parameters for drying dates

<table>
<thead>
<tr>
<th>Drying technique</th>
<th>Parameter</th>
<th>Drying Period</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze drying</td>
<td>-84°C, 30 Pa</td>
<td>48 hours</td>
<td>(Thirupathi et al., 2017b)</td>
</tr>
<tr>
<td>Vacuum oven</td>
<td>70°C, 450 mmHg</td>
<td>48 hours</td>
<td>(AOAC, 1996)</td>
</tr>
<tr>
<td>Tray drying</td>
<td>70°C</td>
<td>48 hours</td>
<td>(Sablani et al., 2008)</td>
</tr>
<tr>
<td>Convection oven</td>
<td>70°C</td>
<td>50 hours</td>
<td>(Sablani et al., 2008)</td>
</tr>
<tr>
<td>Microwave</td>
<td>150 W</td>
<td>2 min</td>
<td>(Punathil &amp; Basak, 2016)</td>
</tr>
</tbody>
</table>

2.4.2 Drying of Date Varieties Having Different Drying Characteristics

Six varieties of dates: Barhee and Khalas (soft varieties); Sagei and Sukkari (semi-dry varieties); and Barakawi and Gundeila (dry varieties) were used for drying. Samples were placed on glass petri dishes (9 cm). Care was taken to not place a removed petri dish back into the dryer again. This was done so as to cause minimum disturbances to the sample in terms of temperature and moisture loss. About 25 g of date sample was
placed on each petri dish. The petri dishes were then randomly placed in a convective oven dryer, microwave oven for a maximum of 7 days and 6 min, respectively. Two different samples of Barakawi and Sukkari purchased from different markets were also tested for any difference in their drying behaviour in a convection oven. For all samples, analysis was conducted in triplicate. Moisture loss was determined as loss in date weight and a subsequent trend was formed based on time of heating.

2.4.3 Cabinet Drying

Two varieties, one semi dry (Sukkari) and one dry (Barakawi) were dried in a cabinet dryer (18.1 m (length) * 12.7 m (breadth)). About 50 g of sample was placed in a marked circular zone of 18cm for 72 hours. The drying process was performed at 65, 70, 75°C and was continued up to 72 hours. All analysis were done in triplicate. The samples were removed from the dryers based on the random technique.

2.5 Milling and Powder Analysis

The samples were removed from the drying equipment at periodic intervals. Once the samples cooled down, they were ground in industrial level grinders (Galite JLT – 50B®, China) for about 3 minutes. The resultant product was packed in airtight sealable pouches for further analysis of the below mentioned parameters.

2.5.1 Moisture

Moisture in samples was tested using a Bidwell and Sterling trap (Bidwell & Sterling, 1925). About 75 ml toluene was added to 15 g powder and the mixture was heated for 6 hours at 150°C. An emulsion in the form of droplets was sometimes observed in the collecting tube which was broken with the help of a metal wire. As this method was
very time consuming, a Codex Alimentarius procedure which employs a vacuum oven was used to determine the moisture content in the powders (AOAC, 1996). About 5 g of sample was placed in the vacuum oven at 70°C for 6 hours at a pressure of 100 mmHg. Since a discrepancy in moisture content was observed between the readings of the vacuum oven and the trap, a calibration was performed to convert vacuum oven values to actual moisture contents.

2.5.2 Water Activity

Water activity was measured using the HygroLab C1 water activity meter (Rotronic® Bassersdorf, Switzerland).

2.5.3 Total Phenolic Content

To measure the Total Phenolic Content (TPC), about 2 g of date powder was added to 100ml of distilled water and the mixture was centrifuged (Digicen 21®, Orto Alresa, Madrid, Spain) at 350 rpm for 15 min. Subsequently, 200 µL of the supernatant was added to 1.5 ml of Folin Ciocalteou reagent (prepared by a dilution of 1:10) and the mixture was allowed to stand for 5 min. Later, about 1.5 ml of sodium bicarbonate (60 g/L) was further added to the mixture. After about 90 min of storage, the readings were taken using a UV/VIS spectrophotometer at 725 nm. A calibration curve was developed prior using known concentration of gallic acid (1 – 100 mg/100 ml distilled water). Results were expressed as milligram of Gallic Acid Equivalent (GAE) per 100g powder (Thirupathi et al., 2017b). As Folin Ciocalteu is sensitive to light, a cover was placed on the rack containing the mixture. Moreover, the entire experiment was performed in a fume hood with the light switched off.
2.5.4 Hydroxymethylfurfural

Hydroxymethylfurfural (HMF) was measured using the procedure stated by White (1979) with slight modifications. About 3 g of date powder was added to 15 ml of distilled water and mixed thoroughly. Later, 300 µL of Carrez Solution I (Potassium ferrocyanide trihydrate) was added and the solution was mixed again. Subsequently 300 µL of Carrez Solution II (Zinc acetate dihydrate) was added. The solution was then centrifuged (Digicen 21®, Orto Alresa, Madrid, Spain) at 7000 rpm for 15 minutes. About 2 ml of supernatant was taken and again re-centrifuged in a micro centrifuge (Hermle Z 216 MK®, HERMLE Labortechnik GmbH, Wehingen, Germany) at 7000 rpm for 15 min to obtain better clarity of the sample. After centrifugation, in a 96 well plate about 100 µL of the supernatant was added to 100 µL of Sodium bisulfite (0.2%). This acted as the blank as bisulfite is known to destroy HMF. In a subsequent well 100 µL of supernatant was added to 100 µL of distilled water. All chemicals were freshly prepared on the day of the experiment. The readings were taken at 284, 336, 900, 975 nm in a Microplate Spectrophotometer (Multiskan Sky®, Thermo Scientific, Waltham, USA). As the study conducted by White (1979) used a spectrophotometer while a microplate reader was used in this study, the absorption (A) in the spectrophotometer would vary from the microplate reader and hence a pathlength correction needed to be applied. To calculate the pathlength corrected absorbance, a k factor was needed to be determined. The k factor was calculated as per Equation 1 (Fisher, 2015).

\[ k \text{ factor} = A_{975} - A_{900} \]  

(Equation 1)
After the k factor was determined, the corrected absorbance to 1 cm as would be the case in a spectrophotometer was determined by using Equation 2 (Fisher, 2015).

\[
A_{corrected} = A_{raw} \times \frac{k \text{ factor}}{A_{975}(\text{well}) - A_{900}(\text{well})}
\]  
(Equation 2)

The final HMF content was determined using Equation 3 (White, 1979).

\[
HMF_{(mg/100g \text{ sample})} = \frac{(A_{284 \text{ corrected}} - A_{336 \text{ corrected}}) \times 74.87}{\text{Sample weight (g)}}
\]  
(Equation 3)

