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(RESEARCH ARTICLE)

Effect of temperature on drying kinetics, physico-chemical properties and antioxidant activity of cabinet dried whole jujubes

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Abstract

The most effective method of preserving fruits is to produce dried ones, which extends their shelf life. The drying properties, physicochemical parameters, total phenolic compounds, antioxidant capability, and vitamin C quantity of fresh and cabinet-dried jujubes at 45°C, 55°C, and 65°C were all investigated in this study. The findings revealed that the drying temperature had a substantial influence on jujube drying. The drying time decreases but the drying rate elevates as the temperature rises. Moreover, the optimal percentage of free moisture was achieved at 65°C. The sample dried at 65°C exhibited superior color characteristics relative to the other dry samples. The greatest loss of vitamin C transpired at 65°C due to increased enzymatic and nonenzymatic degradation. The drying temperature greatly inhibited TPC and antioxidant activity. Sample dried at 45^0 C contained higher amount of TPC (10.82±2.16 mg GAE/g DM), TFC (4.03±2.6 mg QE/g DM) and also showed higher antioxidant activity (IC_{50} 74.47±1.9 µg/mL) than the other dried samples at 55°C and 65°C, where TPC (7.10±1.8 and 5.44±1.18 mg GAE/g DM), TFC (3.20±1.7 and 2.95±1.4 mg QE/g DM) and IC_{50} Values (104.02±1.3 and 133.14±1.6 µg/mL), respectively. While the sample dried at 45°C exhibited superior nutritional characteristics, the sample dried at 65°C was deemed the most appropriate temperature for drying entire jujubes based on other critical criteria, including color change, drying time, and drying rate.

Keywords: Drying Kinetics; Color; Drying Time; Antioxidant Activity; Vitamin C.

1. Introduction

Jujube (*Ziziphus mauritiana*) is a species of Rhamnaceae familly. It is known as Asian jujube or jujube. It can endure a broad spectrum of temperatures and is predominantly found in subtropical regions of Asia, particularly growing in Bangladesh, India, Pakistan, Nepal, Korea, and Southern China [1]. Jujubes, often referred to as Kul or Borai, are widely known and famous fruits. Jujube possesses many nomenclatures based on the cultivation area and/or usage. After the drying process, they are known as "Chinese Dates," "Tsao," or red dates in China. Iran and India name it "ber," while Arabian countries call it "Sedra," and the edible fruit is called "Nbeg" or "Ennab" [2]. There some popular varieties of kul are cultivated in Bangladesh namely Apple kul, BAU kul (Bangladesh Agriculture University Kul), Comilakul, Narikeli kul, Thai kul, Deshi kul, BARI-I, BARI-II kul etc. [3]. According to BBS (2023)[4] total jujube production in Bangladesh was 96844.29 metric tonnes. According to Tanvir et al. (2014) [5], jujube is a great source of bioactive constituents that help treat a number of illnesses and ailments, such as liver disease, chronic bronchitis, allergies, constipation, depression, and sleeplessness. According to Li et al. (2021), Gowd et al. (2020), Xu et al. (2019), Feng et al. (2019), Shishir et al. (2019)[6,7,8,9,10], and others, it also has antiproliferative, anti-inflammatory, antioxidant, antiobesity, antitumor, cardiovascular protective, hepatoprotective, antidiabetic, antimicrobial, and anticancer effects. Jujube has also been used as a basic meal and/or conventional medicine for a very long time. The roots, stems, leaves, blossoms,

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and fruits of the jujube plant are all used as medicinal ingredients [11,12]. The main component is the fruit (pulp with peel), that can be eaten as freshly squeezed jujube pulp or used to make a multi-product of foods, such as drinks, pickles, jams, jellies, liquor (mentioned brodo di giuggiole in Italy and baijiu in China), and compotes [1,13]. The desiccated pulp can serve as an active component in the food industry, including dried items such as Chinese dates, tea ingredients, snack slices, bread, and cakes. Additionally, it can be added to a variety of foods and goods to improve their quality and nutritional value (e.g., goat milk yogurt, red jujube yogurt, etc.) [1,2,9,14]. Therefore, jujube fruit might be an excellent component for functional food products that offer substantial health benefits, consumer acceptance, and cost-effective viability. Jujube fruits cannot be kept for more than ten days in an uncontrolled atmosphere and have a limited shelf life. According to Raswan et al. (2020)[15], producing a dried product out of jujube is therefore one of the greatest ways to preserve it for a longer amount of time.

