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BASIL QUALITY AS AFFECTED BY DRYING SYSTEM, DRYING TEMPERATURE AND PLANT LAYER THICKNESS

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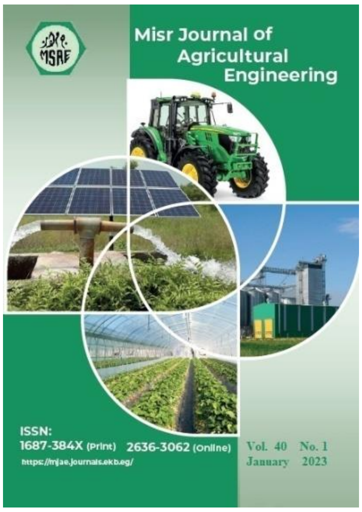

Keywords:
Basil; Hybrid Solar drying; Oven drying; Moisture content; Drying rate; Essential oil content.

ABSTRACT

The main aim of this study is to study the effect of different drying systems drying temperature and plant layer thickness of the quality of dried basil. To achieve that studied the effect of drying systems (hybrid solar and oven drying) and different thickness layer (1, 2 and 3cm) on the weight loss, moisture content, drying rate and essential oil content. The accumulated weight loss of basil leaves ranged from 79.07 to 83.54 % for all treatment under study. The moisture content of basil leaves ranged from 377.83 to 507.10 % d.b. for all treatment under study. The highest value of the drying rate of basil leaves (382.22 g_{water} kg^{-1} h^{-1}) was obtained when the basil dried by oven drying system at 50 °C with 1 cm plant layer thickness. The highest value of the basil oil content (1.8%) was obtained when the basil dried by Hybrid-drying system at 50 °C.

1. INTRODUCTION

The medicinal plants are a good source of natural antioxidants with potential application in the food and pharmaceutical industries **(Milenković et al., 2021)**. Herbs and spices are among the natural compounds that are currently being used as food preservatives, which contain compounds with marked antioxidant and antimicrobial properties **(Nieto, 2020)**. Herb drying is a common stabilization technique in preserving vital qualities of essential oil yield and bioactive compounds **(Nurhaslina *et al.*, 2022)**. Sweet Basil (*Ocimum basilicum L.*) is considered one of the most comically aromatic crops, used as a sedative and digestive due to the presence of essential oil and also is popular for different horticulture uses. It is also used as a toxin eliminator, to treat coughs, colds, and insomnia & constipation treatment **(Sharafati Chaleshtori et al., 2015)**.

Drying is the most common process for preservation of agricultural products. Various methods are applied, depending on the properties and requirements of the product. Sun drying and in-field drying are still applied in developing countries using sun and wind as the only energy sources. In countries with highly mechanized agricultural production, automated high capacity high-temperature dryers are applied for drying almost all agricultural products **(Muhlbauer and Muller, 2020 and El-Kashoty *et al.*, 2020).** Drying must be executed carefully in the interest of retaining the taste, aroma, color, appearance, as well as nutritional value of the plants to maximum possible extent. In addition to quality considerations, drying efficiency is another key aspect for evaluating drying performance **(Jin *et al.*, 2017)**.

Sun drying is one of the oldest methods of drying herbs, and it is still widely used to dry plants such as herbs and spices, particularly in tropical and sub-tropical areas **(Orphanides *et al.*, 2016 and Khater *et al.*, 2019)**. It is considered a superior method due to its low investment needed. Fresh plant parts are usually placed on drying racks and placed under direct sunlight, exposing the plant material to solar radiation **(Nurhaslina *et al.*, 2022)**.

The most common and favored drying method for a lab-scale experiment is the hot-air oven drying at a temperature range of 40–60 °C **(Shaw *et al.*, 2006)**. Hot-air drying (HAD) is widely used in industrial drying fields for the dehydration of food and agricultural products due to its lower risk of microbial contamination, low investment cost and better control of drying conditions**(Isik *et al.*, 2018 and Bi *et al.*, 2022)**.

Solar-assisted drying has developed to improve the traditional sun-drying method. As solar energy is renewable, free energy, the development of this technology has gained recognition among researchers in attempting to overcome major problems commonly posed by sun-drying whilst increasing efficiency in the drying process of plants and herbs (**Mugi *et al.*, 2022)**. Solar drying mechanisms can be classified into three types: natural sunlight drying, indirect solar drying, and a hybrid of both solar drying mechanisms **(Janjai and Bala, 2012)**. In hybrid solar dryers, the moisture in the food products is evaporated by not only solar energy but through other auxiliary energy sources such as biomass, electricity, waste heat, etc**.**

Temperature of drying and plant layer thickness are the most important factors affecting the product quality and shelf life after drying, therefore, the main aim of this work is to study the effect of drying temperature and plant layer thickness on the weight losses of basil, drying time, final moisture content and drying rate.

2. MATERIALS AND METHODS

The experiment was carried out at Agricultural and Bio-Systems Engineering Department, Faculty of Agriculture Moshtohor, Benha University, Egypt (latitude 30° 21\` N and 31° 13\` E). During the period of July and August, 2022 season.

2.1. Materials:

The fresh basil was brought from the Faculty of Agriculture Farm, Moshtohor, Benha University after harvesting for primary analysis.

2.1.1. Drying system:

The basil was dried using different systems as follows:

2.1.1.1. Hybrid solar drying:

Figure (1) illustrates the hybrid solar drying system description. It shows the system which consists of solar collector, drying chamber, trays, fans and electric heater.

