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# Safety improvement of the open sun dried Egyptian Siwi dates using closed solar dryer

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ABSTRACT

Egyptian Siwi dates dried using the open sun drying is exposed to different contaminants. So, the current study aims to use the closed solar dryer to improve Siwi date safety. The impact of washing and closed solar drying on the levels of microbial load, aflatoxins and heavy metals in Egyptian Siwi dates (ESD), in comparison to traditional open sun drying methods were examined. Two different drying techniques were employed to dry 300 kg of ESD. The microbial load was assessed following the two drying procedures. The levels of aflatoxins and heavy metals were analyzed using High-performance liquid chromatography (HPLC) and Inductively Coupled Plasma (ICP) techniques, respectively, after both drying methods. Additionally, the influence of storage time on the microbial load of the ESD was also evaluated using standard methods. The findings of the current study demonstrated that the closed solar drying significantly reduced the total bacterial and fungal counts by 96 % and 93 %, respectively, when compared to open sun-drying. No aflatoxins were detected in both fresh Siwi dates and Siwi dates dried using closed solar drying. However, after open sun drying, two aflatoxins; aflatoxin $B_1$ ($AFB_1$) and aflatoxin $G_1$ ($AFG_1$), were detected in the ESD, with concentrations of 0.95 and 0.23 μg $kg^{-1}$, respectively. The closed solar drying significantly decreased the levels of lead (Pb), cadmium (Cd), copper (Cu), nickel (Ni), chromium (Cr), zinc (Zn), manganese (Mn), and iron (Fe) in the dried dates by 96 %, 94 %, 48 %, 71 %, 64 %, 4 %, 26 %, and 7 %, respectively, when compared to open sun drying. The stored Siwi dates that was exposed to the open sun drying showed a higher increase in bacterial (4.86 log CFU/g) and fungal (4.46 log CFU/g) counts. However, the stored Siwi dates that was exposed to the closed solar dryer showed a lower increase in bacterial (3.21 log CFU/g) and fungal (2.51 log CFU/g) counts. So, the duration of storage significantly impacted the microbial loads of the closed solar dried dates as compared to open sun drying. Overall, closed solar drying reduced the levels of investigated contaminants and extended the shelf life of ESD, thereby enhancing their safety for human consumption.

## 1. Introduction

Fresh fruits and vegetables, which have a short shelf life due to their high-water content, can be effectively preserved through

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drying [1,2]. This not only inhibits the growth of spoilage microorganisms but also prevents browning and other moisture-related deterioration, maintaining the original structure, characteristics, and nutritional content [2,3]. Drying is an ancient and widely used method of preserving food to extend its shelf life by reducing moisture content [4,5]. This technique is commonly employed to preserve agricultural products, as it enhances color, taste, and appearance while preventing the growth of microorganisms, insect infestation, and contamination from foreign substances and toxins [6]. Additionally, drying fruits and vegetables reduces losses, improves storage stability, simplifies transportation, and reduces handling and packaging requirements due to decreased weight and volume [1,2]. However, traditional sun drying methods can be labor-intensive and increase the risk of microbial contamination [2,7].

The Siwi date, a highly nutritious agricultural product rich in vitamins, minerals, carbohydrates, dietary fibers, and flavonoids [8], is widely consumed during the Muslim holy month of Ramadan to break the fast. It is also commonly used as a filling for bakery products [9] and as a natural sweetener in dairy products [10]. However, Siwi dates have high moisture content and are primarily consumed in dried form, necessitating the removal of moisture. In Egypt, open sun drying is the most commonly used method for preserving agricultural products, including Siwi dates. However, this traditional method is slow and hindered by high humidity, requiring a longer drying period [11,12]. Previous studies have identified various contaminants, such as bacteria, fungi, aflatoxins and heavy metals, in date samples from different countries [13–18]. Therefore, drying dates is crucial for safe storage, as their high moisture content makes them susceptible to microbial deterioration [19]. While open sun drying is historically employed due to its affordability and efficiency, it often results in low-quality products due to insect infestation and contamination from foreign substances [20–22]. Closed solar dryers offer a potential solution to these issues [23], as they may address many of the challenges associated with open-air sun drying. Thus, the production of Egyptian Siwi dates would benefit from the implementation of food safety systems, such as solar energy drying [24,25].

Open sun drying (OSD) has been a conventional method for drying food crops for centuries. This method has been particularly popular for producing dried dates due to its cost-effectiveness and efficiency. However, there are several drawbacks associated with the OSD method. These include longer drying times, susceptibility to contamination by microorganisms, infestation by insects, loss caused by animals and birds, and the production of low-quality dates due to contamination by foreign elements like litter, dust, dirt, and sand particles [26,27]. Significant portions of Egyptian Siwi dates have been produced using the traditional OSD method, resulting in a high level of contaminants.