### 2.5.5 Clumping

The powder was separated into fine and coarse fractions by means of a 400 μm sieve which was placed on a sieving machine (Sieve shaker OASS203, Orto Alresa, Madrid, Spain) at a power of 70% for 15 min. The weight of the powder that passed through the sieve and that was left on it was measured. The degree of clumping was calculated using Equation 4 (Thirupathi et al., 2017b).

\[
\text{Degree of clumping} \% = \left(\frac{\text{Powder mass (g) left on sieve}}{\text{Original mass of powder prior to sieving (g)}}\right) \times 100
\]  
(Equation 4)

### 2.5.6 Solubility

The ‘solubility’ of the resultant fine and coarse powders was measured. About 2 g of powder was added to 25 ml of distilled water and the solution was centrifuged at 7000 rpm for 15 min. The supernatant was drained, and the sediment was dried in an oven at 80°C until constant weight (Thirupathi et al., 2017b). The ‘solubility’ was calculated as per Equation 5 mentioned below.

\[
\text{Solubility} = \frac{\text{Sample weight} - \text{Dried sediment weight}}{\text{Sample weight}} \times 100
\]  
(Equation 5)
2.5.7 Color

The color of the different fine and coarse powders was determined using a colorimeter (ColorFlex EZ®, Hunter Lab, Reston, USA). The parameters of lightness ‘L’, redness/greenness ‘A’, and blueness/yellowness ‘B’ were recorded (Ghnimi et al., 2018). Total color change was determined using Equation 6, where \(L_0, A_0, B_0\) are color values of the date while \(L, A, B\) are values of the powder (Thirupathi et al., 2017b).

\[
Total \ color \ change = \sqrt{[L_0 - L]^2 + [A_0 - A]^2 + [B_0 - B]^2} \quad (\text{Equation 6})
\]

2.5.8 Flowability and Compressibility

The bulk density required for the calculation of Hausner ratio (a measure of flowability of the powder) was evaluated by transferring about 3 g of powder into a 15 ml measuring cylinder. The volume was taken, and the bulk density was calculated using Equation 7 (Thirupathi et al., 2017a).

\[
\text{Bulk density} = \frac{\text{mass of powder (g)}}{\text{volume occupied (cm}^3\text{)}} \quad (\text{Equation 7})
\]

The cylinder was then tapped until constant volume was reached. The tapped density was calculated using Equation 8 (Thirupathi et al., 2017a).

\[
\text{Tapped density} = \frac{\text{mass of powder (g)}}{\text{volume occupied (cm}^3\text{)}} \quad (\text{Equation 8})
\]

The Hausner ratio was calculated using Equation 9 (Thirupathi et al., 2017a).

\[
\text{Hausner ratio} = \frac{\text{Tapped density}}{\text{Bulk density}} \quad (\text{Equation 9})
\]
The Carr index representing ‘compressibility’ was calculated using Equation 10 (Thirupathi et al., 2017a).

\[
\text{Carr index} = \left( \frac{\text{tapped density} - \text{bulk density}}{\text{tapped density}} \right) \times 100 \quad \text{(Equation 10)}
\]

The Hausner Ratio and Carr index was classified based on the criteria recorded by Nortuy et al. (2018). The powder could be classified as Free, Medium, Difficult, Very difficult flowing when the Hausner Ratio and Carr index range from 1.0 – 1.1, 1.1 – 1.25, 1.25 – 1.4, >1.4 and 5 – 15%, 15 – 25%, >25%, respectively.

### 2.5.9 Hygroscopicity

Hygroscopicity of the different fine and coarse powders was determined. About 1 g of powder placed on a petri dish was kept in a desiccator containing a saturated solution of NaCl (relative humidity of about 76%) for about one week. Hygroscopicity was expressed as weight gain/100 gram of powder (Manickavasagan et al., 2015).

### 2.6 Storage Study

Three Sukkari date powder bottles (250 g) were stored in jars (300 ml) at ambient room temperature for a period of 30 days to understand the variation in hardness in the date powder upon exposure to moisture. About 4 g of powder was removed daily from the individual jars (the entire process taking about a minute). The room temperature was measured on a daily basis using a laboratory scale thermometer. The hardness of the powder was analyzed as per the procedure stated by Wang and Zhou (2012) using a CT3 Texture analyzer® (AMETEK Brookfield, Middleborough, USA). A compression cycle was conducted using a cylindrical probe of 6mm and a trigger load
of 6.8 g with a test speed of 0.5 mm/s with a test target distance of 10 mm. The powder was confined into the container while taking the measurement for hardness.

2.7 Statistical Design and Analysis

A table of random number was developed using Microsoft Excel 2016 (Microsoft, Redmond, USA) and accordingly the samples were removed from the drying apparatus i.e Conventional oven and Cabinet dryer. As for microwave drying, the oven plate was divided into three equal portions and based on randomization, the petri dish containing the dates for drying was placed on the respective portion of the microwave plate.

All statistical analysis was performed using the SPSS Software, Version 21®. Tukey’s test was used for post – hoc analysis and results reported as mean ± standard deviation. All graphical representations and plots were made using Microsoft Excel®, 2016. All analysis were conducted in triplicate unless otherwise stated.
Chapter 3: Results and Discussion

3.1 Description of Date Fruits

The dates used in the study, namely Barhi, Khalas, Sukkari (2 batches), Sagai and Barakawi (2 batches) were analyzed for moisture. The results are presented in Table 2. The samples showed varying moisture contents.

<table>
<thead>
<tr>
<th>Date variety</th>
<th>Mean ± SD (n=3 determinations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barhi</td>
<td>19.3 ± 0.7</td>
</tr>
<tr>
<td>Khalas</td>
<td>15.1 ± 1.7</td>
</tr>
<tr>
<td>Sagai</td>
<td>12.8 ± 0.5</td>
</tr>
<tr>
<td>Sukkari - I</td>
<td>17.2 ± 3.3</td>
</tr>
<tr>
<td>Sukkari - II</td>
<td>24.7 ± 0.3</td>
</tr>
<tr>
<td>Barakawi - I</td>
<td>5.0 ± 0.3</td>
</tr>
<tr>
<td>Barakawi - II</td>
<td>13.6 ± 0.4</td>
</tr>
</tbody>
</table>

*Moisture was determined using Bidwell – Sterling trap

The moisture content of Sukkari as per the analysis of this study ranged from 17.2 – 24.7%. Previous studies, reported the moisture content in the same variety to be 15.3%, 21.2 g/100 g, 0.3 kg water/ kg dry matter, respectively (Al Juhaimi et al., 2015; Assirey, 2015; Hassan & Hobani, 2000). As per this study, the moisture content of Sagei was observed to be 12.8%. Other studies have reported 16.2%, 14.5 g/100 g, 0.3 kg water/ kg dry matter, respectively (Al Juhaimi et al., 2015; Assirey, 2015; Hassan & Hobani, 2000). As for Khalas, the observation was 15.1% moisture while studies conducted by others report it to be 26.7 g/100g and 13.4%, respectively (Al Juhaimi et al., 2015; Ismail et al., 2008). Lastly, the observation in this study for Barhi was 19.3% moisture while it was reported to be 26.7 g/100g by Ismail et al. (2008).
As observed from the above mentioned literature and the results, major variations in moisture exist within the same variety. To produce a date powder with comparative ease, a variety/version with the lowest moisture content should be chosen. A close observation to Figure 1 shows that, for low moisture Barakawi (5%), heating at 70°C up to 8 hours resulted in a loss of about 2% moisture with only 3% moisture being left in the date; while for high moisture Barakawi (14%), heating for the same time-period (8 hours) resulted in a moisture loss of about 7%, with about 7% still being left in the date. Undeniably, a powder made from 7% date moisture would be different in terms of physical properties from a powder made from 3% date moisture. The drying of the low moisture Barakawi (5%) could not be pursued further due to premature charring.