A common system for the long-term preservation of food and agricultural products is drying. Drying minimizes the risk of spoiling during storage, expedites processing, lowers transportation costs, and brings water activity down to a safe level. Food goods are preserved using a variety of drying methods, including vacuum, spray, natural air, freeze-drying, and hot air cabinet drying. Conventional methods of drying jujube include air and natural sun drying. Because hot air drying is not affected by the weather, it shortens the drying cycle, enhances the dried product's quality, and raises hygienic standards [16]. The selection of hot drying parameters, specifically air temperature and flow rate, should be based on the desired quality of the finished product [17]. Overall, cabinet drying is a more precise, hygienic, and efficient method for preserving fruits compared to traditional methods like sun or air drying. The macroscopic and microscopic combination mechanisms controlling heat and mass transfer during the drying process are frequently explained by drying kinetics. Drying circumstances, dryer types, and the properties of the materials being dried all have an impact on the drying kinetics.

However, hot air drying by cabinet dryer can be a better option regarding this phenomenon and can replace sun drying to shorten drying time. Using a cabinet dryer, the study's goal was to evaluate the drying kinetics, physicochemical characteristics, color characteristics, and antioxidant activity of dried jujube in order to develop standard preservation parameters that could increase shelf life and reduce post-harvest losses of jujube.

2. Materials and methods

2.1. Chemicals and reagents

We purchased quercetin, gallic acid, DPPH (2,2-diphenyl-1-picrylhydrazyl), and the Folin-Ciocalteu reagent (2.0 N) from Sigma-Aldrich in Germany as well as methanol (MeOH), sodium hydroxide (NaOH), sodium bicarbonate (Na2HCO3), and aluminum chloride (AlCl3) from Mark, Germany. Every chemical and reagent used in this investigation was of analytical quality.

2.2. Sample Preparation

The study was performed at Islamic University, Kushtia-7003, Bangladesh, and Hajee Mohammad Danesh Science & Technology University, Dinajpur-5200. Jujube (*Ziziphus mauritiana*) fruits were purchased from local marketplaces in Dinajpur, Bangladesh, between January 2022 and February 2022. The fruits were meticulously rinsed under running tap water to remove dirt and grime from their surfaces, then dried with a clean cloth or tissue paper. Samples were desiccated utilizing a cabinet drier engineered for processing okra, chili pepper, and plantain, with efficacy assessed by Ajuebor et al. (2017) [18]. At 45°C, 55°C, and 65°C, together with a relative humidity of 60% and an air velocity of 3.0 m/s, the cabinet dryer performed at its most effective. At these process parameters values, the drying rate was measured.

2.3. Drying of jujubes

The whole jujubes were then dried at 45^0 C, 55^0 C and 65^0 C temperature up to the equilibrium moisture content in a multipurpose universal cabinet dryer.

2.4. Drying Rate Calculation

The subsequent equation was employed to calculate the drying rate.

$$R= -\frac{LA}{At}\frac{\Delta X}{\Delta t}$$

Where, R= drying rate (g.H_20/m^2); L_A= Bone dry Sample Weight (kg); A_t = total surface area of the trays (m^2); ΔX= weight difference (% MC_{db}) and Δt = drying time difference (hour).

The drying curves of jujube are represented by charting the loss of free moisture against drying duration at several temperatures. The drying rate curves were illustrated by graphing the drying rate versus the percentage of free moisture in the jujube sample.