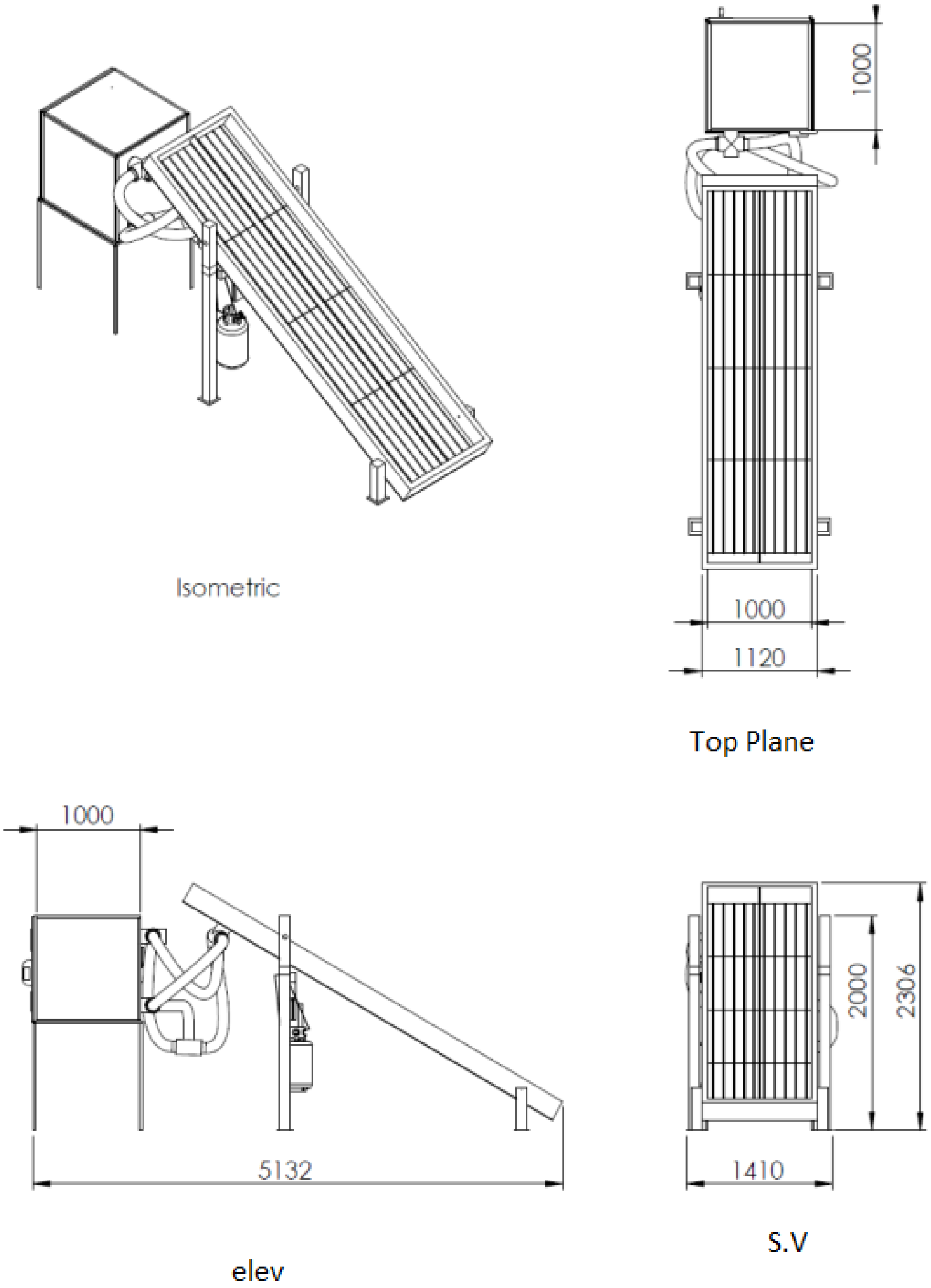

Figure (1): Elevation, plan and side view for the solar dryer.

1-The solar collector:

The solar collector consists of three major components, namely: The glass cover has dimensions of 4.0 m long, 1.0 m width and 5.5 mm thickness. The cover is fixed on a wooden frame with a thickness of 10 cm. It is divided into two lanes, 50 cm wide each. The absorber plate is made from corrugated black aluminum plate. The insulation is thermal wool with a 5.0 cm thickness as shown in figure 2.

2- The drying chamber:

The drying chamber has a length of 1.0 m, width of 0.75 m and height of 1.0 m. It is made of galvanized steel (5 mm thickness). The inner surface of drying chamber is covered an isolated materials to reduce heat loss from the walls as shown in figure 3.