As for low moisture Sukkari (17%) (Figure 1), heating in a hot air oven up to 120 min resulted in a loss of about 16% moisture with about 1% moisture still being left in the date, while for high moisture Sukkari (25%), heating for the same time period (120 minutes) resulted in a moisture loss of about 20%, with about 5% still being left in the date. If a powder is made at 120 min, the powder made from 1% date moisture would be different in terms of physical properties from a powder made from 5% date moisture.

However, it is just not the moisture which would play a role in determining how hard the date will become post drying. A study conducted by Ismail et al. (2006a) showed that Khalas and Fard varieties have a higher moisture content compared to the other varieties that they had studied. However, the modulus of elasticity and pitting pressure was not the lowest in Khalas while for Fard the shear pressure was high. This proves that other factors like fibre, enzyme degradation, type of sugar etc could play a role in
determining the texture of the date. If the date does not harden enough despite long heating times and a modest loss of moisture, it could be due to two reasons: either the moisture loss is incomplete, or the physicochemical characteristic/makeup of the date is as such that despite moisture loss, it might remain soft and prove to be useless in producing a powder.

![Graph](image)

**Figure 1**: Weight loss during convection oven drying (70°C) in two different samples of Barakawi and Sukkari
3.2 Correlating Moisture Content of Dates determined by Vacuum Oven and Bidwell Distillation

Due to the presence of a discrepancy between the results of moisture determination from the vacuum oven and the Bidwell & Sterling moisture trap, a correlation was performed between the two (Figure 2). This correlation was used to convert moisture content recorded from the vacuum oven to a ‘true’ moisture content.

![Correlation and Bland-Altman Plot](attachment:image.png)

**Correlation of moisture content in date powder between vacuum oven and Bidwell trap distillation**

\[ y = 2.4324x - 4.9292 \]

\[ R^2 = 0.8974 \]

**Bland-Altman Plot**

- **ULA** = 9.60
- **MD** = 2.55
- **LLA** = -4.50

Figure 2: Correlation and Bland–Altman Plot between Vacuum oven and Bidwell distillation
3.3 Date Fruit Drying Using Multiple Techniques

Attempts to dry Sukkari dates to produce a successful date powder were done using five different techniques namely, freeze drying (-84°C, 0.3 mBar), vacuum drying (70°C, 600 mBar), tray drying (70°C) for about 48 hours, convective oven (70°C) and microwave (150 W) drying for 50 hours and 2 min, respectively. Drying was not continued beyond this because the dates were undergoing charring. The Sukkari variety was used as it is commonly available/consumed in the UAE. Freeze drying was performed previously at 42 Pa (Thirupathi et al., 2017b). The maximum pressure of the available equipment used in this study was 30 Pa. The temperature for oven drying was chosen to be around 70°C as a previous study observed a high temperature exceeding glass transition temperatures hampered powder flow (Sablani et al., 2008). Around 150 W of microwave power was used as preliminary trials showed that increasing the microwave power beyond this was charring the dates substantially. Decreasing the microwave power would increase the drying time, thereby negating the major advantage of this drying technique (Punathil & Basak, 2016).

Freeze drying, vacuum oven and tray drying did not dry the dates in a manner in which a powder could be produced (the dates were still soft). However, this was not the case with the convection oven and microwave drying. As can be observed in Figure 3, Convective oven and microwave oven resulted in moisture loss by about 25%. These results are comparable to the study conducted on Sukkari dates, which were dried using a convective oven and the moisture loss noted on a dry basis was from 31.8 to 9.7 (30.6%) (Al-Awaadh et al., 2015). Date powder produced after microwave drying can be seen in Figure 4.
Figure 3: Weight loss of Sukkari dates in a convection oven at 70°C and Microwave oven at 150W (25g of dates measuring 3*1 cm (length*breadth) placed in glass petri dishes (9cm diameter))

Figure 4: Date powder produced via microwave drying
In this study, when the dates were freeze dried, they did not dry to a level that a powder could be formed, despite keeping them in the dryer for 48 hours. However, Thirupathi et al. (2017a) did attain a successful date powder using this technique. This could probably be due to the foaming performed prior to freeze drying. In this study, only microwave and convection oven dried the dates enough to produce a powder compared to tray, freeze and vacuum drying. Hence only these techniques were singled out for further studies.

3.4 Drying of Varieties Having Different Drying Characteristics

The Moisture loss for the six variety of dates namely Barhi, Khalas (soft), Sagei, Sukkari (semi-dry) and Barakawi, Gundeila (dry) are shown in Figure 5. The dates were placed in a convection oven (70°C) and a microwave oven (150 W), respectively. During convection oven drying, the soft varieties Barhi and Khalas lost around 30% weight while Sukkari, Gundeila and Barakawi lost around 17, 14, 3 and 2% weight, respectively. As for microwave drying, moisture loss in Barhee, Khalas, Sagei, Sukkari, Barakawi and Gundeila was 21, 18, 9, 12, 3, 3%, respectively. Thus, the moisture loss seemed to be inversely related to the initial moisture content of the dates. Only Barhi and Khalas (soft) did not dry enough to produce a powder from both techniques. A minor increase in weight loss post a plateau stage can be explained by formation of carmalization products and their evaporation after a good amount of moisture removal.
In this study, two setbacks of microwave drying were clearly apparent as can be observed in Figure 6. First being charring (Figure 6 (a)) and second being uneven heating (Figure 6 (b)). Low moisture dates like Barakawi and Gundeila resulted in early charring while the dates with a higher moisture content took the longest to char. The problem of charring has been commonly reported in literature as one of the major disadvantages of using a microwave in general (Zhang et al., 2006).
Figure 6: Dates heated in a microwave indicating Charring and Uneven heating, (a) Charring, (b) Uneven heating

3.5 Cabinet Drying

As it took about 7 days in the convection oven to produce a successful powder, hence cabinet drying was used. These dryers are commonly utilized at the industrial scale. One semi dry variety (Sukkari) and one dry variety (Barakawi) were placed in the cabinet dryer at 65, 70 and 75°C up to 72 hours. Drying was not continued beyond this point as it was deemed to be cost ineffective at the industrial level. The powders formed were tested for various parameters as can be observed below. A date powder was only attained after heating up to 24 hours. Prior to that, the dates upon grinding formed a paste.

