Effect of infrared, hot air, and hybrid drying strategies on appearance acceptability, essential oil yield and quality of volatile compounds of lemongrass leaves (Cymbopogon citratus)

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Research Article

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Abstract

This study aimed to investigate the effect of different strategies of drying with hot air (40, 50, 60°C), infrared (0.5, 0.6, 0.8w/cm²), sequential hot air/infrared, and Simultaneous hot air-infrared on the drying behavior, color, appearance and the yield and the components of essential oil of lemongrass leaves to increase the marketability of the product. Essential oils of lemongrass samples were extracted by hydro-distillation, and Volatile compounds were analyzed by GC-MS. Results showed: a) the suitable method for maintaining a higher color quality of lemongrass leaves was drying only by hot air drying at 60°C; b) for preserving and obtaining a higher yield of the essential oil content of lemongrass, the best strategy was the simultaneous hybrid drying by hot air drying at 50°C and infrared drying with radiation intensity of 0.6 w/cm²; and c) the data analysis represented that for obtaining the higher value of Volatile compounds of neral and geranial were drying only with infrared having the radiation intensity of 0.6 w/cm² and drying with infrared radiation intensity of 0.8 w/cm² respectively.

1. Introduction

_Cymbopogon citratus_ (Family: _Poaceae_) is one of the famous and expensive aromatic herbs that is called lemongrass because of its lemony odor. This lemony smell is also because of its high content of the citral (Hanaa et al. 2012). Other known names for lemongrass are oil grass, silky heads, and citronella grass (Nguyen et al. 2019). Lemongrass is an important genus of approximately a hundred and twenty species that grows in tropical and subtropical areas around the world. Also, it is cultivated on a large scale because of its various uses in the pharmaceutical, cosmetics, food, flavor, and agriculture industries (Hanaa et al. 2012; Akhila 2009). Its various uses in medicine can be mentioned that its treatment of nervous and gastrointestinal disturbances, and also antispasmodic, antimicrobial, and anticancer (Mukarram et al. 2021), analgesic, anti-inflammatory, antipyretic, diuretic and sedative properties (Santin et al. 2009). It is not easy to supply fresh plants all over the world with preserving their quality, so drying is a suitable way for maintaining quality because dried herbs lose their quality slower than fresh herbs and also makes storage and transport of dried herbs more manageable (Díaz-Maroto et al. 2007; Szumny et al. 2010). Drying is considered as the most common and fundamental method for the postharvest preservation and retaining of bioactive compounds of herbs (Chua et al. 2019). The results of research on the effect of various methods of drying on the chemical composition and content of essential oil showed that the drying method had a considerable impact on the essential oil content and composition of aromatic herbs (Venskutonis 1997; Morsy 2004; Okoh et al. 2008; Shanjani et al. 2010; Omidbaigi et al. 2004). One of the best drying methods for increasing the shelf life of the products is convection drying (hot-air drying) (Nguyen et al. 2019). While there are several important advantages of infrared drying over hot-air drying. The time of the drying process can be reduced, and the quality of dried products, including fruits, vegetables, and grains, can be increased by infrared drying (Zhu et al. 2002; Balbay et al. 2011). The other benefits of infrared drying include its higher rate of drying and energy saving (Nowak and Lewicki 2004; Alibas 2007).

Hybrid-drying techniques have shown promising results in the improvement of dried herbs quality, including both color and aroma (Thamkaew et al. 2021). In recent years, the application of combined infrared and hot air drying is considered to be more efficient over radiation or hot air heating alone as it gives a synergistic effect. The results indicated that hybrid drying could significantly reduce the drying load time compared with hot air or infrared drying (Hebbar et al. 2004).

Although a few reports are available on the drying behavior of lemongrass, no scientific work has been reported yet on the effects of the infrared and hybrid hot-air-infrared drying on the Cymbopogon leaves. Therefore, the aims of this study were to evaluate the efficacy of hot air drying (40, 50, 60 °C), infrared drying (0.5, 0.6, 0.8w/cm²), and combined hot air-infrared drying to investigate the global color difference between dried and fresh lemongrass leaves and determining the optimum drying method for drying lemongrass leaves considering the higher yield of essential oil and the higher yield of necessary and main volatile compounds of essential oil such as two geometric isomers of the aldehyde citral; geranial (citral a) and neral (citral b).