2.5. Determination of moisture content

The AOAC (2000) technique 7.045 [19] was conducted to determine the jujube sample's moisture percentage. A crucible that had been previously weighed and cleaned and dried yielded a 5g sample. After that, the crucible was placed in an oven and dried for 16 hours at 105˚C. After cooling in desiccators, the sample was weighed. After that, the sample was dried in an oven until its weight remained constant. After cooling, the sample was assessed.

The moisture percentage was calculated utilizing the subsequent formula. (1):

$$\%\ Moisture = \frac{Initial\ weight\ of\ sample - Bone\ dry\ weight\ sample}{Initial\ weight\ of\ sample} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.6. Sample Extraction

Solvent extraction was performed using 80% methanol, which is considered the optimal solvent due to its enhanced solubility for polar compounds. The polar organic properties of 80% methanol facilitate more effective extraction [20]. Briefly, 4.18gm dried at 45^0 C, 3.99gm dried at 55^0 C, 3.92gm dried at 65^0 C samples were taken to equate to 10 gm of fresh sample with 100 mL of solvent (80% methanol, 20% water) separately in a 250 mL conical flask at a ratio of sample/solvent (1:20, w/v), equivalent weights of samples were calculated as per fresh jujube weight by following formula (2) that was developed by this study. The extraction was conducted at ambient temperature in a temperature-regulated Orbital Shaking Incubator (LabTech-LSI3016R) for 48 hours at a shaking speed of 100 rpm. The extracts underwent centrifugation at 4000 rpm for a duration of 10 minutes. The supernatant was filtrated via a Buchner funnel using whatman No. 1 filter paper. Then Dry Oven (SH-DO-54FG) was used to obtain dry matter of phytochemicals resulting various concentration of extracts were prepared, which were subsequently stored at -18°C for further test. The following equation is developed to get equivalent weight of dried samples were measured as per Fresh Weight

$$= W_f - \{(F_m - D_m) x W_f \div 100\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where,

W_f=Weight of Fresh Sample

F_m=Moisture Percent of Fresh Sample

D_m= Moisture Percent of Dried Sample

2.7. Determination of Ascorbic acid content

The AOAC (1990) method was conducted to determine the sample's ascorbic acid amount [21]. Ten milliliters of 20% metaphosphoric acid were combined with four milliliters of each extracted sample (prior to oven drying). After that, the solution was filtered through filter paper Whatman No. 1. 10 ml of distilled water were then added to a beaker containing one milliliter of the filter, and everything was thoroughly mixed. Two milliliters of the diluted suspension were transferred to a distinct beaker. The filtrate was rapidly titrated with a standard solution of 2,6-dichlorophenol indophenol (DCPIP) as the titrant, adhering to the approach of Ali et al. (2016) and Toh et al. (2013) [22,23], with slight adjustments to attain a faint pink endpoint that persists for 15 seconds. Every sample was examined three times. The findings were articulated as an equation (3):

$$Ascorbic\ acid\ (mg\ /\ mL) = \frac{Titre\ value \times Dye\ Factor \times Volume\ made\ up}{Volume\ of\ filtrate\ taken \times Volume\ of\ sample\ taken} \times 100 \quad \ldots\ldots\ldots\ldots (3)$$

2.8. Determination of Total Phenolic Content (TPC)

Total phenolic compound (TPC) of each extract was assessed using, with minor modifications made, the methodology outlined by Kabir et al. (2024) [24]. Finally, 0.5 mL of the Folin-Ciocalteu reagent was added to a Falcon tube containing

0.5 mL of the sample. After mixing thoroughly the liquid, 1 milliliter of saturated sodium bicarbonate had been added to each tube for neutralization. 8 mL of distilled water were then added, and everything was appropriately vortexed. The tubes were centrifuged for 10 minutes at 4000 rpm after being allowed to sit at the ambient temperature in the dark for 35 minutes. Using a UV-1800 UV/Vis spectrophotometer (Shimadzu, U.S.A.), the absorbance of the resulting supernatant has been measured at 760 nm after appropriate blanks were applied for background correction. Each extract was analyzed for total phenolic compound (TPC), which was then converted to mg of gallic acid equivalents (mg GAE) per gram of powdered material. The standard curve was created in this study (y = 0.0039x + 0.0256, R2 = 0.9958).