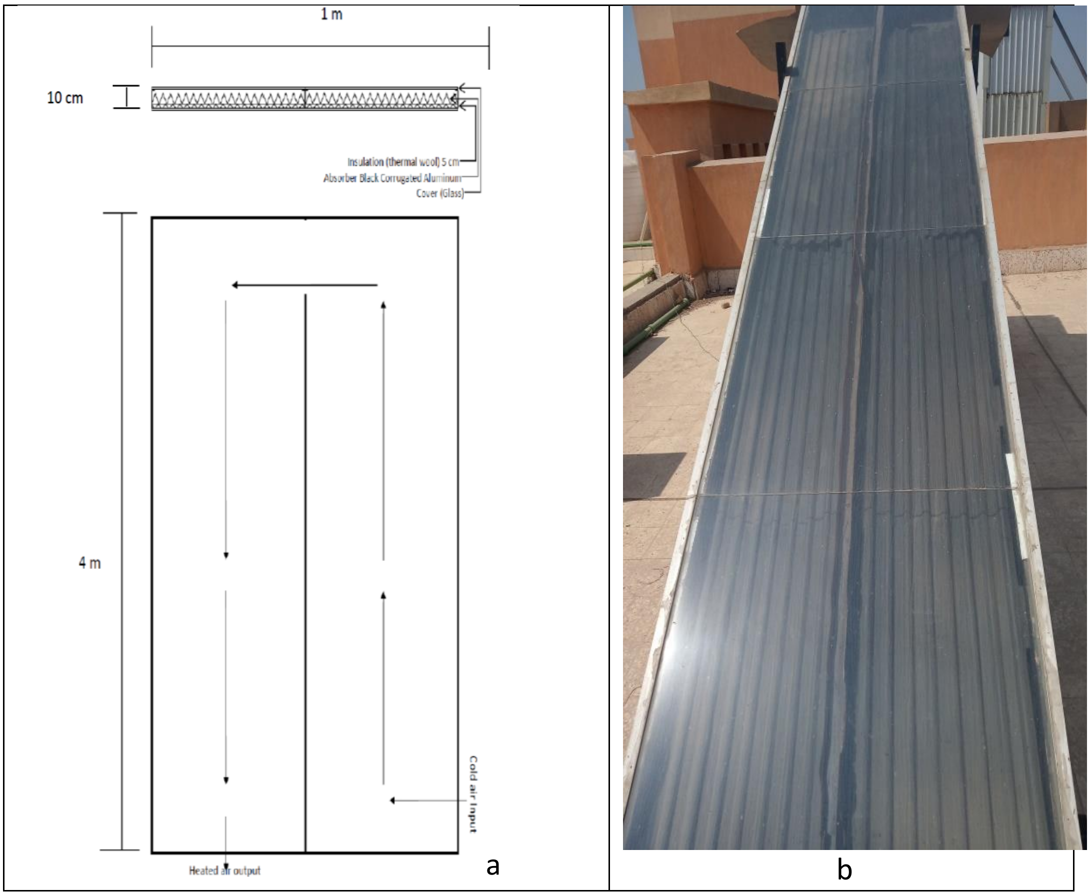

Figure 2: Solar collector. (a) Geometric view (b) Top view.

Figure 3: The drying chamber.

3- The trays:

The trays are made of stainless steel and have a length of 0.30 m, width of 0.20 m and height of 0.07 m. They have perforated bottom which allows heated air to pass through products.

4- Temperature control unit

Digital temperature controller (REX_C100 PID) it is used to control the start and stop of the additional heat source (the electric heater 2000 watts) to ensure the stability of the temperature inside the drying room as shown in figure (4).

Figure 4: Temperature control unit.

2.1.1.2. Oven-drying:

Basil plants were spread evenly on baking sheets and placed in conventional laboratory oven (Fisher Scientific Isotemp Oven, Model 655F Cat. No. 13- 245-655, Fisher Scientific, Toronto, Ontario, Canada).

2.2.Methods:

Basil was cleaned by removing undesired stems and waste materials as shown in the process flow chart (figure 5).

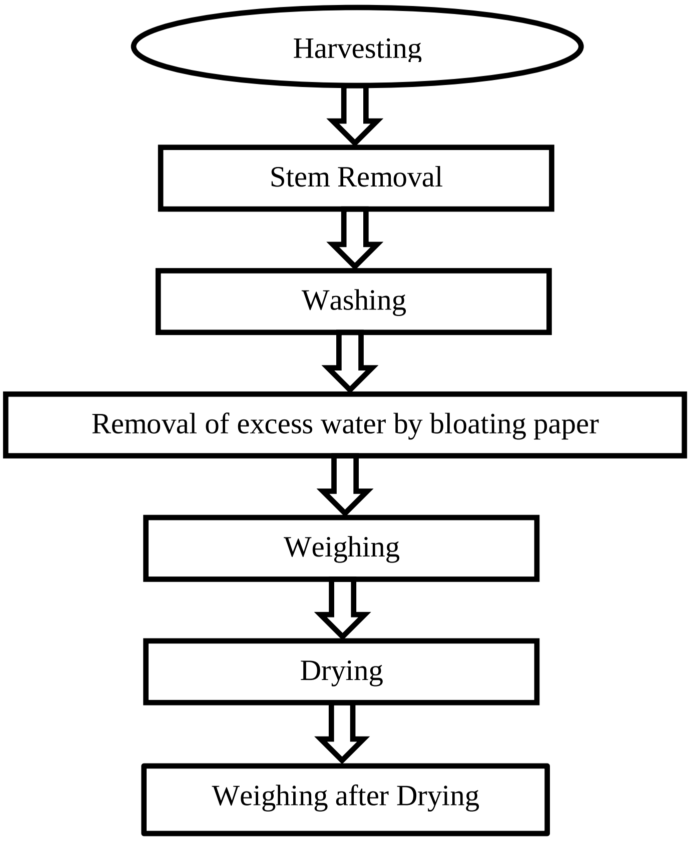

Figure 5: Flow chart of basil processing

2.2.1. Treatments:

In this study, the treatments include: two drying systems (hybrid solar and oven systems), drying temperatures (50, 60 and 70 °C) and three thickness layer were (1, 2 and 3 cm).

2.2.2. Measurements:

The mass was measured by electric digital balance (Model HG – 5000 – Range 0 - 5000 g ± 0.01 g, Japan) hourly for solar, hybrid solar and oven drying methods. Temperature and relative humidity were recorded by using a HOBO Data Logger (Model HOBO U12 Temp/RH/Light – Range -20 to 70 °C and 5 to 95% RH, USA) every hour. The content of oil was determined in basil plants according to **(Kiferle *et al.*, 2011).**

2.2.3. Calculations:

- Moisture content:

Moisture content of the fresh and dried mint leaves was determined using conventional laboratory oven kept at 105 °C until constant weight was reached. Triplicate determinations were made and the moisture content calculated as the following equation:

$$MC = \frac{\mathrm{M_{wet}} - M_{dry}}{\mathrm{M_{dry}}} \times 100 \tag{1}$$

Where:

MC is the moisture content, % d.b.

M_{wet} is the wet mass of samples, g

M_{dry} is the dry mass of samples, g

- Drying rate:

The drying rate (DR) of basil was calculated using the following equation:

$$DR = \frac{\mathrm{M_{t+dt}} - M_t}{\mathrm{dt}} \tag{2}$$

Where:

DR is the drying rate, ($kg_{water}/kg_{dry\ base}.hr$)

Mt is the moisture content at any time t, % d.b.

Mt+dt is the moisture content at t+dt, % d.b.