To address these challenges and ensure the production of safe dates, the use of closed solar drying could be employed as an alternative to traditional open sun drying. Closed solar drying is a cost-effective and environmentally friendly technology, utilizing the abundant and renewable energy of the sun. It has been recognized as a promising solution for reducing post-harvest losses in developing countries [28,29]. Several studies have already explored the use of solar dryers for drying various agricultural crops, including apples slices, tomatoes, apples and date fruits to increase drying rates, reduce spoilage, and extend storage life [30–34]. This study aims to utilize solar energy as a clean and renewable energy source to dry Siwi dates and investigate the impact of the washing process and closed solar drying on levels of microbial load, aflatoxins and heavy metals in Egyptian Siwi dates in comparison to traditional open sun drying method.

## 2. Materials and methods

### 2.1. Materials

#### 2.1.1. Chemicals and regents

The high purity solvents like chloroform, acetonitrile, methanol and trifluoroacetic acid (TFA) were purchased from Merck, Darmstadt, Germany. The standards of aflatoxins (AFs) were purchased from Sigma Aldrich, USA. All other chemicals and reagents used, were at least of analytical grade.

#### 2.1.2. Dates samples

The Siwi dates (300 kg), which are freshly harvested from production farms (September 30, 2021) in Masjed Moussa village, Atfeeh city, Giza governorate, Egypt, undergo a sorting process to remove any immature or overripe dates.

### 2.2. Methods

#### 2.2.1. Pre-processing of the dates

The Siwi dates were washed using tap water to eliminate physical particles like dust. The 300 kg of washed fresh dates are then divided into two groups, with 150 kg in each group. The first group is dried using a closed solar dryer, while the second group is dried using the open sun drying method. Each group is further divided into three replicates, with 50 kg in each replicate. The levels of microbial load, aflatoxins and heavy metals were determined in the washed, unwashed and dried Siwi dates.

#### 2.2.2. Drying experiments

*2.2.2.1. Open sun drying (OSD).* The open sun drying (OSD) process for Egyptian Siwi dates was carried out at a production site located in Masjed Moussa village, Atfeeh city, Giza governorate, Egypt (Fig. 1). During this process, the water content of the dates (Agwa) is naturally removed through sun drying for a period of 10–15 days at a temperature ranged from 20 to 33 °C (Figure S1).

**Fig. 1.** Picture of open sun drying (traditional method).

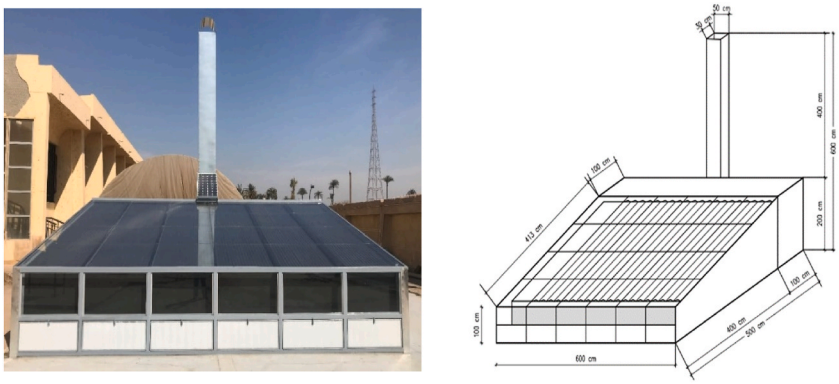


**Fig. 2.** Picture and schematic view of closed solar dryer.

However, this open system is exposed to various elements including dust, soil particles, pests, birds, rodents, and rain.

*2.2.2.2. Description of the study area (closed solar dryer).* This study was carried out at the National Research Centre, Solar Energy Department, Giza (longitude of 31.13° N and latitude 30.03° E). The experiment was conducted on the first three days of October 2021. During the winter season, the minimum temperatures ranged from 15 to 16 °C, while the maximum temperatures ranged from 36 to 39 °C during the summer season (Figure S1). On an annual basis, the wind speed averages around 4 m/s. The Egyptian climate in the Sunbelt region leads to higher levels of irradiation and more sunshine hours throughout the year.

Figure S2 illustrates the monthly mean sunshine hours in Cairo, with the summer months experiencing the highest values due to the elevated temperatures, as indicated in Figure S1. Figure S2 also demonstrates that the location of the solar dryer used in this study receives ample sunshine hours year-round, ranging from 365 to 370 h/month in the summer season and 290–300 h/month in the winter season, with a total of over 3870 h/year. Figure (S3) presents the instantaneous irradiation on selected days during summer and winter, considering the optimal tilt angle and zero azimuth angles. The figure clearly shows that the site receives higher irradiation values during the summer and winter, with longer daylight hours in the summer.