2.9. Determination of Total Flavonoids Content (TFC)

A spectrophotometric test with modifications as described by Pękal and Pyrzynska (2014) was used to evaluate the TFC [25]. This study involved mixing 1 milliliter of the extract with 0.3 milliliters of 5%, w/v NaNO2, and then adding 0.5 milliliters of 2%, w/v AlCl3 after 5 minutes. After mixing the sample for six minutes, it was neutralized with 0.5 ml of 1 M NaOH solution.

This mixture was permitted to rest for 10 minutes at ambient temperature, after which absorbance was assessed at 510 nm utilizing a blank where the sample was substituted with 80% methanol. Quercetin, dissolved in the aforementioned solvent, was utilized as the standard solution at varying doses (0.0125-0.4 µg/mL). The standard curve (y = 0.004x + 0.001, R^2 = 0.9998) was derived in this study.

2.10. DPPH radical scavenging assay

The free radical scavenging activity was determined in vitro using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) test, which was designed by Brand-Williams et al. (1995) with a few modifications [26]. 2.5 mL of each extract in different concentrations were added to glass bottles, followed by 0.5 mL of a freshly prepared 80% methanol solution containing DPPH (0.2 mM of DPPH mixed with 80% methanol). The mixture gets stirred with a vortex mixer and then let to stand at ambient temperature in a dark area for 30 minutes. Using a spectrophotometer, the absorbance of the sample at 517 nm was determined. The scavenging capability has been expressed by the inhibition percentage, which is calculated using the following formula:

The equation that follows is used to determine the percentage of anti-radical activity:

{(control absorbance – sample absorbance) / control absorbance} × 100.

Then IC_{50} value has been determined, which is the sample concentration required to reduce the DPPH radical by 50 percent.

2.11. Statistical analysis

SPSS software (version 22, SPSS Inc., Chicago, IL, USA) was applied to statistically analyze the data, and the findings were presented as mean ± standard deviation (SD). With a significance level of p = 0.05, analysis of variance (ANOVA) was employed to assess treatment differences. The Duncan test was applied to assess group differences.

3. Result and discussion

The final moisture content of fresh sample was 78.3%, where the moisture percentage range of jujubes that dried at 45°C, 55°C, and 65°C were 20.09%, 18.22% and 17.5%, respectively.

3.1. Effect of temperature on drying kinetics of dried whole jujubes by cabinet dryer

Changes in weight of dried samples with the time of drying are shown in Figure-1. The drying rate exhibited an increase with temperature across all samples. Because of the large beginning water content, drying took place during the falling rate interval rather than the steady rate drying term. This outcome is consistent with previous studies on food drying [27,28,29]. The findings demonstrate that the main physical mechanism influencing the release of moisture in jujubes is diffusion. The higher temperature of 65°C shortened the drying time in comparison to the lower temperatures of 45°C and 55°C. Elevating the temperature from 45°C to 65°C results in a shorter drying time. In Figure 2 and 3(a-c), the relationship between drying rate with time as well as the percentage of free moisture in hot air-dried jujubes and the drying rate variation is displayed, respectively. In contrast to a constant drying rate time, the drying process for jujubes using hot air occurs throughout the falling rate interval. The results of this investigation conform to previous studies on a range of foods [30,31,32]. The material exhibited a high moisture content during the initial drying phase, leading to increased power absorption and elevated drying rates attributed to enhanced moisture diffusion. The drying process

led to a reduction in moisture content, which subsequently decreased power absorption and lowered the drying rate. The diminished drying rate may be ascribed to the reduced porosity of the samples caused by shrinkage over time, which heightens resistance to water flow and consequently results in additional drops in drying rates [29,33,].