2. Materials And Methods

2.1. Material

Fresh lemongrass leaves were collected from a farm in a village in Hormozgan province, Iran (Fig. 1). The initial moisture content of the material was 70.0 ± 3% (W.b). First of all, fresh leaves with uniform physical characteristics were manually selected and cleaned to become devoid of any dirt and dust. Then they were cut into 15 cm lengths and chopped into 5 cm pieces (Fig. 2) with a clean and sharp carpet knife (Lonkar et al. 2013).

2.2. Methods

2.2.1. Moisture content
The moisture content of samples was obtained by AOAC standard method (Hashim et al. 2019). About 20g of fresh chopped lemongrass before and about 5g of dried chopped pieces after each drying process were put into an oven dryer on an aluminum foil on the oven dryer tray at 80.0 ± 2.0 °C for 48 h to obtain the initial and final moisture content respectively and after taking the samples out of the oven drying, their weight was measured by a digital balance having most minor count of 0.01 mg and their moisture content were obtained by using the following equation (Eq. 1):

\[ M_0 = \frac{m_1 - m_2}{m_1} \times 100 \]  

(Eq. 1)

Where \( M_0 \) is the percentage of moisture content of the sample (%), \( m_1 \) is the weight of the sample before drying (g), and \( m_2 \) is the weight of the sample after drying (g).

### 2.2.2. Drying Procedure

The constructed laboratory-scale hybrid hot air-infrared dryer was used for hot air, infrared, and hybrid drying experiments (Fig. 3). In all drying procedures, first of all, the dryer was set at Specific intensity of infrared radiation or temperature. Then after achieving steady-state conditions, a thin layer of the samples (100g) was put on the tray dryer. The weight of samples was measured by a pre-calibrated digital balance at 3-minute intervals during the drying process and recorded in an Excel file through an RS232 connection connected to a computer unit. Each drying experiment stopped when the samples’ moisture content reached 12%.

#### 2.2.2.1. Hot air drying

The hot air-drying method was operated at three temperatures of 40°C, 50°C, and 60°C with a constant air velocity of 1 m s\(^{-1}\) with three replications (Nguyen et al. 2019).

#### 2.2.2.2. Infrared drying

The infrared drying method was operated at three intensities of infrared radiation of 0.5 w/cm\(^2\), 0.6 w/cm\(^2\), and 0.8 w/cm\(^2\) with three replications. The distance between the infrared lamp and the tray was 28 cm, determined from preliminary trials.

#### 2.2.2.3. Hybrid drying

Based on preserving the highest content of essential oil and color of the product, the combination of the optimum temperature of the hot air-drying method and the best intensity of infrared radiation of infrared drying, this method was conducted as follows:

1. Simultaneous drying by hot air and infrared
2. Two-stage sequential hot-air and infrared drying (firstly, hot air drying until 50% of the moisture content of the product was removed and then continued with infrared until the end of drying).
3. Two-stage sequential infrared and hot-air drying (Firstly, infrared drying until 50% of the moisture content of the product was removed and then continued with hot air until the end of drying).

### 2.2.3. Colorimetric parameters of lemongrass leaves

Before and after drying, five leaves at five different locations in the tray were selected randomly and photographed in the Hunter lab chamber to determine Colorimetric parameters (L*, a*, and b* values) by the Matlab software. L*, a*, and b* stand for Lightness, Redness, and Yellowness, respectively. After obtaining the values of color coordinates, the total color difference (\( \Delta E \)) was obtained by using the following equation (Eq. 2):

\[ \Delta E = \sqrt{(l_0^* - l_i^*)^2 + (a_0^* - a_i^*)^2 + (b_0^* - b_i^*)^2} \]  

(Eq. 2)

Where the index “0” refers to the color of fresh leaves and the index “i” in the equation refers to the color of dried leaves.