*2.2.2.3. Description of closed solar dryer.* The closed solar dryer prototype consists of a single flat plate air heating solar collector. The collector has dimensions of 5 m × 3 m and a height of 2 m (see Fig. 2). The top, side, and back walls are constructed using stainless-steel plate sheets, which are separated by a suitable thermal insulation layer with a thickness of 5 cm. The collector portion of the dryer utilizes black painted galvanized corrugated metal sheets measuring 5 m × 4 m and having a thickness of 0.4 mm. These metal sheets serve as the absorber plate and are covered by glass plates with a thickness of 0.5 mm. The inner body holder for the absorber consists of square iron bars measuring 6 m × 1.9 m x 4 m with dimensions of 4 mm × 4 mm. To ensure practical air tightness, air gates are incorporated at the bottom-front of the dryer. The dryer is constructed on concrete block structures positioned 40 cm above the ground surface. It employs both natural and forced circulations by utilizing a 50-W fan installed in the dryer chimney. The absorber of the dryer is made from black tin plate with a thickness of 0.4 mm and is coated with a black coating. The dates to be dried are prepared and placed in the dryer over the plates as shown in Fig. 3. A fan driven by a photovoltaic module located on the dryer housing was used to circulate hot air in the system. Solar dryers offer several advantages, including protection from flies, vermin, rain, and dust, as well as a


**Fig. 3.** Photographs of solar dryer and trays loaded with the Siwi dates (a) before and (b) after, drying process.

reduced chance of spoilage due to the rapid drying process. The drying rate (d) was calculated using the following equation [4]:

$$d = (M_1 - M_2)/T. \quad \text{(Equation 1)}$$

where $M_1$ is the initial weight of the product (dates), $M_2$ is the final weight of dates and T is time (days).

### 2.2.3. Microbiological analyses

A representative sample (10 g) was homogenized for 30 s in 90 mL of 0.9 % NaCl. In saline tubes, serial 10-fold dilutions were made, and 1 mL of each solution was used for the microbiological count. According to American Public Health Association (APHA) [35] and Food and Drug Administration (FDA) [36], the pour plate method was used for microbial enumeration.

*2.2.3.1. Total viable count.* The plate count agar medium was used to accomplish the total viable count as advised by the APHA [35] and FDA [36]**.** There were manufactured dilutions that were then transferred to sterile plates (1 mL per plate, approximately). The plates were examined for total increasing population (CFU/gram) after two days of aerobic incubation at 35 °C.

*2.2.3.2. Coliforms count and Escherichia coli examination.* Coliforms count and *Escherichia coli* testing were conducted following the methodology outlined by El-Hadedy and Abu El-Nour [37]. Each sample was inoculated into a 9 mL Bromo-Cresol Purple McConkey broth tube using 1 mL of each of the initial three dilutions (3 tubes per dilution). After incubating the tubes at 37 °C for 24 h, the presence of acid and gas formation indicated positive tubes. The count was then determined using the most probable number (MPN) index [38]. From each positive tube, a fresh MaCconkey broth tube was inoculated and incubated at 45 °C for 24 h to detect the presence of fecal coliforms based on gas and acid production. *Escherichia coli* was identified as purple colonies with a green metallic sheen on the EMB Agar plate after streaking from the positive tube incubated at 45 °C [39].

*2.2.3.3. Detection of Salmonella.* The detection of *Salmonella* was carried out in accordance with the guidelines provided by APHA [35] and FDA [36]. To initiate pre-enrichment, a well-homogenized sample weighing 25 g was added to 225 mL of sterile buffered peptone water. A growth solution of 10 mL was then combined with 90 mL of selenite broth that had been sterilized by boiling, containing 4 g per liter of sodium bi-selenite (Oxoid). The mixture was incubated at 37 °C for 24 h. Following incubation, the selenite broth was used to streak XLD plates [40,41]. *Salmonella* colonies were identified by the presence of red cores with black edges.

*2.2.3.4. Fungal counts.* Malt extract agar was utilized for the enumeration of fungi [42]. Dilutions were prepared and subsequently transferred onto sterilized plates (approximately 1 mL per plate). After incubating the plates for a period of 3 days at a temperature of 30 °C, the fungal population (CFU/gram) was determined. Additionally, specific agar media was employed to assess the morphology of growing colonies, and target colonies were examined microscopically [35,36].