3. RESULTS AND DISCUSSION

3.1. Weight loss:

Figures (6a, b and c) show the accumulated weight loss of basil leaves that dried in different drying systems (hybrid solar and oven drying) under different drying temperatures (50, 60 and 70 °C) and different air thickness layers (1, 2 and 3 cm) during experimental period. The results indicate that the accumulated weight loss of basil leaves increases with increasing drying temperature and thickness layer during drying period. It could be seen that the accumulated weight loss of basil leaves increased from 37.85 to 80.10, 26.27 to 82.98 and 17.46 to 80.50 %, when the drying period increased from 1 to 6.5, 1 to 8.5 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature for hybrid solar drying system. For oven drying system, the accumulated weight loss of basil leaves increased from 37.52 to 79.07, 26.22 to 82.39 and 16.97 to 82.38 %, when the drying period increased from 1 to 6.5, 1 to 8.0 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature. These results agreed with those obtained by **Abd El-Haq *et al.* (2020)**.

At 60 °C drying temperature, the accumulated weight loss of basil leaves increased from 49.28 to 81.09, 34.76 to 83.14 and 26.02 to 80.80 %, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the accumulated weight loss of basil leaves increased from 48.76 to 81.38, 35.56 to 83.08 and 26.93 to 80.29 %, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer.

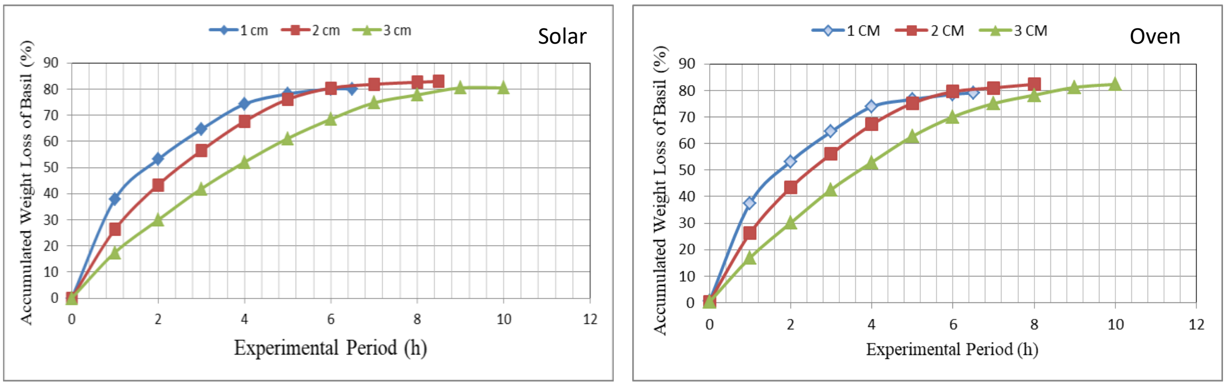

Figure (6a): The accumulated weight loss of basil leaves at 50 °C drying temperature for different drying systems.

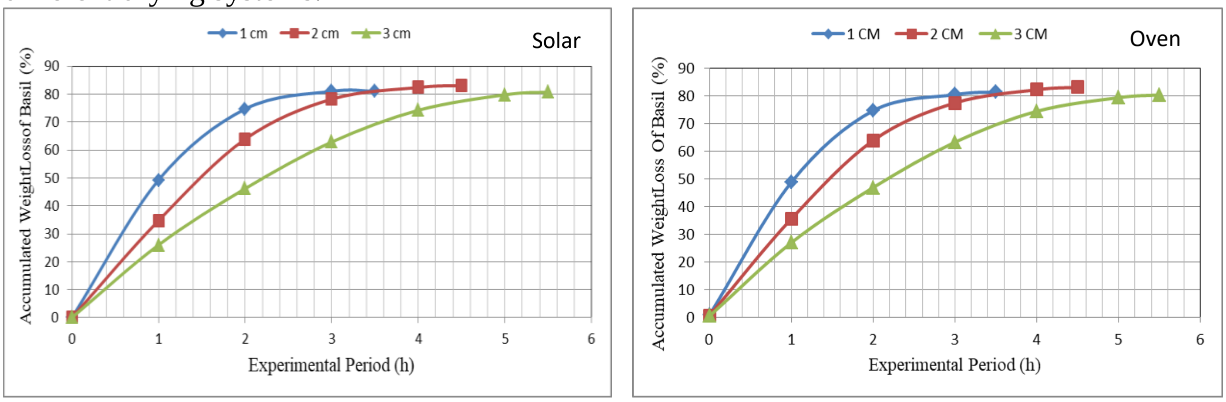

Figure (6b): The accumulated weight loss of basil leaves at 60 °C drying temperature for different drying systems.

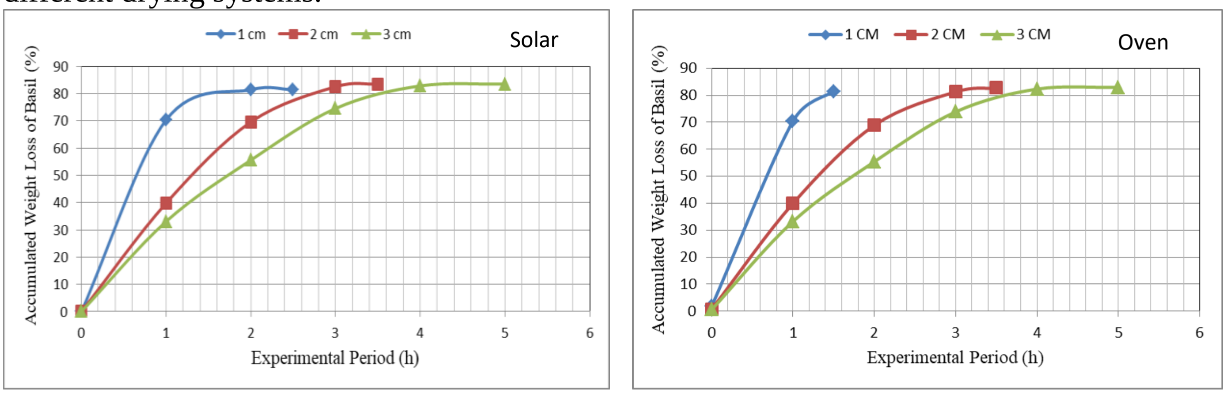

Figure (6c): The accumulated weight loss of basil leaves at 70 °C drying temperature for different drying systems.