### 2.2.4. Extraction of essential oil from lemongrass leaves

After each drying process, the dried lemon grass leaves (50g) were used to extract the essential oil by hydro-distillation method for 3–4 hours(until the essential oil volume remained constant) using a Clevenger-type apparatus at the temperature of 60°C (Shahrivari et al. 2022; Guenther and Althausen 1948).
2.2.5. Gas chromatography-mass spectroscopy analysis of essential oil

The analysis and identification of the Volatile compounds of essential oil of lemongrass were made by gas chromatography-mass spectroscopy (GC/MS) apparatus. GC–MS analyses were carried out using an Agilent, 19091S-433, GC–MS system equipped with an HP-5MS column (30 m × 0.25 mm, film thickness 0.25 µm); oven temperature was 70-240°C at a rate of 7 °C/min, transfer line temperature 240°C, carrier gas was helium with a flow rate of 1 ml/min, split ratio 1:35, ionization energy 70 eV, and mass range 2–800 a.m.u.

2.2.6. Statistical analysis

In this study, statistical analysis was performed using IBM SPSS statistics version 26 software. All comparisons were subjected to a one-way analysis of variance (ANOVA), and significant differences between treatments means were determined using the Least Significant Difference (LSD) test at p < 0.05. All graphs were drawn by Excel software.

3. Results

3.1. Drying curves of lemongrass leaves

The drying curves of lemongrass leaves underwent different conditions, showing that the moisture content decreased from 70% (wet basis) to 10–12% (wet basis) with increasing drying time, with drying times varying from 150–1500, 65–170, and 165–405 min for hot air drying, infrared drying, and hybrid drying, respectively (Figs. 4, 5 and 6). The pattern of the drying process described in all figures differs from the standard drying process, which consists of three periods (initial period, constant-rate period, and falling-rate period) because it shows only two periods. According to recent studies, the constant rate period occurs very quickly in fruit and vegetable drying processes, which is why this period does not exist in them (Nguyen et al. 2019; Onwude et al. 2016). The drying process of the lemongrass samples continued from the initial moisture content of 70% (the initial period) until reaching the final moisture content of 10–12% (the falling-rate period). The reason for reaching this range of the final moisture content is to preserve the essential oil in the lemongrass plant because in lower than these amounts, due to excessive drying of the plant, the essential oil in it will decrease (Kumar et al. 2015; Coradi et al. 2014; Barbosa et al. 2008). Also, because of these low final moisture content values, the shelf life of dried samples is more likely to be longer (Olusola 2009).

The rate of surface evaporation and diffusion of moisture from the center to the surface accelerates with the increase in drying air temperature, and with the increase in the rate of evaporation, the drying time decreases (Nguyen et al. 2019). In Fig. 4, Successive increases in temperature significantly reduced drying time, especially when the temperature was increased from 40 to 60°C. Hot air drying led to a 90% reduction in the drying time, which may be due to the increase in thermal driving force in lemongrass due to the increase in temperature. It took 1500,660 and 150 minutes to dry lemongrass leaves to a final moisture content of 10–12% at 40, 50, and 60°C, respectively. Mujaffar and John (2018) found that increasing temperature from 40 to 60°C resulted in a considerable decrease in the total drying time of lemongrass leaves. Unfortunately, the hot air drying was not effective in improving the drying efficiency, except at 60°C. Concerning the effect of temperature, similar results were reported by Kohout et al. (2005) and Xu et al. (2022).

Penetration into the depth of wet materials and uniform distribution of temperature and heat, as well as the higher power density in the infrared dryer than the hot air dryer, significantly reduce the drying time in infrared drying and increase the quality of the final dried product (Riadh et al. 2015). In Fig. 5, infrared drying curves show a significant reduction in drying time with the increase in the intensity of infrared radiation level. Drying times for infrared drying having the radiation intensity of 0.5, 0.6, and 0.8 w/cm² were 170, 90, and 65 minutes, respectively. On the other hand, infrared drying has higher energy efficiency compared to hot-air drying (Thamkaew et al. 2021). These results are in agreement with the similar observation of Sharma et al. (2009).