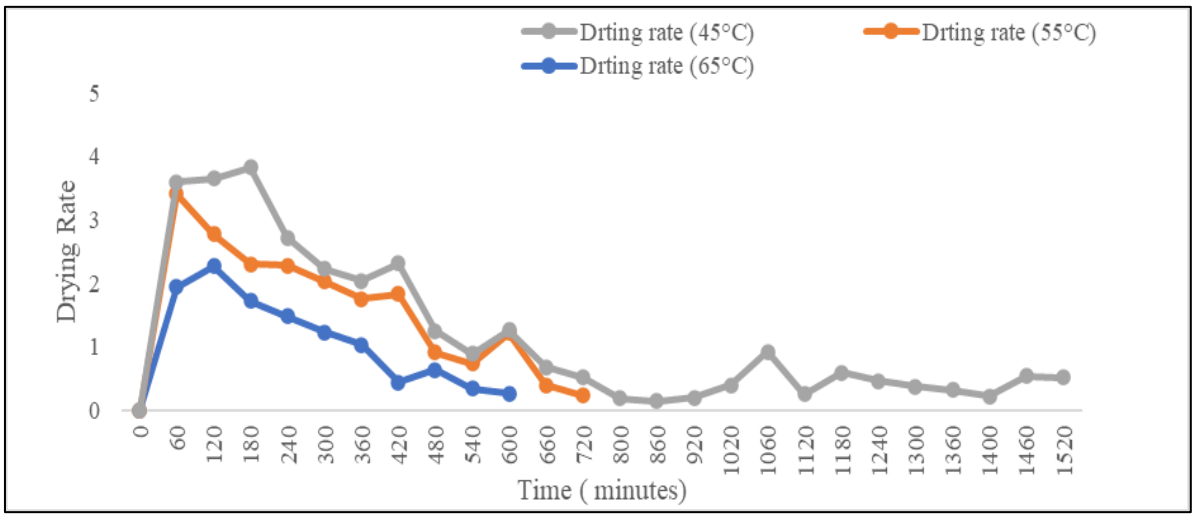


Figure 1 Drying curves of weight loss at 45°C, 55°C, and 65°C of jujubes