3.5.1 Moisture

Moisture content is a combined determination of ‘bound’ and ‘free’ water commonly found in foods (Vaclavik & Christian, 2014). In dates, the water molecules bind strongly to the sugar molecules and hence are difficult to extract. As it can be observed in Figure 7, in terms of moisture content for Barakawi, the lowest drying rate in the moisture curve was at 65°C, while the highest was observed at 70°C. The moisture
content decreased from 11% to 3.6, 2.1 and 2.9% at 65, 70 and 75°C, respectively. As for Sukkari (Figure 7), lowest drying rate was observed at 65°C, while the highest was observed at 75°C. No significant difference (p<0.05) was found between the moisture levels at 70 and 75°C in both varieties, except for Sukkari after 8 hours of drying. The moisture content for Sukkari decreased from 17% to 4.8, 3.7, 2.3% at 65, 70 and 75°C, respectively.

![Barakawi moisture loss graph](image)

![Sukkari moisture loss graph](image)

Figure 7: Curves indicating moisture loss in the dates during cabinet drying in Barakawi and Sukkari (Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference)
In this study, the minimum moisture content in the date powder was around 2%. Previous studies reported a minimum date powder moisture content of 3.5% and 1.5%, respectively (Manickavasagan et al., 2015; Nortuy et al., 2018). These studies spray dried a filtered date paste and added anticaking agents. In comparison, the moisture content in this study is quite similar with an added benefit of no clogging, being ‘100%’ natural, and is likely to retain more fibre as it did not involve any filtration step.

As per this study, although the moisture content was not significantly different between 70°C and 75°C, the curve was the lowest at 70°C in Barakawi (Figure 7). During drying at 75°C, it was observed that the exterior of the date hardened while the interior still remained soft, this phenomenon is commonly referred to as ‘case hardening’ (Gulati & Datta, 2015). This should be a factor that is kept into perspective during drying. Just increasing the drying temperatures might not be of benefit to reduce moisture content significantly if the date is prone to undergo case hardening. A similar finding of date moisture being higher at 80°C compared to 70°C was reported by Falade and Abbo (2007). Another study conducted on Jamun (Syzygium cumini) powder reported the same findings (Santhalakshmy et al., 2015). At higher temperatures, where moisture is lost from the surface at a faster rate compared to its interior, the surface enters a glassy state and hardens while the moisture is still trapped inside, resulting in a lower quality powder (Bhandari et al., 1997).

Comparing Barakawi and Sukkari heated for 24 and 72 hours (Figure 8), it can be observed that Barakawi powder has a significantly lower moisture content (p<0.05) compared to Sukkari when the dates were dried at 65 and 70°C for 24 hours. This can be attributed to the initial low moisture content in Barakawi (11%) compared to
Sukkari (17%). However, after 72 hours of drying, no significant difference (p<0.05) was observed between the two varieties. This could probably be attributed to the case hardening Barakawi had undergone.

Figure 8: Curves comparing the moisture content in Barakawi and Sukkari dates after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

3.5.2 Water Activity

Water activity can be defined as the ratio of vapor pressure of water in a solution (Ps) to the vapor pressure of pure water (Vaclavek & Christian, 2014). It is a measure of the ‘free water’ present in a food material. As it can be observed in Figure 9, the water activity of Barakawi powder formed by drying the dates at 65°C was significantly higher (p<0.05) compared to the powder formed at 70 and 75°C. The water activity of the powder at 75°C was intermediate to that of 60 and 70°C. It decreased from 59% to 28.1, 23.1, 28.3% at 65, 70 and 75°C, respectively. This could firstly be attributed to the higher moisture content observed at 75°C in Barakawi due to case hardening.
Secondly, a study conducted by Syamaladevi et al. (2016) showed that water activity increased as temperature increased. This is also in accordance with the guides of FDA (2016). It is possible that high temperatures destroy the makeup of the date and release bound water into free water thereby increasing water activity. A similar result was observed in Sukkari where the water activity was the highest at 65°C while no significant difference was observed between the water activities at 70 and 75°C (Figure 9).

Figure 9: Curves indicating changes in water activity in date during cabinet drying in Barakawi and Sukkari (Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference)
The water activity decreased from 75.5% to 44, 30.2, 32.8% at 65, 70 and 75°C, respectively. Compared to Sukkari (Figure 10), Barakawi generally resulted in a powder with lower water activity. This is rational because of lower initial moisture content of Barakawi compared to Sukkari. Significantly (p<0.05) higher water activity was observed in Sukkari.

![Figure 10: Curves comparing the water activity in Barakawi and Sukkari dates after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)](image)

### 3.5.3 Total Phenolic Content

Phenolic compounds are known for their anti-oxidant, anti-inflammatory, anti-cancer and anti-ageing action (Lin et al., 2016). In Barakawi powder (Figure 11), as drying time increased, the phenolic content increased drastically at 75°C while this was not the case at 65°C. The phenolic content in Barakawi was 11.8, 28, 31 (mg of GAE/100 g powder) at 65, 70 and 75°C, respectively. A similar observation was made in Sukkari (Figure 11). The phenolic content in Sukkari was 6.5, 24.8, 27.3 (mg of GAE/100 g powder) at 65, 70 and 75°C, respectively.
Figure 11: Curves indicating changes in Phenolic Content in dates during cabinet drying in Barakawi and Sukkari (Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference)

An increase in phenolic content with an increase in drying temperature has been observed in dates, apricot and grapes (Carranza-Concha et al., 2012; İzli, 2017; Sultana et al., 2012). The increase could be explained by increased extractability or release of bound phenolic compounds due to heat associated cellular breakdown (e.g. phenolic compounds associated with lignin) besides tannin degradation (George et al., 2020; İzli, 2017). It could also be explained by the formation of phenolic compounds as a byproduct of Maillard reactions (İzli, 2017). On the other hand, Shahdadi et al. (2015)
recorded a decrease in phenolic content as temperature increased. Whether the phenolic content increases or decreases during drying would probably depend on the type and sensitivity of the phenolic compound.

Comparing Barakawi and Sukkari (Figure 12), not much of a difference in terms of phenolic content existed between them, but a general trend of significantly higher (p<0.05) phenolic content after 72 hours of drying compared to 24 hours was observed. This could either be due to the release of phenolics from bound components or a result of higher phenolic concentration in dry matter (İzli, 2017).