At 70 °C drying temperature, the accumulated weight loss of basil leaves increased from 70.35 to 81.49, 39.81 to 83.52 and 33.09 to 83.54 %, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the accumulated weight loss of basil leaves increased from 70.64 to 81.51, 39.95 to 82.73 and 33.25 to 82.97 %, when the drying period increased from 1 to 1.5, 1 to 3.5 and 1 to 5 h, respectively, for 1, 2 and 3 cm thickness layer.

The results indicate that the accumulated weight loss of basil leaves increases with increasing drying temperature for hybrid solar and oven drying systems, it could be seen that the accumulated weight loss of basil leaves increased from 80.10 to 81.49, 82.98 to 83.52 and 80.50 to 83.54 % when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for hybrid solar drying system. Also, the accumulated weight loss of basil leaves increased from 79.07 to 81.51, 82.39, 82.7 and 82.38 to 82.97 % when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for oven drying system. These results agreed with those obtained by **El-Kashoty *et al.* (2020)** whose found the accumulated weight loss increases with increasing drying temperature.

The results also indicate that the shorter drying period (1.5 h) was occurred under the 1 cm plant layer thickness due to the higher temperature (70 °C). Meanwhile, the longer drying period (10 h) was occurred under the 3 cm plant layer thickness due to the lower temperature (50 °C). The trend of these results agreed with those obtained by **Khater and Bahnasawy (2017)**.

3.2. Moisture content:

Figures (7a, b and c) show the moisture content of basil leaves that dried in different drying systems (hybrid solar and oven drying) under different drying temperatures (50, 60 and 70 °C) and different air thickness layers (1, 2 and 3 cm) during experimental period. The results indicate that the moisture content of basil leaves decreases with increasing drying temperature and thickness layer during drying period. It could be seen that the moisture content of basil leaves decreased from 402.64 to 0.90, 487.29 to 1.91 and 412.89 to 13.83 % d.b., when the drying period increased from 1 to 6.5, 1 to 8.5 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature for hybrid solar drying system. For oven drying system, the moisture content of basil leaves decreased from 377.83 to 2.25, 467.62 to 7.78 and 467.36 to 6.71 % d.b., when the drying period increased from 1 to 6.5, 1 to 8.0 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature. These results agreed with those obtained by **Abd El-Haq *et al.* (2020)**.

At 60 °C drying temperature, the moisture content of basil leaves decreased from 425.91 to 0.90, 493.01 to 4.8 and 420.93 to 5.03 % d.b., when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the moisture content of basil leaves decreased from 437.24 to 5.19, 489.52 to 5.02 and 407.29 to 4.81 % d.b., when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer.

At 70 °C drying temperature, the moisture content of basil leaves decreased from 440.38 to 0.09, 507.10 to 5.89 and 507.63 to 4.11 % d.b., when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the moisture content of basil leaves decreased from 441.08 to 0.097, 507.09 to 10.51 and 487.26 to 3.83 % d.b., when the drying period increased from 1 to 1.5, 1 to 3.5 and 1 to 5 h, respectively, for 1, 2 and 3 cm thickness layer.

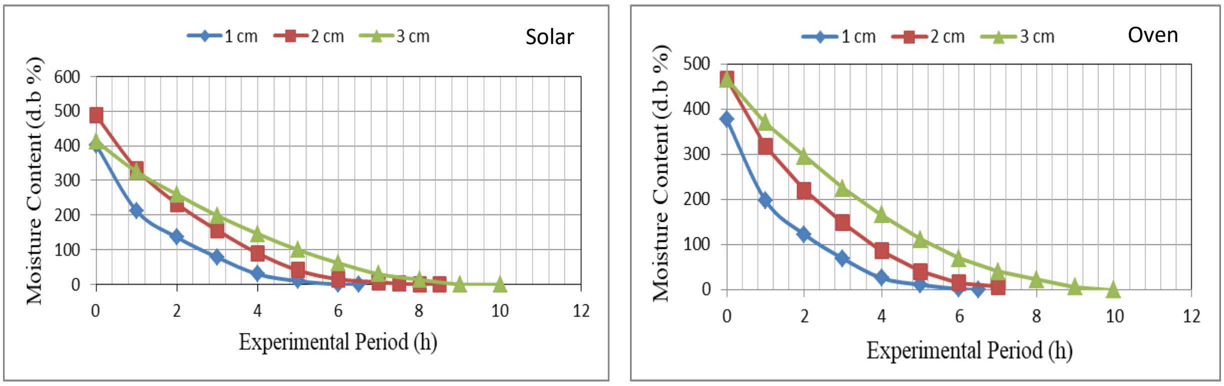

Figure (7a): The moisture content of basil leaves at 50 °C drying temperature for different drying systems.

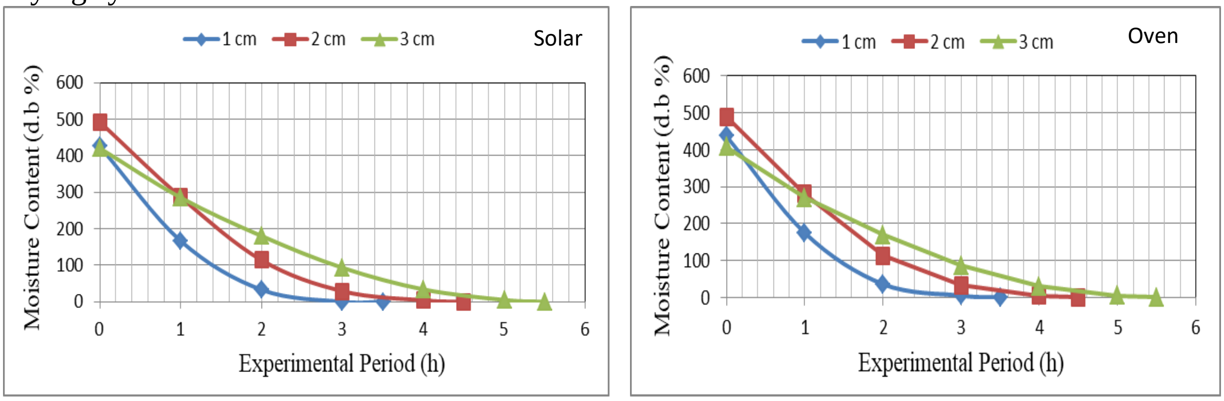

Figure (7b): The moisture content of basil leaves at 60 °C drying temperature for different drying systems.