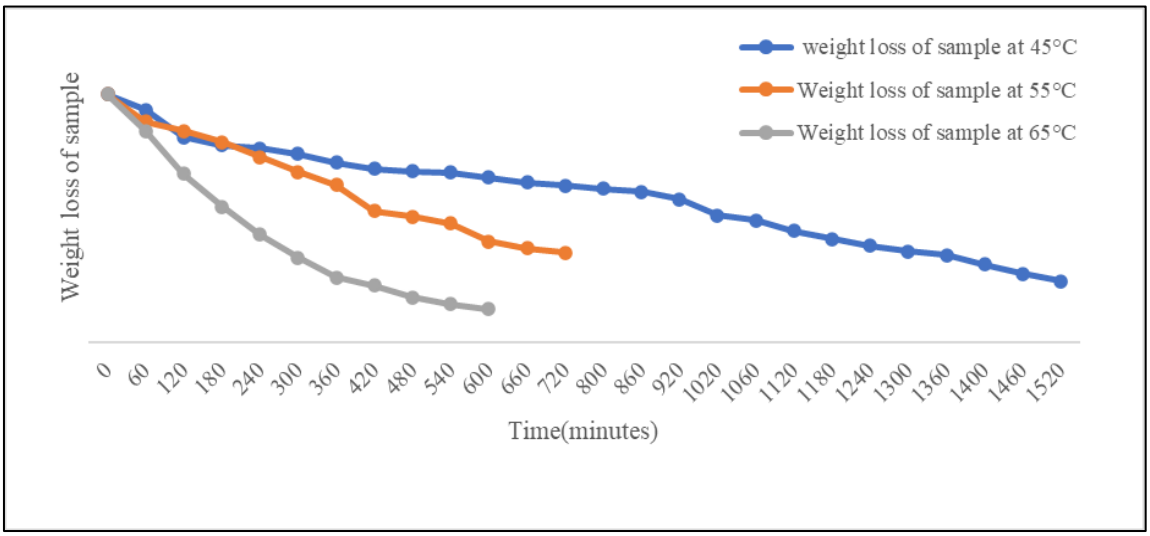
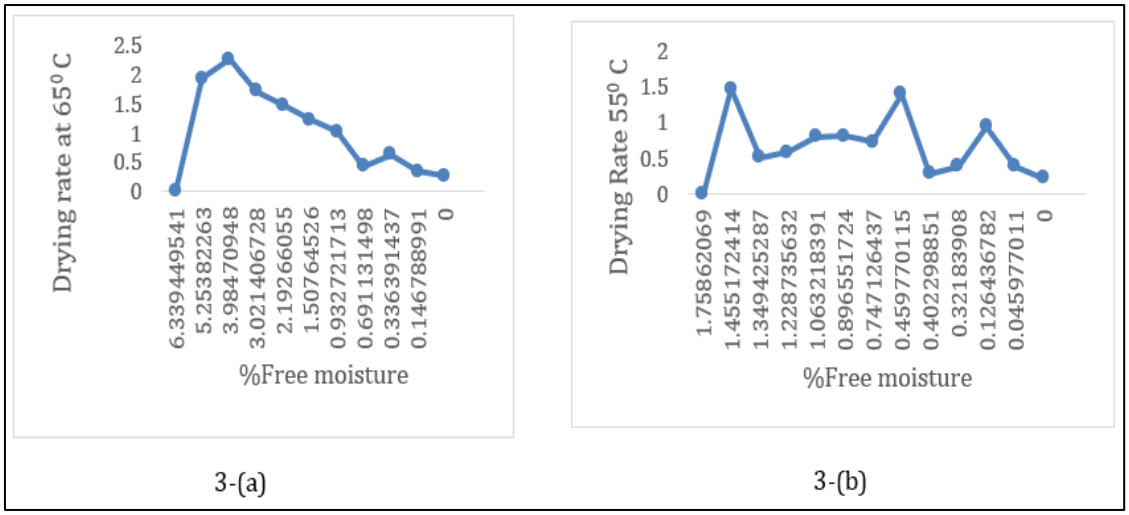
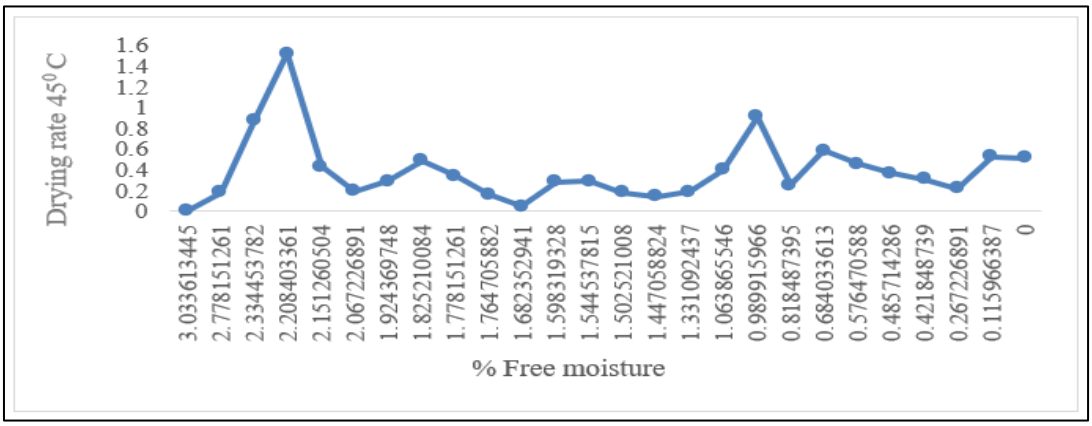