Figure 12: Curves comparing phenolic content in Barakawi and Sukkari dates after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

### 3.5.4 Hydroxymethylfurfural

HMF is a compound formed due to dehydration of sugars upon thermal treatment (Capuano & Fogliano, 2011). It is classified as a carcinogen, organotoxic agent and an enzyme inhibitor (Shapla et al., 2018). The major reagents required for formation include fructose or glucose (Kowalski et al., 2013), which are commonly found in
dates (Ramchoun et al., 2017). As can be observed in Figure 13, the HMF content was the highest at 75°C being 104 and 123 (mg/1 kg sample) after 72 hours of drying for Barakawi and Sukkari, respectively. This is in accordance with the study conducted by Ribeiro et al. (2012), where it was observed that the levels of HMF increase as temperature increases. Thus, using high temperatures for drying although might improve moisture loss, it will also increase HMF content.

Figure 13: Curves indicating changes in HMF Content in dates during cabinet drying in Barakawi and Sukkari (Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference)
A very high HMF content would nullify the sole purpose of marketing the date powder as a healthy alternative to cane sugar. Certain international standards exist to determine the minimum acceptable values of HMF. Although to the best of my knowledge, no standard limit exists for food powders, as per FAO (2000), the HMF content in honey should not be more than 80 mg/kg. Demands to decrease the levels to 60 and 40 mg/kg have also been made. In this study the HMF content after 72 hours of drying at 75°C in Barakawi and Sukkari was 104 and 123 mg/kg, respectively (Figure 13). This is considerably higher than the acceptable limit. However, considering heating for the same time period i.e. 72 hours at 70°C, the HMF content becomes lower to about 27.8, 34.4 mg/kg, respectively. This falls into the acceptable limit and is much lower than the range found at 75°C.

Although the drying parameters could be held constant to manage HMF levels in the date powder, a huge deal of variation could possibly arise in the HMF content of the final product if the type of date used is not kept constant. This is because the fructose content varies considerably from one variety to another (Ramchoun et al., 2017), it also varies based on the stage of ripening (Ahmed et al., 1995). The date with a higher fructose content is expected to produce a higher HMF during a specific period of drying time compared to a date with lower fructose content (Göğüş et al., 1998). Thus, the drying temperature, time, stage of ripening, type of variety, variation within varieties are important parameters that are needed to be kept into perspective to produce a date powder with consistent quality.

Comparing the two varieties (Figure 14), it can be observed that the HMF content did not vary much in between varieties especially at 65 and 70°C. However, at 75°C the HMF content was significantly higher (p<0.05) in Sukkari compared to Barakawi.
Moreover, at 75°C, increasing the drying time (72 hours) was associated with an increase in HMF content albeit insignificantly (p>0.05). Such an effect was not observed to that degree at 65 and 70°C. This observation was expected as HMF production is commonly associated with longer heating times and high temperatures (Kowalski et al., 2013). This further concretes the need to devise better drying techniques whereupon a powder could be produced at lower temperatures with short durations of drying.

![Figure 14](image)

**Figure 14**: Curves comparing HMF content in Barakawi and Sukkari dates after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

### 3.5.5 Clumping

Clumping/Agglomeration is caused by inter particle sticking which could be due to various forces acting between particles. As date are rich in sugars, clumping is a major challenge (Chen & Özkan, 2007). Clumping is not limited to moisture alone, there could be various reasons for clumping like low melting point of sugars, their low glass transition temperatures, high hygroscopicity besides an increase in ‘solubility’ of
sugars with temperature (Bhandari et al., 1997). A clumped mass with no flow cannot be classified as a good powder, hence this characteristic was measured to better evaluate quality. A powder was attained only after drying for up to 24 hours.

In Barakawi (Figure 15), clumping was lower at 70°C, while it was the highest at 65°C (p<0.05). The clumping at 75°C was intermediate to that of 65 and 70°C. The degree of clumping at 65, 70, 75°C was 79.9, 36.9 and 40.6%, respectively. One would expect lower clumping at 75°C compared to 70°C. However, in this study no significant difference in clumping (p<0.05) between the two temperatures was observed. This is understandable because the water activity at 75°C was not lower than that of 70°C (case hardening, bound water release at 75°C) (Figure 9). Another reason for not observing lower degree of clumping at 75°C is possibly the effect of temperature on sugars present in the dates; the ‘solubility’ of the reducing sugars present in dates (glucose and fructose) would have increased with increasing drying temperature (75°C). Moreover, the sugars would have transformed from the glassy state to a rubbery state once the glass transition temperature exceeded, overall encouraging clumping (Bhandari et al., 1997).

As for the Sukkari powder (Figure 15), similar results to Barakawi were observed where clumping was highest at 65°C, while there was no significant difference (p<0.05) in clumping between 70 and 75°C. The degree of clumping in Sukkari at 65, 70, 75°C was 77.8, 51.2 and 48.2%, respectively. This is understandable as no significant difference in water activity was observed between 70 and 75°C (Figure 9), hence there seems to be no significant difference in clumping too. A previous report suggests a good association between water activity and clumping (Fontana, 2000).
Figure 15: Curves indicating changes in clumping in date powder during cabinet drying Barakawi and Sukkari (Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference)

Comparing Barakawi and Sukkari (Figure 16), no significant difference (p<0.05) exists between them. One evident observation is that higher clumping was significantly associated (p<0.05) with shorter drying times (24 hours) in both varieties.
Figure 16: Curves comparing clumping in Barakawi and Sukkari dates after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

In the subsequent parameters, an additional comparison between fine and coarse powder formed after 24 and 72 hours of drying has been made. The yield of a fine powder was very low at 24 hours of drying at 65°C. Hence powder produced at this parameter has not been considered for comparison between fine and coarse. A powder could only be formed after 24 hours of drying. Prior to 24 hours, the dates upon grinding resulted in the formation of a paste rather than a powder.

3.5.6 Solubility

The ‘solubility’ of a powder is of utmost importance to put it into any practical use. If the product is soluble, only then could it be incorporated into various food products like milk, flavored coffee, yoghurts etc. In this study, ‘solubility’ was determined as the ability of 2 g of date powder to be dissolved in 25 ml of distilled water stored at room temperature. The sedimented powder was considered as ‘insoluble’ while the powder dispersed in water was considered as ‘soluble’.
No significant difference (p<0.05) in ‘solubility’ based on temperature of drying was observed in the Barakawi powder formed after 24 and 72 hours (Figure not shown). As for the Sukkari powder, significantly (p<0.05) higher ‘solubility’ was observed in the powder at 75°C compared to 65 and 70°C (Figure not shown).