### 2.2.4. Aflatoxins determination

*2.2.4.1. Extraction and cleanup.* The process of extracting, purifying, and determining aflatoxins was conducted following the guidelines set by AOAC [43]. Aflatoxins (AFs) were extracted from date samples using the contamination branch (CB) method [43]. Each sample, weighing 50 g, was placed in a 500 mL Erlenmeyer flask along with 25 g of diatomaceous earth, 250 mL of chloroform, and 25 mL of distilled water. The mixture was shaken for 30 min using a horizontal shaker. The resulting extract was then filtered using Whatman No. 4 filter paper. The first 50 mL of the extract was collected and transferred to a silica gel column for purification. Chromatographic columns were prepared by filling a glass column (22 × 300 mm) with 5 g of anhydrous sodium sulfate. A slurry consisting of chloroform and 10 g of silica gel was added to the column. The excess chloroform was drained, and the stopcock was opened to allow the settling of the silica gel packing. To prevent drying, an additional 10 g of anhydrous sodium sulfate was added to the top of the silica gel during draining. A 50 mL portion of the filtrate was loaded into the column and allowed to flow at a rate of one drop per second. The extract was rinsed with 150 mL of n-hexane followed by 150 mL of diethyl ether. Aflatoxins were eluted in a 250

mL Erlenmeyer flask using 150 mL of chloroform: methanol (97:3 v/v) and then evaporated to dryness using a rotary evaporator. The resulting residue was quantitatively transferred to a small vial with chloroform and dried under nitrogen. To clean up the samples, 200 μl of hexane was added to the dried film, followed by 50 μl of trifluoroacetic acid (TFA), and thoroughly mixed for 30 s. After allowing the mixture to stand for 5 min, 450 mL of $H_2O$:$CH_3CN$ (9:1 v/v) was added and vortexed for 30 s. The mixture was allowed to stand for 10 min to separate into two layers. The lower aqueous layer was subjected to HPLC analysis.

*2.2.4.2. HPLC analysis.* Agilent 1260 HPLC system (Germany) with quaternary pump, fluorescence detector, and a C18 column chromatography Phenomenex (250 × 4.6 mm, 5 μm) was used for Aflatoxins determination. At 360 nm excitation and 440 nm emission, the mobile phase was water: methanol: acetonitrile (60:30:10) with an isocratic flow rate of 1.2 mL $min^{-1}$.

### *2.2.5. Heavy metals analysis*

*2.2.5.1. Sample preparation.* A closed system microwave (Milestone, model Ethos Easy, total power 1900 Watts, the cavity volume 70 L, maximum press 90 bar and maximum temperature 200°C) was used to digest the date samples [44]. About 0.5 g of the homogenized dates sample was transferred into special PTFE vessels. Then, 2 mL of $H_2O_2$ and 8 mL of nitric acid (69 %) were added to the sample. The vessel was tightly and completely sealed before being placed in the microwave to finish the digestion process. In the microwave, they followed a temperature-controlled protocol: 15 min of heating at 200 °C, 15 min of holding, and 15 min of cooling at 85 °C. After that, the contents of the vessel were transferred to a 25 mL volumetric flask and diluted with ultrapure water to the appropriate concentration. Finally, the sample was ready for analysis using Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES).

*2.2.5.2. Determination of heavy metals.* In the National Research Center, Water Pollution Department, analysis for the examined heavy metals was carried out using an Agilent 5100 Synchronous Vertical Dual View (SVDV), ICP-OES in accordance with APHA [45] and an Agilent Vapor Generation Accessory VGA 77. The intensity calibration curve was built for each set of observations using at least three Merck Company standards and a blank (Germany). Using external reference standards from Merck as well as standard reference material and quality control samples from the National Institute of Standards and Technology (NIST), the accuracy and precision of the $Fe^{3+}$, $Mn^{2+}$, $Cd^{2+}$, $Pb^{2+}$, $Ni^{2+}$, $Cr^{3+}$, $As^{3+}$, $Hg^{2+}$, $Zn^{2+}$, and $Cu^{2+}$ ions readings were confirmed.

### *2.2.6. Effect of storage period on the microbial counts of open sun and closed solar dried Siwi dates*

The dried Siwi dates from Egypt were obtained through two methods: closed solar drying and open sun drying. To ensure preservation, the dried dates were placed in vacuum bags (30 cm × 25 cm x 0.4 mm), then stored in reinforced cartons (30 cm × 25 cm x 15 cm) in a storage room for 2, 4, 6, and 8 months. The temperature (20–25 °C) and relative humidity (65–70 %) were maintained constant and monitored by temperature and relative humidity data logger omega (Model OM-73 USA). The microbial load present in the dates was assessed at each storage period.