As shown in Fig. 6, during drying, the moisture content of leaves was found to decrease in a typical manner, with an initial rapid decline followed by a gradual decrease toward equilibrium. Also, there is a direct relationship between drying temperature and drying speed and an inverse relationship between drying temperature and drying time. So, as the temperature increases, the drying speed also increases, but the drying time decreases. Drying time for simultaneous drying by infrared and hot air drying, sequential drying by first infrared and then hot air drying, and sequential drying by first hot air and then infrared drying were 375, 165, and 405 minutes, respectively. These results are in agreement with the results obtained by Belghit et al. (2000). Also, Heber et al., conducted a similar study on potatoes and carrots. They concluded that infrared drying time and a combination of that with hot air drying were reduced by 48% compared to hot air drying (Onwude et al. 2016). Time is one of the most critical factors in industrial food drying, which can be reduced and improved by using infrared drying instead of some other drying methods, such as hot air drying. Considering the effect of drying methods on the leaves of lemongrass, infrared drying with the shortest drying time was found to possess a higher drying efficiency than the other drying methods. This higher drying efficiency may be because lemongrass leaves are thick and difficult to dry, but infrared radiation with penetrating ability can quickly heat the leaves by instigating the vibration and friction of water molecules and, as a result, can reduce the drying time by increasing the
drying speed. These results are in agreement with the results of Huang et al. (2021), regarding the evaluation of drying characteristics and quality of *Stevia rebaudiana* leaves by far-infrared radiation.

### 3.2. Selection of best condition for combination in hybrid drying

Color is one of the most important quality parameters that consumers pay attention to before buying any food. There is an inverse relationship between the quality and color difference between fresh and dried plants. A decrease in the amount of color difference increases the quality. The analysis of variance and mean comparisons of the effect of infrared and hot air drying on the global color difference and yield of essential oil of lemongrass leaves were investigated to find out what radiation intensity of infrared and what temperature of hot air is the best condition for hybrid drying (Tables 1 and 2). There was a significant difference between the yields of essential oil of lemongrass leaves dried under infrared and hot air drying. Nevertheless, global color difference was insignificantly (p > 0.05) affected by the infrared and hot air-drying methods. According to Table 1, the highest yield of essential oil was obtained for infrared drying with a radiation intensity of 0.6 w/cm².

**Table 1**

<table>
<thead>
<tr>
<th>The Yield of essential oil</th>
<th>∆E</th>
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<tr>
<td>0.5 w/cm²</td>
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</tr>
<tr>
<td>0.6 w/cm²</td>
<td>1.85a</td>
</tr>
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<td>0.8 w/cm²</td>
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**Table 2**

<table>
<thead>
<tr>
<th>The Yield of essential oil</th>
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<td>Hot air drying</td>
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<td>1.56b</td>
</tr>
<tr>
<td>50°C</td>
<td></td>
</tr>
<tr>
<td>60°C</td>
<td>2.09a</td>
</tr>
<tr>
<td></td>
<td>1.38b</td>
</tr>
</tbody>
</table>

According to Table 2, the highest yield of essential oil was obtained for hot air drying at the temperature of 50°C. Given that the purpose of this study is to maintain the essential oil and the appearance quality of lemongrass, it is clear that the temperature of 50 degrees Celsius and the radiation intensity of 0.6 w/cm² are more suitable and recommended to preserve higher essential oil yield and use them in hybrid hot air-infrared drying.

### 3.3 Effect of drying strategies on the color of lemongrass leaves

The color parameters (*L**, *a**, *b**) and the global color difference (∆*E*) of fresh lemongrass leaves and those obtained after drying with hot air, infrared, and combined hot air-infrared drying are presented in Table 3. There was a significant difference (p < 0.05) between the color acceptability of lemongrass leaves dried under different drying methods. *L**, *a**, and *b* mean values of dried leaves ranged from 51.38 to 58.82, from −3.04 to 3.95, and from 27.21 to 31.70, respectively. In general, compared to the fresh leaves, the different drying methods reduced the *L* and *b* values, and increased the *a* values. The reason for the reduction in *L* values was probably related to the production of dark pigments due to the Maillard reaction (Xiao et al. 2014). Samples dried by hot air and hybrid drying methods showed relatively higher *L* values than those dried by infrared drying, respectively, which indicated that hot air and hybrid drying could produce brighter products.
The loss of quality or the increase in a* values in dried leaves compared to fresh leaves, especially at higher temperatures, can be attributed to Maillard reactions, a decrease in chlorophyll content and essential oils, and thus lead to the formation of a reddish-brown substance (Mujaffar and John 2018; Gong et al. 2021). Samples dried by hybrid and infrared drying methods showed relatively lower a* values than those dried by hot air drying, respectively, indicating that hybrid and infrared drying can produce brighter green products. Also, the low b* values obtained for dry leaves compared to fresh leaves showed that despite the increase of this parameter with increasing temperature in all methods, the amount of yellowness of the plant has decreased, which increases the marketability and acceptability of the plant. These results are in agreement with the similar observation of Xu et al. (2022).