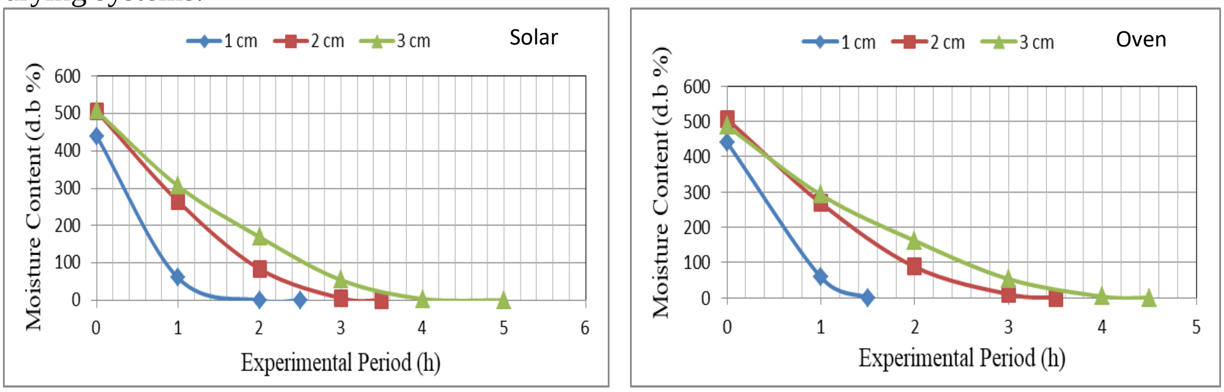

Figure (7c): The moisture content of basil leaves at 70 °C drying temperature for different drying systems.

The results indicate that the moisture content of basil leaves increases with increasing drying temperature for hybrid solar and oven drying systems, it could be seen that the moisture content of basil leaves increased from 402.64 to 440.38, 487.29 to 507.10 and 412.89 to 507.63 % d.b., when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for hybrid solar drying system. Also, the moisture content of basil leaves increased from 377.83 to 441.08, 467.62 to 507.09 and 467.36 to 487.26 % d.b., when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for oven drying system. This is due to increased drying temperature and air recirculating further decrease the relative humidity of a product. This can be explained by the fact that increased temperature and hot airflow inside the drying chamber increases mass and heat transfer, leading to sharper drops in moisture content. These results agreed with those obtained by **Doymaz (2006)** whose found the moisture content increases with increasing drying temperature.

3.3. Drying rate:

Figures (8a, b and c) show the drying rate of basil leaves that dried in different drying systems (hybrid solar and oven drying) under different drying temperatures (50, 60 and 70 °C) and different air thickness layers (1, 2 and 3 cm) during experimental period. The results indicate that the drying rate of basil leaves decreases with increasing drying temperature and thickness layer during drying period. It could be seen that the drying rate of basil leaves decreased from 190.26 to 0.18, 154.33 to 6.38 and 87.69 to 13.79 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 6.5, 1 to 8.5 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature for hybrid solar drying system. For oven drying system, the drying rate of basil leaves decreased from 179.39 to 2.17, 148.86 to 7.78 and 96.3 to 6.71 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 6.5, 1 to 8.0 and 1 to 10.0 h, respectively, for 1, 2 and 3 cm thickness layer at 50 °C drying temperature.

At 60 °C drying temperature, the drying rate of basil leaves decreased from 286.28 to 0.18, 206.19 to 8.16 and 135.54 to 10.06 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the drying rate of basil leaves decreased from 261.98 to 5.19, 209.66 to 4.974 and 136.65 to 4.78 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer. This is due to that the product after short period is getting close to the equilibrium moisture content, which causes decreasing in the drying even when we increase temperature.

At 70 °C drying temperature, the drying rate of basil leaves decreased from 380.19 to 0.18, 241.74 to 11.78 and 201.10 to 4.07 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 3.5, 1 to 4.5 and 1 to 5.5 h, respectively, for 1, 2 and 3 cm thickness layer for hybrid solar drying system. For oven drying system, the drying rate of basil leaves decreased from 382.22 to 0.194, 238.63 to 0.1 and 195.28 to 7.59 g_{water} kg^{-1} h^{-1}, when the drying period increased from 1 to 1.5, 1 to 3.5 and 1 to 5 h, respectively, for 1, 2 and 3 cm thickness layer.

The results indicate that the drying rate of basil leaves decreases with increasing drying temperature for hybrid solar and oven drying systems, it could be seen that the drying rate of basil leaves increased from 190.26 to 380.19, 154.33 to 241.74 and 87.69 to 201.10 g_{water} kg^{-1} h^{-1}, when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for hybrid solar drying system. Also, the drying rate of basil leaves increased from 179.39 to 382.22, 148.86 to 238.63 and 96.30 to 195.28 g_{water} kg^{-1} h^{-1}, when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for oven drying system. These results agreed with those obtained by **Amer *et al.* (2018) and El-Kashoty *et al.* (2020)**.