Figure 2 Drying rate curve of cabinet dried jujubes at 45°C, 55°C and 65°C



3-(a) 3-(b)



3-(c)

Figure 3(a-c) Drying rate curve with free moisture of dried jujubes by cabinet dryer

3.2. Color properties of cabinet dried jujubes

The color is a vital consistency indicator for cabinet-dried jujubes. Table 1 presents color measurements for both raw samples and those dried at 45°C, 55°C, and 65°C. The unprocessed sample displayed a greater L* value of 51.17±4.01, but the diminished value was noted in the sample dried at 55°C. Table 1 indicates that when the temperature rises, brightness diminishes. The a* value, indicating redness, was found to be higher in the sample dried at 55°C and lower in the sample dried at 65°C. The value of the fresh sample was markedly lower, although the b value was considerably larger than that of the dried samples. All the desiccated samples exhibited a greater color disparity than the fresh samples. Nonetheless, the overall color alteration is negligible with respect to the drying temperature.

Table 1 L*, a*, b* and ΔE value of cabinet dried jujubes

Samples	L* value	a* value	b* value	ΔE
Fresh jujubes	51.17±4.01^{a}	-3.34±2.98 ^{c}	26.22±3.28 ^{a}	12.31±5.59 ^{b}
45⁰C dried jujubes	32.96±0.19 ^{b}	10.71±0.17 ^{a}	7.05±0.64 ^{c}	35.37±0.31 ^{a}
55⁰C dried jujubes	22.95±16.95 ^{b}	10.90±1.58 ^{a}	10.67±0.21 ^{b}	36.21±1.15 ^{a}
65⁰C dried jujubes	29.88±2.30 ^{b}	5.56±1.05 ^{b}	3.02±0.49 ^{d}	30.55±2.35 ^{a}

Each value represents the Mean ± SD; [Different letters in a row indicate significant differences (P≤0.05) among the samples]

3.3. Ascorbic acid content of jujube fruits

Table 2 displayed the ascorbic acid content of the jujube fruits. The ascorbic acid content, measured in both fresh weight (FW) and dry weight (DW), was found to be mg/100 gm. The ascorbic acid contents were measured of the raw jujube and dried jujubes at three different temperatures 45^0C, 55^0C, 65^0C. Sample dried at 45^0C showed highest vitamin C containing value as dry weight.

Table 2 Ascorbic Acid contents of Raw and Dried Jujube Fruit

Sample	Ascorbic acid content
Fresh jujubes	68.83±0.32 [a] (mg/100g FW)
45 ^{0}C dried jujubes	141.1±0.21[b] (mg/100g DW)
55 ^{0}C dried jujubes	108.37±0.3 [b] (mg/100g DW)
65 ^{0}C dried jujubes	54.43±0.22 [c] (mg/100g DW)

Each value represents the Mean ± SD [FW=Fresh weight; DW=Dry Weight]

The whole jujube fruit's vitamin C concentration was considerably reduced by the drying process, with the drying temperature having the most significant effect ($p < 0.05$). According to Fang et al. (2009), hot air drying reduced the vitamin C content of the whole jujube fruit [17]. In imitation of Chen et al. (2015), sliced jujube fruit's vitamin C levels decreased during the hot air-drying process [34]. As a thermolabile substance, vitamin C can be broken down by heat-related procedures like drying [35]. Furthermore, at higher temperatures, vitamin C might oxidize more quickly [36,37].