Comparing fine and coarse powders, the finer version of Barakawi powder (Figure 17), seemed to be more significantly soluble after 24 hours of drying at 70 and 75°C. No significant difference between the two versions was observed after 72 hours of drying except at 65°C. As for Sukkari (Figure 17), no significant difference was observed between fine and coarse powders except at 75°C, where ‘solubility’ was significantly higher for the finer version of the powder. The overall ‘solubility’ for the coarse Barakawi and Sukkari powders was around 65 – 75%. Fine Barakawi powder ‘solubility’ ranged from 77 – 82% while the ‘solubility’ of the fine Sukkari powder ranged from 71 – 82%. These results are in accordance with the study conducted by Manickavasagan et al. (2015), where the ‘solubility’ index ranged from 66 to 88.6% for the date powder. It was expected that finer particles would be more soluble compared to their coarser counterparts due to a smaller surface area, however this may always not be the case. Finer particles due to lower weight are more prone to floating in the liquid media and not getting wet while coarser particles would sink and dissolve faster (Goula & Adamopoulos, 2005). The phenomenon of floating of the date powder was observed in this study. Probably using a large sieve during separation would result in greater particle size and higher dissolution. The ‘solubility’ of the powder is expected to vary based on the fibre content of the date besides the stage of ripening, with Tamr stage powders being more soluble than Rutab and Khalal stages (Thirupathi et al., 2017b). Comparing Barakawi and Sukkari (Figure 18), major difference in terms of ‘solubility’ cannot be observed.
Figure 17: Difference in ‘solubility’ between fine and coarse date powder in Barakawi and Sukkari (p<0.05) (Statistical analysis compares observations between fine and coarse versions of the powder at constant and different drying intervals. Different letters indicate significant (p<0.05) difference. Fine powder was not formed at 65°C after 24 hrs of drying)
3.5.7 Colour

It is just not the taste of the food which plays a valuable role in satiety, growing evidence of research has shown that the visual cues one gets from the food also play a major role in consumption (Spence et al., 2016). Good colour is one of the many visual cues a food can have.

The lightness of the resultant date powder considerably decreased especially at 70 and 75°C both in Barakawi and Sukkari powders while it showed an increasing trend when the dates were heated at 65°C in both varieties (Figure not shown). The decrease in lightness at 70 and 75°C is in accordance with the study conducted by İzli (2017), where increasing the temperature was associated with a decrease in lightness. This could probably be due to Maillard reaction and carmalization which ensue during heating (Al-Abid et al., 2006). The melanoidins formed during the Maillard process are associated with increasing ‘browness’ and thereby decreasing lightness (Chandra...
et al., 2008). The redness of the powders (A parameter) insignificantly increased with temperature (Figure not shown).

Comparing fine and coarse powders, the finer versions of both the powders consistently were significantly (p<0.05) lighter compared to their coarse counterparts (Figure 19).

Figure 19: Difference in lightness (L parameter) between fine and coarse date powder in Barakawi and Sukkari (Statistical analysis compares observations between fine and coarse versions of the powder at constant and different drying intervals. Different letters indicate significant (p<0.05) difference. Fine powder was not formed at 65°C after 24 hrs of drying)
Comparing the two varieties, it was observed that a significant difference (p<0.05) in lightness (L parameter) did not exist between the two varieties after 24, 72 hours of drying at 70°C (Figure 20). However, increasing the drying time (72 hours) was significantly associated (p<0.05) with lower lightness levels at 70 and 75°C.

The total colour change after the completion of the drying process (72 hours) in Barakawi ranged from 2.61 – 12.73, 5.09 – 11.61 for coarse and fine powders, respectively. In Sukkari, the total colour change ranged from 11.38 – 22.39, 7.09 – 15.61 in the coarse and fine powders, respectively.

Figure 20: Curves comparing Lightness (L parameter) in coarse Barakawi and Sukkari date powders after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

An ideal colour for the date powder would vary on an individual basis. There lies a probability that lighter powder could be regarded as a powder with additives while a darker one because of its closeness in color to the date be regarded as natural. As per this study, since the finer version of the powders were lighter than their coarser
counterparts (Figure 19), perhaps keeping the powder in a mixed form and not separating it based on size would result in neutrality in terms of perception.

### 3.5.8 Flowability and Compressibility

Good flowability is a characteristic of any powder. A powder with low flowability could hamper production by resulting in low outputs and potentially clog the machines too. As for compressibility, high compressibility would not be a desired characteristic of a powder as this would hamper flow. The flowability and compressibility of the powder was calculated using the Hausner Ratio and Carr Index, respectively. The variation in Hausner ratio with time and temperature of heating in coarse Barakawi and Sukkari powders can be observed in Table 3.

Considering a drying period of 24 hours, increasing temperature from 65 to 75°C significantly improved flow (p<0.05) of coarse Barakawi powder (Table 3). There was an improvement in its fine counterpart too. As for Sukkari (Table 3), increasing temperature from 65 to 75°C after 72 hours of drying significantly (p<0.05) improved flow properties of coarse powder. No significant improvement (p<0.05) due to an increase in temperature was noticed in its finer version.

The discrepancy in flow properties of Barakawi and Sukkari upon increasing temperatures, could probably be attributed to the difference in their sugar compositions. It was observed that variations in the quantity of fructose, sucrose and glucose has an impact on the co-melting behaviour of associated sugars (Wang et al., 2019). In Sukkari, It is probable that increasing temperatures lead to comelting, promoting inter particle liquid bridge development which eventually lead to resistance of flow (Foster et al., 2006).
Table 3: Flowability, Compressibility classification of Barakawi, Sukkari date powders produced at various temperatures and time intervals of drying