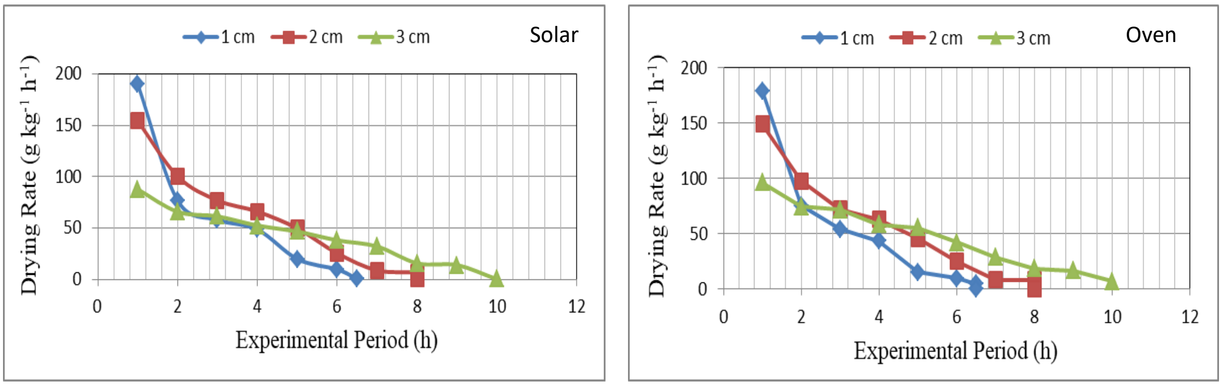

Figure (8a): The drying rate of basil leaves at 50 °C drying temperature for different drying systems.

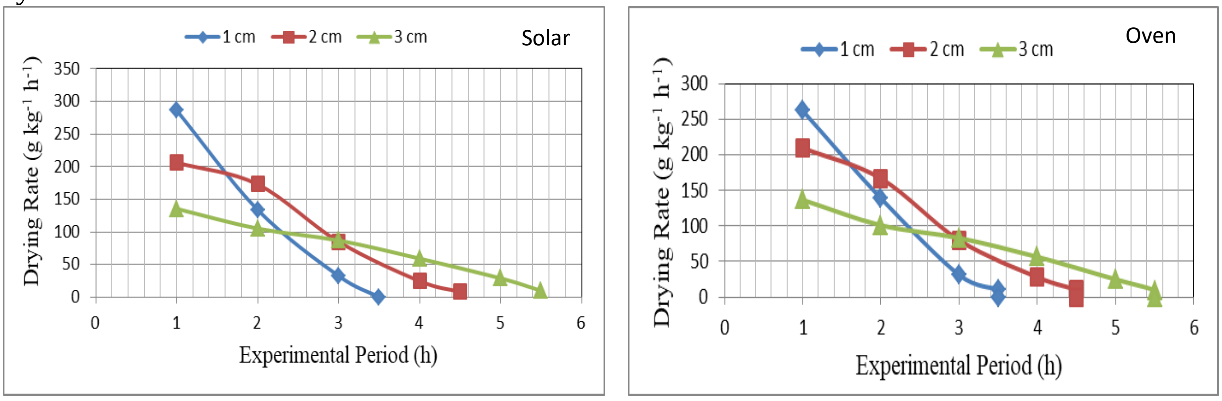

Figure (8b): The drying rate of basil leaves at 60 °C drying temperature for different drying systems.

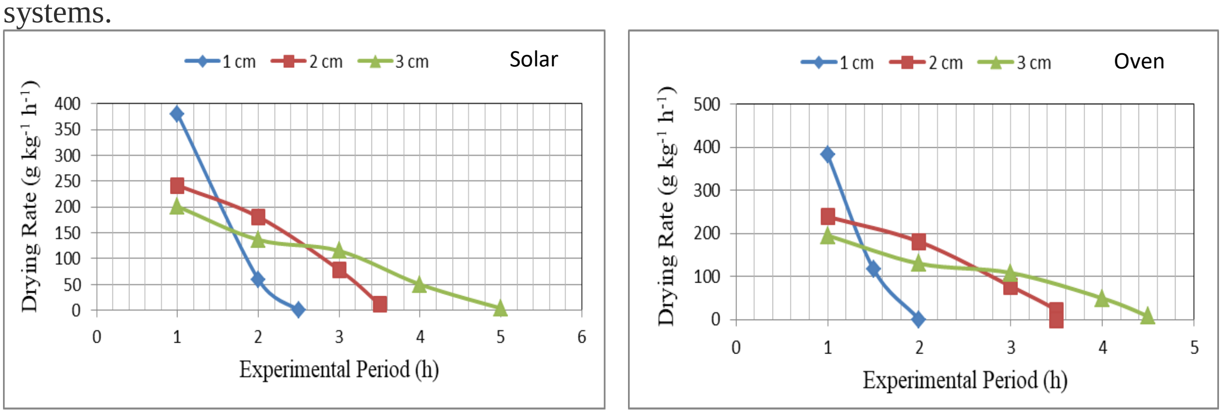

Figure (8c): The drying rate of basil leaves at 70 °C drying temperature for different drying systems.

3.4. Content of oil:

Figure (9) shows the essential oil content of basil leaves that dried in different drying systems (hybrid solar and oven drying) and under different drying temperatures (50, 60 and 70 °C) at the end of experiment. The results indicate that the basil essential oil content decreases with increasing drying temperature for hybrid solar and oven drying systems, it could be seen that the basil essential oil content decreases from 1.8 to 1.0 and 1.5 to 0.2 %, when the drying temperature increased from 50 to 70 °C for hybrid solar and oven drying systems, respectively. The results indicate that the highest value of the basil oil content (1.8%) was obtained when the basil dried by Hybrid-drying system at 50 °C. Meanwhile, the lowest value of the basil oil content (0.20%) was found at the oven-drying system at 70 °C. These results were in agreement with those obtained by **Khater et al. (2019) and Abd El-Haq *et al.* (2020)**. This is due to that some of the essential oil evaporate with moisture the evaporate due to the temperature increment.