### *2.2.7. Statistical analysis*

The program of statistical analytical system (SAS), version 8 was used for statistical analyses. The data obtained undergo a one-way analysis of variance (ANOVA) using the general linear model (GLM) in the SAS statistical package [46]. The results presented here represent the average of three separate experiments, with statistical significance set at $p \leq 0.05$.

## 3. Results and discussion

Based on a previous study of Abdel-Rahman et al. [47], the Egyptian Siwi dates collected through open sun drying were found to be contaminated with microbes, aflatoxins and heavy metals. The Siwi dates showed elevated levels of total bacterial count (ranging from 2.54 to 4.85 Log CFU/g) as well as fungal count (ranging from 2.61 to 3.97 Log CFU/g). Furthermore, 50 % of the date samples obtained through open sun drying were contaminated with $AFB_1$, while only 10 % were contaminated with $AFG_1$. Additionally, the highest concentrations of heavy metals detected in the Siwi dates were 2.05 mg $kg^{-1}$ for Pb, 0.26 mg $kg^{-1}$ for Cd, 1.07 mg $kg^{-1}$ for Cr, 3.04 mg $kg^{-1}$ for Ni, 5.42 mg $kg^{-1}$ for Cu, 31.4 mg $kg^{-1}$ for Zn, 12.96 mg $kg^{-1}$ for Mn, and 148.3 mg $kg^{-1}$ for Fe. Increase the contamination levels in the Egyptian Siwi dates dried by open sun drying may be due to longer drying times and exposure to microorganisms, dust and insects [26,27]. To minimize the aforementioned contaminants and improve the safety of the Siwi dates, the closed solar drying was investigated as an alternative to the open sun drying.

### *3.1. Drying performance*

The solar systems directly convert solar radiation into thermal energy through the collectors, resulting in increased system output when there is more solar radiation incidence on its surface. In this method, the thermal energy from a solar air collector is transferred to the air. The heated air is then directed into a chamber where the Siwi date fruits are placed, effectively reducing their moisture content. The drying period for Siwi date fruits occurred over a span of three days. Fig. 4 displays the hourly variation of ambient temperature, dryer temperature, relative humidity, and solar radiation for three days in October using a closed solar dryer. It is evident that the temperature reaches its maximum value of around 65 °C during the day inside the dryer, while dropping to 19–20 °C during the night

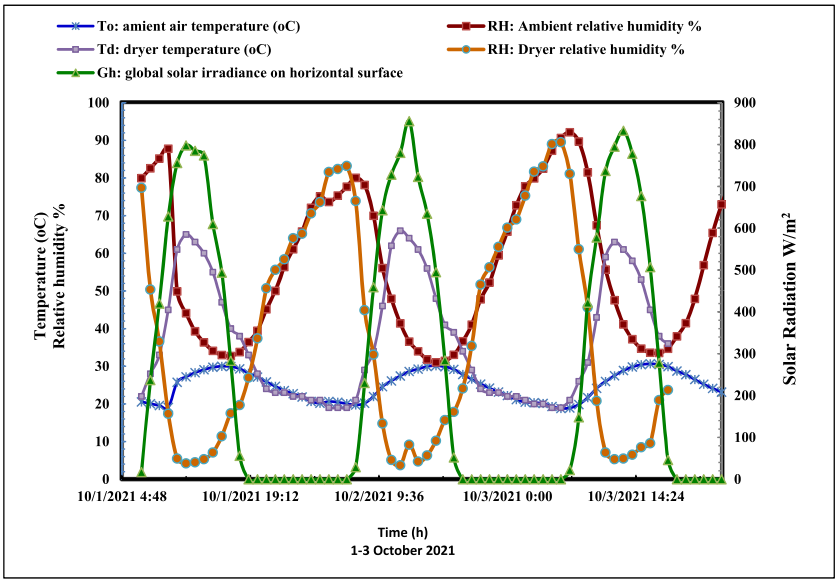


**Fig. 4.** Hourly variation of ambient temperature, dryer temperature, relative humidity, and solar radiation for three days in October using a closed solar dryer.