<table>
<thead>
<tr>
<th>Temp</th>
<th>Fine/coarse</th>
<th>Time</th>
<th>Hausner Ratio</th>
<th>Classification</th>
<th>Carr Index</th>
<th>Classification</th>
<th>Hausner Ratio</th>
<th>Classification</th>
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</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>Coarse</td>
<td>4</td>
<td>1.11±0.01a</td>
<td>Medium</td>
<td>9.70±0.52a</td>
<td>Excellent</td>
<td>1.26±0.01a</td>
<td>Difficult</td>
<td>20.35±0.61a</td>
<td>Medium</td>
</tr>
<tr>
<td>75</td>
<td>Coarse</td>
<td>8</td>
<td>1.09±0.01a</td>
<td>Free</td>
<td>8.47±0.56a</td>
<td>Excellent</td>
<td>1.11±0.01b</td>
<td>Medium</td>
<td>10.07±1.01b</td>
<td>Excellent</td>
</tr>
<tr>
<td>75</td>
<td>Coarse</td>
<td>24</td>
<td>1.07±0.01a</td>
<td>Free</td>
<td>6.55±0.52a</td>
<td>Excellent</td>
<td>1.09±0.01a</td>
<td>Free</td>
<td>7.94±0.69a</td>
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<tr>
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<td>72</td>
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<td>Medium</td>
<td>11.84±1.14a</td>
<td>Excellent</td>
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<td>Medium</td>
<td>10.07±1.01b</td>
<td>Excellent</td>
</tr>
<tr>
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<td>Coarse</td>
<td>4</td>
<td>1.11±0.01a</td>
<td>Medium</td>
<td>10.07±1.01a</td>
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<td>Free</td>
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<td>Free</td>
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<td>Medium</td>
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<td>Excellent</td>
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<td>Medium</td>
<td>19.39±1.05a</td>
<td>Medium</td>
</tr>
<tr>
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<td>1.31±0.05a</td>
<td>Difficult</td>
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<td>Medium</td>
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<td>Difficult</td>
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<td>Medium</td>
<td>19.39±1.05a</td>
<td>Medium</td>
</tr>
<tr>
<td>70</td>
<td>Fine</td>
<td>72</td>
<td>1.43±0.03a</td>
<td>Difficult</td>
<td>30.04±1.27b</td>
<td>Poor</td>
<td>1.26±0.02a</td>
<td>Difficult</td>
<td>20.74±1.28a</td>
<td>Medium</td>
</tr>
<tr>
<td>65</td>
<td>Fine</td>
<td>72</td>
<td>1.49±0.04a</td>
<td>Very Difficult</td>
<td>32.66±1.58b</td>
<td>Poor</td>
<td>1.30±0.00a</td>
<td>Difficult</td>
<td>23.08±0.00a</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Statistical analysis compares observations made at different temperatures at constant drying time. Different letters indicate significant (p<0.05) difference.
In both Barakawi and Sukkari powders produced after 24 and 72 hours of drying, the finer versions of the powder were more ‘difficult flowing’ compared to their coarser counterparts (Figure 21). This could be because the finer versions had a higher compressibility (Carr Index) compared to their coarser counterparts (Figure 22). The flow of a powder depends on various factors like gravity, friction, cohesion, adhesion besides particle shape and size (Dhanalakshmi et al., 2011). There are various forces like Van der Waals and molecular forces besides liquid and solid bridges; which act as attractive forces between particles and these could hamper flowability (Dhanalakshmi et al., 2011). In this study, the flowability being lower for fine particles is understandable because the fine particles can pack more efficiently and under usual circumstances, the forces of cohesion and adhesion are stronger in fine particles compared to their coarser versions (Chen & Özkan, 2007). The fine powders in this study as per the Hausner Ratio classification ranged from ‘very difficult flow’ to ‘medium flow’ in Barakawi and ‘difficult flow’ to ‘medium flow’ in Sukkari, respectively (Table 3).

To maintain good flow of the powder, excellent packaging needs to be done in airtight pouches/container. Measures like reducing the serving size can be taken so that once a sachet of date powder is opened, a need to store the leftover does not exist.
Figure 21: Difference in flowability between fine and coarse date powder in Barakawi and Sukkari (Statistical analysis compares observations between fine and coarse versions of the powder at constant and different drying intervals. Different letters indicate significant (p<0.05) difference. Fine powder was not formed at 65°C after 24 hrs of drying.)
Figure 22: Difference in compressibility between fine and coarse date powder in Barakawi and Sukkari (Statistical analysis compares observations between fine and coarse versions of the powder at constant and different drying intervals. Different letters indicate significant (p<0.05) difference. Fine powder was not formed at 65°C after 24 hrs of drying)

3.5.9 Hygroscopicity

The ability of the food material to absorb moisture from the environment could be defined as hygroscopicity (Thirupathi et al., 2017b). A powder with high hygroscopicity would not be deemed as suitable because it would cake and harden
making it inappropriate to be put to any use. The hygroscopicity in this study was determined to be the ‘g’ of water absorbed per 100 g of powder.

The hygroscopicity of the coarse powders produced at 75°C was significantly (p<0.05) higher compared to powders from 65 and 70°C (Figure not shown). This was the case in the powders from both the varieties, which is in accordance with previous results (Sablani et al., 2008; Thirupathi et al., 2017b). This is understandable because at 20°C above glass transition temperature, the sugars tend to change from a glassy to a rubber state (Foster et al., 2006). Moreover, with an increase in temperature, the ‘solubility’ of sugars also increases (Bhandari et al., 1997) and the number of moisture binding sites are expected to become more available due to texture degradation (Ribeiro et al., 2016). These factors could act as vehicles for increasing hygroscopicity (Manickavasagan et al., 2015). The hygroscopicity values for Barakawi and Sukkari ranged from 19 – 25 and 8 – 17 g of water/100 g of powder based on the temperature of drying, respectively. Manickavasagan et al. (2015) and Thirupathi et al. (2017b) reported hygroscopicity levels of 0.03 – 0.08 (MD and GA substituted) and 0.16 – 0.18 g of water/g of powder, respectively. These values are pretty close to this study. The variations could probably be linked to the addition of the anticaking agents, variations in variety, method of drying besides the stage of ripening (Thirupathi et al., 2017b).

The finer versions majoritarily showed significantly higher hygroscopicity compared to the coarser versions in both varieties (Figure 23). This could be because, the surface area of fine particles is greater than the coarse, hence encouraging more moisture absorption in the finer version compared to its coarser counterparts.
Comparing Barakawi and Sukkari (Figure 24), it was observed that Barakawi consistently had significantly higher hygroscopicity (p<0.05) than Sukkari at all temperatures. This variation could probably be ascertained to the lower moisture content in Barakawi compared to Sukkari (Section 3.3.1). A high moisture gradient between Barakawi and air compared to Sukkari would probably be the reason for
higher moisture absorption capability (Ferrari et al., 2012). Moreover, hygroscopicity would also depend on the quantity and structural arrangements of sugars and fibres within the fruit.

Figure 24: Curves comparing Hygroscopicity in coarse Barakawi and Sukkari date powders after drying for 24 and 72 hours, respectively (Statistical analysis compares observations between two date varieties and drying times. Different letters indicate significant (p<0.05) difference)

3.6 Storage Study

A storage study was performed using Sukkari powder. Storage studies are of utmost importance to understand the behavior of the food material. As dates are very hygroscopic in nature due to their high sugar content, the utmost concern about the powder is its predisposition to harden upon exposure to the environment. Hence about 4 g of powder were removed every day within a span of a minute so as to mimic everyday home use. Opening it for such short periods of time increased the moisture content from 2% to 8%. This drastic increase within such a short storage time further testifies to the challenge regarding the storage of date powder.
The change in hardness of the powder upon storage for a month was also measured (Figure 25). The increase in hardness of the powder followed a linear trend in the first 17 days after which the curve started to flatten. The decrease in flowability could be assessed by observing Figure 26, where the indentions of the cylindrical probe can be observed in the powder. A good flowing powder would not have allowed an indentation to form. The increased cohesion of individual date particles upon moisture exposure might have contributed to increase in hardness. Probably if the date powder could be stored at temperatures below glass transition like in a fridge at 4°C, it could have reduced the progression of hardness (Bhandari et al., 1997).

Moreover, packing the date powder in materials which do not let in moisture and reducing serving sizes, such that a fresh packet, could be opened on every use are options that should be considered by producers.