3.4. Total Content of Flavonoids and Phenolics

The TPC of the extracts from the selected jujube fruit is shown in Table 3. The TPCs were determined to mg GAE/g DM that means gallic acid equivalent per gram of dry weight. In comparison to the samples dried at 55^0 C and 65^0 C (7.10±0.2 mg GAE/g and 5.44±0.18 mg GAE/g, respectively), the investigation found that the TPC content of the fresh sample and the sample that dried at 45^0 C were approximately the same (11.33±0.14 mg GAE/g and 10.82±0.16 mg GAE/g DM, respectively). Overall, the results were comparable with Li Jin-wei *et al.,* (2005) who founds 5.18±0.29 to 8.53± 0.47 mg GAE/g DM TPC for jujubes [38]. The selection of extraction techniques, solvent, extraction time, and temperature may all affect the TPC results [39]. The fresh jujube fruit sample's total flavonoid compound (TFC) was 4.25±0.8 mg QE/g, and the dried sample at 45^0 C had a TFC of 4.03±0.6 mg QE/g DM, which was roughly the same as the fresh sample. Conversely, the dried samples at 55^0 C and 65^0 C were 3.20±0.7 and 2.95±0.4 mg QE/g DM, respectively (Table 3). Quercetin equivalent mg/gm of dry matter were used to display the results. With the application of higher temperatures, the TFC content of dried samples may degrade [40]. The amount of TFC was highest in the fresh sample and sample that dried at 45^0 C when compared to the other dry samples.

3.5. DPPH Scavenging Activity

The DPPH scavenging ability of jujube fruit was used to investigate its antioxidant potential. The percentage (%) scavenging activity was examined, and the IC_{50} values were shown in table 3. Using pulp extract of fresh jujube, the DPPH radical scavenging activity was 54.67 µg/mL, which was the result that was closest to Rajaei, A., et al., (2021) [41]. For samples dried at 45^0, 55^0, and 65^0 Celsius, the corresponding IC_{50} values were 74.47 µg/mL, 104.02 µg/mL, and 133.14 µg/mL. Compared to other dried samples, the scavenging activity at 45^0C had the greatest values. IC_{50} values of dried sample comparatively higher than the fresh sample due to heat exposure during drying may cause the bioactive chemicals to partially degrade [42]

Table 3 TPC, TFC and Antioxidant activity of fresh and dried (at 45^0 C, 55^0 C and 65^0 C) jujubes

Smaple	TPC (mg GAE/g DM)	TFC (mg QE/g DM)	IC_{50} µg/mL
Fresh Jujube	11.33±2.14	4.25±2.8	54.67±2.0
Dried Jujube at 45^0 C	10.82±2.16	4.03±2.6	74.47±1.9
Dried Jujube at 55^0 C	7.10±1.8	3.20±1.7	104.02±1.3
Dried Jujube at 65^0 C	5.44±1.18	2.95±1.4	133.14±1.6

4. Conclusion

The health-promoting fruit jujube (*Ziziphus mauritiana*) was studied for its drying properties and quality metrics at different drying temperatures. Then the dried samples were subjected to physico-chemical properties, bio-active compounds and antioxidant capacity determination along with fresh sample. The drying temperature has a significant effect on the jujube's drying process. At 45°C, the longest drying time ever measured was 25 hours, and at 65°C, the shortest was 10 hours. As drying temperatures rose, more free moisture was lost. According to the research, jujubes' drying properties, nutritional makeup, and physical attributes are significantly impacted by the drying temperature. When considering a balance between efficiency (shorter drying time, higher drying rate), improved color properties, and adequate moisture removal, 65°C was found to be the most suitable drying temperature. The highest nutritional values, such as total phenolic compounds (TPC), total flavonoid compounds (TFC), and antioxidant capability, were preserved by cabinet drying at 45°C. However, the higher temperature of 65°C led to the greatest loss of vitamin C, highlighting a trade-off between nutritional preservation and drying efficiency. Thus, the choice of drying temperature should depend on the priority of desired outcomes nutritional retention or process efficiency. The impact of various drying techniques, such as microwave, vacuum, vacuum–microwave, and microwave–hot air combinations, on the dehydration of jujube fruits should be investigated in future studies. Therefore, by examining the breakdown of nutritious substances during the process, ideal circumstances and techniques can be identified.

Compliance with ethical standards

Disclosure of conflict of interest

The authors confirm that there are no conflicting interests.

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