**Table 1**
Effect of washing and closed solar drying on microbial count of the Siwi dates.

| Microbial count (Log CFU/g) | Fresh date | | Dried date | | LSD | MPLs [49] |
|---|---|---|---|---|---|---|
| | Unwashed date | Washed date | Open sun drying | Closed solar drying | | |
| **Total bacterial count** | $3.59^{a} \pm 0.02$ | $2.30^{c} \pm 0.04$ | $3.28^{b} \pm 0.02$ | $1.85^{d} \pm 0.03$ | 0.09 | 5 |
| **Fungal count** | $3.53^{a} \pm 0.01$ | $2.60^{c} \pm 0.02$ | $3.20^{b} \pm 0.02$ | $2.04^{d} \pm 0.03$ | 0.07 | 3 |
| **Total coliforms count** | $1.36^{a} \pm 0.02$ | Nil | Nil | Nil | – | 2 |
| ***Escherichia coli*** | Negative | Negative | Negative | Negative | – | Absent |
| ***Salmonella*** | Negative | Negative | Negative | Negative | – | Absent |

Means followed by different subscripts within row are significantly different at the 5 % level.
MPLs: maximum permissible limits.

hours. The ambient average relative humidity and the relative average humidity inside the dryer recorded 32–92 % and 3.7–89.5 %, respectively. The initial ($M_1$) and final ($M_2$) weights of the dates were 50 and 28.5 Kg, respectively after drying for 3 days (T). The drying rate was calculated as 7.17 Kg/day (Equation (1)). These results are in agreement with those recorded by **Sansaniwal et al**. [33] who reported that the closed solar drying of date palm fruits had a high drying rate as compared to the open sun drying.

### *3.2. Effect of washing and closed solar drying on microbial count of the Siwi date*

Dates are resistant to microbial deterioration, except for a few osmotolerant fungi that may compromise their microbiological integrity [48]. As compared with the unwashed fresh dates, washing decreased the total bacterial and fungal counts by 95 and 88 %, respectively (Table 1). The closed solar energy drying of Siwi dates decreased the average bacterial and fungal counts by 96 and 93 %, respectively. This is compared with open sun drying as a traditional drying method. The fungal counts in the washed fresh dates and Siwi dates produced by closed solar dryer were reached to below maximum permissible limits (MPLs) which are 3 log CFU/g [49]. Total coliform count was only detected in unwashed fresh dates (1.36 log CFU/g) and was less than MPLs (2 log CFU/g). Microbial contamination may result from production procedures such as using contaminated irrigation water, inadequately treated manure, and improper post-harvest and date processing [47]. Microbial load is affected by intrinsic factors of dates such as pH, moisture content, water activity, quantity of sugars and nature, as well as external environmental conditions such as temperature, humidity (%) and storage conditions [50].

### *3.3. Effect of washing and closed solar drying on aflatoxins levels in the Siwi dates*

A few studies have found aflatoxins (AFs) in dates. For instance, a study conducted in Saudi Arabia [14] examined the mycological profile of retail date fruits from various markets and identified the presence of *A. flavus* and *A. niger* species, both of which have the potential to produce AFs and Ochratoxin A. Similar surveys conducted in Pakistan [51] and Brazil [52] reported AFs contamination

**Table 2**
Effect of washing and closed solar drying on aflatoxins levels in the Siwi dates.

| Aflatoxins (μg kg$^{-1}$) | Fresh date | | Dried date | | MPLs [54] |
|---|---|---|---|---|---|
| | Unwashed date | Washed date | Open sun drying | Closed solar drying | |
| **$AFB_1$** | BDL | BDL | 0.95 ± 0.06 | BDL | 5 |
| **$AFB_2$** | BDL | BDL | BDL | BDL | – |
| **$AFG_1$** | BDL | BDL | 0.23 ± 0.02 | BDL | – |
| **$AFG_2$** | BDL | BDL | BDL | BDL | – |
| **Total AFs** | BDL | BDL | 1.18 | BDL | 10 |

BDL: below detection limit. MPLs: maximum permissible limits according to Egyptian Standard.
$AFB_1$: aflatoxin $B_1$; $AFB_2$: aflatoxin $B_2$; $AFG_1$: aflatoxin $G_1$; $AFG_2$: aflatoxin $G_2$, Total AFs: total aflatoxin.