Figure 25: Variation in hardness (g) in Sukkari date powder upon storage
Figure 26: Indentations of the cylindrical probe on the date powder after storage for 30 days
Chapter 4: Conclusions

4.1 Summary of the Results

Date powder, due to its soluble sugars, fibre, polyphenols, vitamin, and mineral content could provide a healthier substitute to cane sugar and other artificial sweeteners present in the market today. This project aimed to reduce the moisture content of dates by drying so that a date powder can be produced. In this study, vacuum freeze dryer (-84°C), tray dryer (80°C), and vacuum oven were not suitable for drying, while hot air oven (70°C) and microwave oven (150 W) were able to dry the dates enough to produce a date powder. While the dry (Barakawi and Gundeila) and semidry (Sagei and Sukkari) varieties dried in the microwave and hot air oven, the soft varieties (Barhi and Khalas) were not able to produce a powder. It was observed that variations in moisture content exist within the same variety, thus the initial moisture content of the date needs to be kept into perspective prior to drying. In a cabinet dryer, drying at 65°C resulted in a very low yield (high clumping) of a good quality powder while drying up to 75°C was associated with case hardening, lower colour, higher HMF and higher hygroscopicity. Thus, drying at 70°C for 24 - 72 hours was deemed as the most appropriate. Finer versions of the powder were significantly lighter in color but had lower flowability and higher hygroscopicity compared to the coarser version. Using the powder on a daily basis was associated with an increase in hardness levels due to moisture absorption.

4.2 Research Implications

The initial part of the study was aimed at identifying best techniques to produce date powder. The aim was to find one fixed method, which could be deployed to dry and
convert any variety of dates into a powder. However, it was apparent that a standard technique was not applicable for all date varieties. It was also observed that discrepancies were present in outcomes even within the same variety of dates, due to a difference in moisture levels. Using a specific variety of dates with confirmed low initial moisture content was identified as the best approach for successfully producing a date powder.

Prior to the study, based on available literature, it was assumed that an increase in drying temperature would increase the HMF content of dates, and reduce the moisture and phenolic quotient. However, the study found inconsistency in this assumption; while an increase in HMF content was noticed, higher temperature hardened the outer covering layer of the date, preventing the release of moisture and producing a low quality powder.

As production of date powder entails huge amounts of dates for each variety, any fruit wastage is bound to be minimal. Moreover, surge in demand for date powder would inspire and incentivize the farming community to boost date farming, thereby adding to their earnings and eliminating storage costs. On a positive note, converting dry dates into date powder and utilizing it for nutritional purposes will be a major step towards reduction of significant wastage that is presently considered as routine. On one hand this will be a source of revenue for dates that are otherwise thrown away, and on the other hand the date powder could be an excellent nutritional supplement with various beneficial health effects. The possibility of using the powder in regions of the world that are nutritionally deficient is also an attractive opportunity.

This study is a launchpad for both academia and date palm growers to work together so as to improve and optimize the utilization of date fruit. Henceforth, the industry can
diversify into producing date powder, cubes and tablets and other allied by-products. The date powder could be added to confectionary items and sold in the form of small sachets to have with tea/coffee. Since dates and its products are part and parcel of Arab culture, the date powder added food items would reflect the culture and heritage of the country and bring ‘originality’ to foods in terms of taste and flavour. Tourists might get attracted to these products, provided they are appropriately packaged, properly marketed, and their health benefits are highlighted in the process.

Backed by inexorable technological advancement, newer avenues ought to be explored to see how date products can be developed further to meet the requirements of the market.

**4.3 Managerial Implications**

Any research to understand the overall value and benefits of date powder, obviously, calls for a range of studies and analysis, because present literature on creation of date powder from dried dates is sparse. From a food engineering perspective, little is known about the methods of powder production, its characteristics, processing, packaging and subsequent utilization as a meal substitute or a sweetener. Hence, a variety of studies are needed in the future to understand the underlying processes of date powder production and transitioning it into a usable commercial product. Packaging, shelf-life and temperature/humidity conditions etc. are additional aspects in which research is needed. From a classical food science perspective, a very important and interesting future prospect, is a comparative study on the sweetness quotient between cane sugar and date powder. Furthermore, the sensory analyses component needs to be explored in detail as this aspect will be critical from a sales perspective of products using date powder. Additionally, studies can be undertaken to assess the ‘solubility’,
disintegration time, wetness span and nutritional value of the date powder. Converting the powder into tablets/cubes and using them as sweetener additives to tea, coffee, milk etc. also needs to be understood. Furthermore, developing an ideal concoction of date powder with chocolate, wafer or fruit needs to be explored for creating candies and similar products for children and adults. Studies can also be launched in the future to assess other factors like chewiness, gumminess, adhesiveness and hardness to help better understand the palatability of the ensuing products.

From a ‘nutrition’ viewpoint, dates are traditionally considered to have several health benefits. Yet, the paucity of literature to support these value propositions lends credence to initiating studies; where date powder could also be tested for its ability to serve as a neuroprotective, hepatoprotective, and cardioprotective agent. Concurrently, its effects on glycaemic load and obesity can also be evaluated.

Thus, as a result of this work many other avenues need to be carefully assessed and their potential evaluated. The sweetness, rich nutritious content and likely health benefits, all point to strong future prospects.
References


İzli, G. (2017). Total phenolics, antioxidant capacity, colour and drying characteristics of date fruit dried with different methods. Ciência e Tecnologia de Alimentos, 37(1), 139-147.


Appendix

Summary Flowchart of experiment

**Step I:** Analyse best drying technique to produce date powder (Sukkari variety)

- **Freeze dryer** (-84°C, 0.3 mBar, 48 hrs)
  - Dates not dried
  - Method discontinued

- **Vacuum oven** (70°C, 450 mmHg, 48 hrs)
  - Dates not dried
  - Method discontinued

- **Tray dryer** (70°C, 48 hrs)
  - Dates not dried
  - Method discontinued

- **Convection oven** (70°C, 48 hrs)
  - Powder
  - Method continued in Step II

- **Microwave oven** (150W, 2 min)
  - Powder
  - Method continued in Step II

**Step II:** Analyse best variety

<table>
<thead>
<tr>
<th>Type</th>
<th>Variety</th>
<th>Convection oven</th>
<th>Microwave oven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>Barhi, Khalas</td>
<td>Dates not dried</td>
<td>Dates not dried</td>
</tr>
<tr>
<td>Semidry</td>
<td>Sukkari, Sagei</td>
<td>Powder</td>
<td>Slight charring</td>
</tr>
<tr>
<td>Dry</td>
<td>Barakawi, Gundeila</td>
<td>Powder</td>
<td>Complete charring</td>
</tr>
</tbody>
</table>

Chosen for Cabinet drying*

Method discontinued
Step III: Cabinet drying (Sukkari and Barakawi variety)

65°C  70°C  75°C

Moisture, Water activity, Phenolic content, HMF, Clumping, Solubility, Colour, Compressibility, Flowability, Hygroscopicity

Step IV: Storage study

*Cabinet drying uses the same principle as convection oven, it is used at industrial scale, hence was used in the experiment.