| Table 3 | Effect of different drying methods on the colorimetric parameters of lemongrass leaves |
|---------|-----------------|---------|---------|-------|
|         | L*   | a*     | b*     | ΔE    |
| Fresh leaves | -     | 58.82 ± 3.09 | -3.04 ± 1.83 | 31.70 ± 2.36 | - |
| Hot air drying |    |       |       |       |  |
| 40°C    | 56.47 ± 2.35 | -1.77 ± 2.49 | 27.21 ± 0.65 | 6.61<sup>ab</sup> |
| 50°C    | 56.33 ± 1.62 | 0.32 ± 2.39  | 28.23 ± 2.48 | 8.19<sup>ab</sup> |
| 60°C    | 55.94 ± 1.44 | -1.82 ± 4.44 | 30.02 ± 0.83 | 4.75<sup>b</sup> |
| Infrared drying |       |       |       |       |  |
| 0.5w / cm<sup>2</sup> | 53.36 ± 3.41 | 1.12 ± 1.73  | 27.82 ± 1.97 | 6.95<sup>ab</sup> |
| 0.6w / cm<sup>2</sup> | 51.38 ± 5.60 | 3.95 ± 2.62  | 28.01 ± 3.88 | 5.99<sup>ab</sup> |
| 0.8w / cm<sup>2</sup> | 54.30 ± 1.56 | 2.40 ± 2.34  | 28.73 ± 1.38 | 7.28<sup>ab</sup> |
| Combined hot air-infrared drying |       |       |       |       |  |
| d<sub>hi</sub> | 56.99 ± 3.74 | -0.46 ± 1.96 | 27.75 ± 2.91 | 8.51<sup>a</sup> |
| d<sub>fhi</sub> | 56.13 ± 0.79 | -0.94 ± 1.21 | 27.41 ± 2.88 | 7.01<sup>ab</sup> |
| d<sub>fi</sub> | 54.27 ± 1.91 | -0.08 ± 0.34 | 28.96 ± 2.30 | 6.47<sup>ab</sup> |

L*: Lightness, a*: Redness/greenness, b*: Yellowness/blueness, ΔE: the global color difference between fresh and dried samples, d<sub>hi</sub>: Drying by hot air and infrared drying concurrently, d<sub>fhi</sub>: Drying by hot air drying first, until 50% of the moisture content of the product was removed, and then drying by infrared drying, d<sub>fi</sub>: Drying by infrared drying first, until 50% of the moisture content of the product was removed, and then drying by hot air drying

According to a similar study reported by Senadeera et al. (2020), high temperatures and extended drying times cause color deterioration. According to the global color difference (ΔE) determined based on fresh leaves (Table 3), The best method to preserve the color of lemongrass leaves (the lowest value, 4.75, obtained for the color difference between fresh and dried leaves) is hot air drying at the temperature of 60°C. During the study on the qualitative changes of chrysanthemum cake in a hot air drying (Sefidkon et al.), combined infrared and hot air drying (IR-HAD), and sequential IR-HAD and HAD (IR-HAD + HAD), they concluded that the sequential IR-HAD and HAD (IR-HAD + HAD) show better color protection effects (Xu et al. 2022).