**Table 3**
Effect of washing and closed solar drying on the levels of heavy metals in the Siwi dates.

| Metals (mg kg$^{-1}$ dry weight) | Fresh date | | Dried date | | LSD | MPLs |
|---|---|---|---|---|---|---|
| | Unwashed dates | Washed dates | Open sun drying | closed solar drying | | |
| **Pb** | $0.59^{b} \pm 0.04$ | $0.09^{c} \pm 0.01$ | $2.57^{a} \pm 0.08$ | $0.09^{c} \pm 0.01$ | 0.15 | 0.1 [59] |
| **Cd** | $0.27^{b} \pm 0.01$ | $0.04^{c} \pm 0.01$ | $0.75^{a} \pm 0.02$ | $0.05^{c} \pm 0.01$ | 0.04 | 0.05 [60] |
| **Ni** | $2.37^{b} \pm 0.12$ | $1.17^{c} \pm 0.06$ | $3.50^{a} \pm 0.12$ | $1.25^{c} \pm 0.07$ | 0.32 | 1.5 [61] |
| **Cr** | $0.51^{b} \pm 0.01$ | $0.21^{c} \pm 0.01$ | $0.76^{a} \pm 0.02$ | $0.22^{c} \pm 0.01$ | 0.04 | 1.3 [62] |
| **Cu** | $4.16^{b} \pm 0.21$ | $3.67^{b} \pm 0.22$ | $7.24^{a} \pm 0.31$ | $3.74^{b} \pm 0.23$ | 0.80 | 10 [63] |
| **Zn** | $15.45^{a} \pm 0.18$ | $14.82^{b} \pm 0.15$ | $15.50^{a} \pm 0.17$ | $14.88^{b} \pm 0.17$ | 0.55 | 60 [64] |
| **Mn** | $8.21^{b} \pm 0.21$ | $7.61^{b} \pm 0.15$ | $10.40^{a} \pm 0.24$ | $7.65^{b} \pm 0.16$ | 0.63 | 90 [64] |
| **Fe** | $88.52^{b} \pm 0.37$ | $86.96^{b} \pm 0.47$ | $104.46^{a} \pm 1.04$ | $87.06^{b} \pm 0.51$ | 2.13 | 150 [64] |
| **As** | BDL | BDL | BDL | BDL | – | – |
| **Hg** | BDL | BDL | BDL | BDL | – | – |

Means followed by different subscripts within row are significantly different at the 5 % level; BDL: below detection limit.
MPLs: maximum permissible limits according to the European Commission, WHO, Codex and FAO/WHO.

levels ranging from 0.1 to 5 μg kg$^{-1}$ in dates. However, in the fresh dates analyzed in this study (Table 2), none of the investigated aflatoxins were detected, these is may be due to absence of the aflatoxins producing fungi [14]. In contrast, two aflatoxins, $AFB_1$ and $AFG_1$, were found in the open sun dried dates, with concentrations of 0.95 and 0.23 μg kg$^{-1}$, respectively. This detection of aflatoxins in the open dried dates may be attributed to the extended drying period of 10–15 days, which allowed aflatoxin-producing fungi to invade the dates [53]. In contrast, closed solar dryers, which have a faster drying rate of 3 days, in addition there was no aflatoxin observed in dried dates of the closed solar dryers, compared to the traditional method of open sun drying. In general, the detected levels of $AFB_1$ and total AFs in the Siwi date were below the MPLs (5 and 10 μg kg$^{-1}$, respectively) [54].

### *3.4. Effect of washing and closed solar drying on heavy metals level in the Siwi dates*

Regarding fresh dates, the washing process reduced the levels of Pb, Cd, Ni, Cr, Cu, Zn, Mn and Fe by 85, 85, 51, 59, 12, 4, 7, and 2 %, respectively compared to unwashed ones (Table 3). These results agree with Abdel-Rahman et al. [55] who reported that the levels of Pb, Cd, Cu and Ni in washed potato were decreased by 46, 38, 31 and 53 %, respectively, compared to the unwashed ones. Consequently, most heavy metal contamination may be due to surface deposition from polluted air and soil [56]. Also, Sharma et al. [57] and Abdel-Rahman [58] reported that the main source of metal contamination might be return to aerial deposition and adhesion to plant fruits. Levels of Pb, Cd and Ni in the washed fresh dates reached to below the MPLs which are 0.1, 0.05, and 1.5 mg kg$^{-1}$, respectively [59–61].

The fresh washed dates were dried by closed solar and open sun drying methods. According to Table (2), the levels of Pb, Cd, Ni, Cr, Cu, Zn, Mn, and Fe ions in the Siwi dates dried by closed solar dryer were reduced by 96 %, 93 %, 64 %, 71 %, 48 %, 4 %, 26 %, and 17 %, respectively compared to their levels in the Siwi dates dried by open sun drying. As a result, the toxic metals, *i.e.* Pb, Cd, and Ni in Siwi dates produced by closed solar dryer were reduced below the limits set by the European Commission [59], the European Commission [60] and the WHO [61], respectively, which are 0.1, 0.05, and 1.5 mg kg$^{-1}$, respectively. The decrease of heavy metals in dried dates by closed solar dryer may be attributed to avoiding litter, dust, soil, and sand particles, as well as the deposition of metals from polluted air [65].