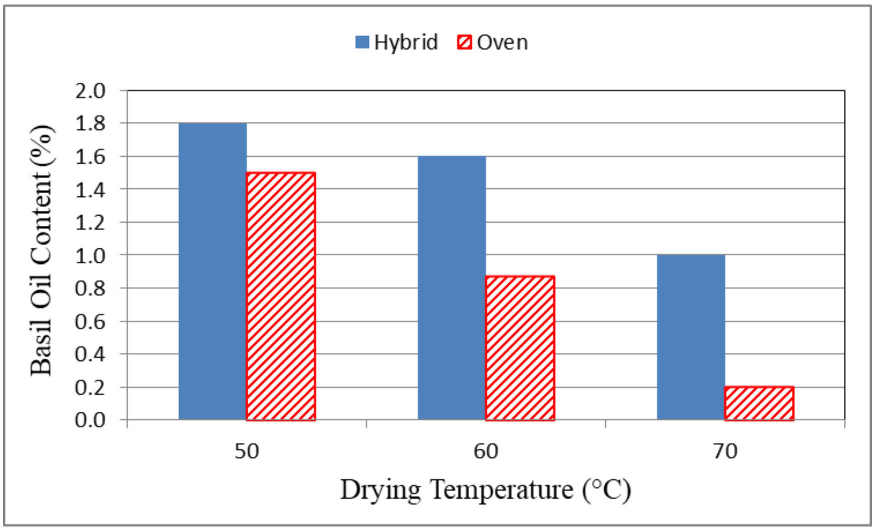

Figure (9): The essential oil content of basil leaves that dried in different drying systems and different drying temperatures.

4. CONCLUSION

The experiment was carried out to study the effect of drying systems (hybrid solar and oven drying) and different thickness layer (1, 2 and 3cm) on the weight loss, moisture content, drying rate and essential oil content. The obtained results can be summarized as follows:

- The accumulated weight loss of basil leaves increased from 80.10 to 81.49, 82.98 to 83.52 and 80.50 to 83.54 and 79.07 to 81.51, 82.39, 82.7 and 82.38 to 82.97%, when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for hybrid solar and oven drying systems, respectively.
- The moisture content of basil leaves increased from 402.64 to 440.38, 487.29 to 507.10 and 412.89 to 507.63 and 377.83 to 441.08, 467.62 to 507.09 and 467.36 to 487.26% d.b., when the drying temperature increased from 50 to 70 °C for 1, 2 and 3 cm thickness layer, respectively, for hybrid solar and oven drying systems, respectively.
- The highest value of the drying rate of basil leaves (382.22 g_{water} kg^{-1} h^{-1}) was obtained when the basil dried by oven drying system at 50 °C with 1 cm plant layer thickness.
- The highest value of the basil oil content (1.8%) was obtained when the basil dried by Hybrid-drying system at 50 °C.

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تأثير نظام التجفيف ودرجة حرارة التجفيف وسمك طبقة النبات على جودة الريحان

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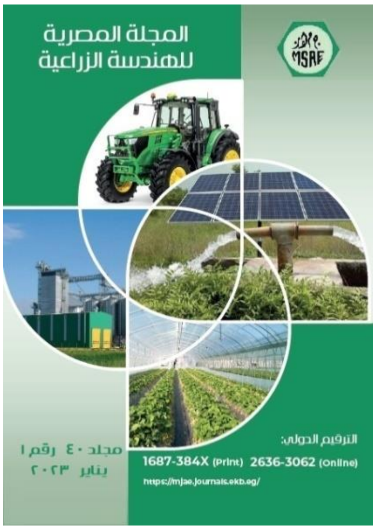

الكلمات المفتاحية:

الريحان؛ التجفيف الشمسي؛ المحتوى الرطوبي؛ معدل التجفيف؛ محتوي الزيت.

الملخص العربي

الهدف الرئيسي من هذه الدراسة هو دراسة تأثير درجات حرارة التجفيف المختلفة لأنظمة التجفيف وسمك طبقة النبات على جودة الريحان المجفف. ولتحقيق ذلك تم دراسة تأثير أنظمة التجفيف (التجفيف الشمسي الهجين والتجفيف بالفرن) وطبقة سماكة مختلفة (١ و ٢ و ٣ سم) على فقدان الوزن ومحتوى الرطوبة ومعدل التجفيف ومحتوى الزيت العطري. زاد فقدان الوزن المتراكم لأوراق الريحان من ٨٠,١٠ إلى ٨١,٤٩ و ٨٢,٩٨ إلى ٨٣,٥٢ و ٨٠,٥٠ إلى ٨٣,٥٤ ومن ٧٩,٠٧ إلى ٨١,٥١ و ٨٢,٣٩ و ٨٢,٧ و ٨٢,٣٨ إلى ٨٢,٩٧٪ ، عندما زادت درجة حرارة التجفيف من ٥٠ إلى ٧٠ درجة مئوية لمدة ١ و ٢ و طبقة بسماكة ٣ سم ، على التوالي ، لأنظمة التجفيف الشمسي والفرن ، على التوالي. زاد المحتوى الرطوبي لأوراق الريحان من ٤٠٢,٦٤ إلى ٤٤٠,٣٨ ومن ٤٨٧,٢٩ إلى ٥٠٧,١٠ ومن ٤١٢,٨٩ إلى ٥٠٧,٦٣ ومن ٣٧٧,٨٣ إلى ٤٤١,٠٨ ومن ٤٦٧,٦٢ إلى ٥٠٧,٠٩ ومن ٤٦٧,٣٦ إلى ٤٨٧,٢٦٪ على اساس الوزن الجاف، عندما زادت درجة حرارة التجفيف من ٥٠ إلى ٧٠ درجة مئوية لمدة ١ و ٢ و طبقة بسماكة ٣ سم ، على التوالي ، لأنظمة التجفيف الشمسي والفرن ، على التوالي. تم الحصول على أعلى قيمة لمعدل تجفيف أوراق الريحان (٣٨٢,٢٢ جم ماء كجم - ساعة واحدة) عند تجفيف الريحان بواسطة نظام التجفيف بالفرن عند ٥٠ درجة مئوية بسمك طبقة نباتية ١ سم. تم الحصول على أعلى قيمة لمحتوى زيت الريحان (١,٨٪) عند تجفيف الريحان بواسطة نظام التجفيف الهجين عند ٥٠ درجة مئوية.