### 3.4 Effect of drying strategies on yield of essential oil of lemongrass leaves

The uses of lemongrass essential oil are: It is a primary raw material for the synthesis of ionone, which is used for the synthesis of some aromatic constituents and vitamin A. Also, it is the major substitute for ‘cod liver oil’ (Kumar et al. 2015). The data of essential oil yield of dried lemongrass leaves have been shown in Fig. 7. The yield of pale-yellow essential oil obtained from different drying methods was between 1.3467 and 2.0967%. Different drying methods were significantly different (p < 0.05) in terms of essential oil yield. Sellami et al. (2012) showed that dried sage plant yielded more essential oils than fresh one.
While according to Fig. 7, the highest yields of essential oil (2.0967% and 2.09%) on a dry weight basis were obtained from the samples dried in the hot air drying at 50°C and from the samples dried by using the hybrid drying (simultaneous drying by hot air and infrared drying), respectively with no significant difference between them. This is due to the fact that the minimum volatile component of essential oil is lost in both of these drying methods (hot air drying at 50°C and simultaneous drying by hot air-infrared drying), so the yield is more. The results are in agreement with the observation of Kumar et al. (2015). Some plants whose effective ingredients are located on the surface of the leaves are most sensitive to temperature and lose a large amount of essential oil due to the rupture of the essential oil glands and its rapid evaporation (Baser and Buchbauer 2009). The long drying process causes more evaporation and reduces the amount of essential oil, and also causes a waste of energy and time. Therefore, considering that the drying method with hot air at 50 °C has a longer drying time (drying time for 22 hours) compared to the hybrid drying method (drying time for 16 hours), it could be concluded that drying of lemongrass leaves in the simultaneous hybrid drying by hot air drying at 50°C and infrared drying with radiation intensity of 0.6 w/cm² is more suitable and recommended for saving time and obtaining higher essential oil yield. These results are in agreement with those obtained by Hanaa et al. (2012).

IR 1: infrared drying with radiation intensity of 0.5w/cm². IR 2: infrared drying with radiation intensity of 0.6w/cm². IR 3: infrared drying with radiation intensity of 0.8w/cm². Air 1: hot air drying at the temperature of 40°C. Air 2: hot air drying at the temperature of 50°C. Air 3: hot air drying at the temperature of 60°C. Air + IR: Simultaneous drying by hot air and infrared drying. Air (first): drying by hot air drying first, until 50% of the moisture content of product was removed, and then drying by infrared drying. IR (first): Drying by infrared drying first, until 50% of the moisture content of product was removed, and then drying by hot air drying

3.4 Analysis of essential oil compounds

Essential oils of dried Cymbopogon citratus leaves, by using different drying methods were analyzed by GC/MS. According to the results of the analysis, the components of the essential oil of each treatment were identified, and their yields were calculated. The yield of major chemical compounds of lemongrass essential oils are presented in Table 4 and listed in order of their retention indices (RI) on the HP-5MS column. The drying method had a significant effect on the proportion of the various components. Based on the results of the analysis, in general, seventeen main constituents were identified in the essential oil of dried lemongrass leaves by different drying methods, which represented 94.75-58.80% of the oil constituents. The main components of the essential oils were geranial (50.43%,... and 33.94%), and neral (39.22%,... and 30.30%) in oils extracted from lemongrass leaves dried by hot air, infrared and hybrid drying, respectively (Table 4); the quality of lemongrass is generally determined by its geranial (citral-a) and neral (citral-b) contents (Hanaa et al. 2012). These results are in agreement with Hanaa et al. (2012); Morsy (2004); Omidbaigi et al. (2004); Sefidkon et al. (2006). The yields of geranial and neral in the essential oil of lemongrass leaves dried by using infrared drying were more than the other drying methods. In the first treatment (infrared drying with radiation intensity of 0.5w/cm²); 52.4%, 39.98%, and 0.35% of the identified compounds were monoterpene, monoterpenoid and sesquiterpenoid, respectively, and the total of compounds was 92.73% (Table 4). In the second treatment (infrared drying with radiation intensity of 0.6w/cm²); 43.68%, 48.74%, and 0.86% of the identified compounds were monoterpene, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 93.28% (Table 4). In the third treatment (infrared drying with radiation intensity of 0.8w/cm²); 53.39%, 40.14%, and 0.55% of the identified compounds were monoterpene, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 94.08% (Table 4). In the fourth treatment (hot air drying at 40°C); 47.16%, 43.1%, 1.34%, and 2.47% of the identified compounds were monoterpene, monoterpenoid, sesquiterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 94.07% (Table 4). In the fifth treatment (hot air drying at 50°C); 43.16%, 41.96%, and 1.21% of the identified compounds were monoterpenone, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 86.95% (Table 4). In the sixth treatment (hot air drying at 60°C); 47.3%, 46.47%, and 0.98% of the identified compounds were monoterpenone, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 94.75% (Table 4). In the seventh treatment (d₁₀₀); 42.97%, 39.59%, 0.48%, and 4.03% of the identified compounds were monoterpenone, monoterpenoid, sesquiterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 87.07% (Table 4). In the eighth treatment (d₂₀₀); 37.60%, 34.45%, and 5.01% of the identified compounds were monoterpenone, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 77.15% (Table 4). In the ninth treatment (d₁₀₀); 33.94%, 38.61%, and 2.94% of the identified compounds were monoterpenone, monoterpenoid, and sesquiterpenoid, respectively, and the total of compounds was 75.49% (Table 4).
antispasmodic, antimicrobial, anti-inflammatory, analgesic, and chemotherapeutic activities (Aprotosoaie et al. 2012). Citral isomers of the citral compound and the most important components of the essential oil of lemongrass. Citral has used such as and the characteristic smell of lemongrass is due to its high content of the aldehyde citral (Hanaa et al. 2012). Monoterpenes give plant oils their characteristic smell, for example, geranial in lemon oil (Webb 2008). The total of compounds, monoterpenes, and sesquiterpenoids of lemongrass essential oil were higher in the first six treatments than in other treatments. Some monoterpenes give plant oils their characteristic smell, for example, geranial in lemon oil (Webb 2019). Citral is a monoterpenoid aldehyde, and the characteristic smell of lemongrass is due to its high content of the aldehyde citral (Hanaa et al. 2012). Neral and geranial are isomers of the citral compound and the most important components of the essential oil of lemongrass. Citral has used such as antispasmodic, antimicrobial, anti-inflammatory, analgesic, and chemotherapeutic activities (Aprotosoaie et al. 2019; Bakkali et al. 2008; 2007).