### *3.5. The impact of storage duration on the microbial levels of dried Siwi dates exposed to open sun and closed solar drying methods*

Bacteria, and fungi are the primary causes of spoilage in date fruits during various stages of ripening, as well as during storage and processing [66]. In the case of Siwi dates, they are typically stored at room temperature for 8–12 months before consumption. As presented in Table 4, the total bacterial counts in Siwi dates produced using the traditional method (open sun drying) increased from 3.26 to 4.86 log CFU/g after 8 months. In contrast, the total bacterial counts in Siwi dates produced using the modified method (closed solar dryer) increased from 1.84 to 3.21 log CFU/g, with no significant increase observed after 2 months. Additionally, the bacterial

**Table 4**
The impact of storage duration on the microbial levels of Siwi dates dried using open sun and closed solar dryers.

| Storage period (months) | Microbial counts Log CFU/g (Mean ± SE) | | | |
|---|---|---|---|---|
| | Total bacterial counts | | Fungal counts | |
| | Open sun dried date | Closed solar dried date | Open sun dried date | Closed solar dried date |
| 0 | $3.26^{e} \pm 0.02$ | $1.84^{d} \pm 0.04$ | $3.20^{e} \pm 0.01$ | $2.04^{d} \pm 0.01$ |
| 2 | $3.70^{d} \pm 0.01$ | $1.95^{d} \pm 0.02$ | $3.61^{d} \pm 0.04$ | $2.11^{d} \pm 0.02$ |
| 4 | $4.08^{c} \pm 0.01$ | $2.26^{c} \pm 0.05$ | $3.99^{c} \pm 0.02$ | $2.26^{c} \pm 0.04$ |
| 6 | $4.46^{b} \pm 0.01$ | $2.89^{b} \pm 0.04$ | $4.28^{b} \pm 0.01$ | $2.39^{b} \pm 0.02$ |
| 8 | $4.86^{a} \pm 0.01$ | $3.21^{a} \pm 0.03$ | $4.46^{a} \pm 0.01$ | $2.51^{a} \pm 0.03$ |
| LSD | 0.03 | 0.11 | 0.06 | 0.07 |
| **MPLs** [49] | 5 | | 3 | |

Means followed by different subscripts within column are significantly different at the 5 % level.
MPLs: maximum permissible limits.

levels in the closed solar dryer Siwi dates at the end of the storage period (3.21 log CFU/g) were lower than the initial bacterial levels in the open sun-dried Siwi dates (3.26 log CFU/g). The total bacterial counts in non-stored and stored Siwi dates dried using two methods were below the MPLs [49]. This may be as a result of the decrease of the moisture content in the dried Siwi dates [67].

Additionally, it was observed that the levels of fungi in the open sun-dried Siwi dates increased from 3.20 to 4.46 log CFU/g by the end of the storage period and were above MPLs [49]. In contrast, the closed solar dried Siwi dates showed a smaller increase in fungi levels, rising from 2.04 to 2.51 log CFU/g and displaying no significant increase after 2 months. Notably, the final levels of fungi (2.51 log CFU/g) in the dried Siwi dates by closed solar drying system were lower than the initial levels of bacteria in the open sun-dried Siwi dates (3.20 log CFU/g). The reduced microbial load in the stored solar energy-dried Siwi dates can be attributed to the shorter drying period of 3 days, during which temperatures can reach 65–70 °C, as reported in Figure (4). The combination of high temperature and brief drying time can effectively decrease the initial microbial load [65]. Moreover, the moisture level of the Siwi dates plays a crucial role in their storage stability and shelf life [67]. Consequently, the high temperature during solar energy drying can contribute to a decrease in the moisture content of the Siwi dates, which serves as a preservation factor throughout the storage period.

## 4. Conclusion

The utilization of closed-system solar technology for drying Siwi dates offers a protective measure against damage caused by birds, insects, and unexpected rainfall. Additionally, it serves to minimize the presence of microbial load (such as bacteria, and fungi), aflatoxins, and heavy metals in both dates and date products. Findings from this study indicate that solar energy drying significantly reduces contamination levels in Egyptian Siwi dried dates. Moreover, the duration of storage for solar energy dried dates exhibited a notable impact on the microbial loads, surpassing that of open sun drying. Consequently, this study strongly recommends the adoption of solar technology for drying Egyptian Siwi dates and other agricultural crops to enhance the safety of dates during production and preservation for human consumption among local processors in the study areas and Egypt as a whole.

## Data availability statement

The authors confirm that the data supporting the findings of this study are available from the corresponding author Abdel-Rahman G. N. on request.

## CRediT authorship contribution statement

**Gomaa N. Abdel-Rahman:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation. **Essam M. Saleh:** Methodology, Formal analysis, Data curation, Conceptualization. **Aiat Hegazy:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Ahmed S.M. Fouzy:** Writing – original draft, Software, Formal analysis, Data curation. **Mohamed A. Embaby:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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