<table>
<thead>
<tr>
<th>No.</th>
<th>compound</th>
<th>RI</th>
<th>IR0.5w/cm²</th>
<th>IR0.6w/cm²</th>
<th>IR0.8w/cm²</th>
<th>air40°C</th>
<th>air50°C</th>
<th>air60°C</th>
<th>dhi</th>
<th>dfh</th>
<th>dfi</th>
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IR and air stand for infrared drying and hot air drying respectively. $d_{hi}$: Simultaneous drying by hot air and infrared drying, $d_{hi}$: Drying by infrared drying first, until 50% of the moisture content of the product was removed, and then drying by hot air drying, $d_{hi}$: drying by hot air drying first, until 50% of the moisture content of the product was removed, and then drying by infrared drying.

Some components were just in one treatment. For example, Trans farnesol (0.48%) was identified only in the ninth treatment ($d_{hi}$). Beta-farnesene (0.83%) and Citronella (0.37) were identified only in the fourth treatment (hot air drying at 40°C). The applications of Beta-farnesene include DPPH free radical inhibition, anticancer, antibacterial, and antifungal activity, as well as its application in neurodegenerative diseases has shown dose-dependent neuro-protective effects on rat cortical primary neurons, inhibiting the propagation of Intracellular LDH induced by H2O2 and reduction of DNA damage by 47.8% (Shahrivari et al. 2022). The total of compounds, monoterpenes, and sesquiterpenoids of lemongrass essential oil were higher in the first six treatments than in other treatments. Some monoterpenes give plant oils their characteristic smell, for example, geranial in lemon oil (Webb 2019). Citral is a monoterpenoid aldehyde, and the characteristic smell of lemongrass is due to its high content of the aldehyde citral (Hanaa et al. 2012). Neral and geranial are isomers of the citral compound and the most important components of the essential oil of lemongrass. Citral has used such as antispasmodic, antimicrobial, anti-inflammatory, analgesic, and chemotherapeutic activities (Aprotosoaie et al. 2019; Bakkali et al. 2008;
The use of its anti-mutagenic activity to reduce DXR-induced genotoxicity in mouse peritoneal macrophages was reported by Porto et al., 2014. According to Table 4, the higher amount of essential oil of lemongrass plant includes neral and geranial, which have different amounts depending on each drying method. The high amount of these two compounds is due to their high evaporation temperature, and this feature makes them not evaporate much during the drying process (Kumar et al. 2015). It could be concluded that drying lemongrass leaves by using the infrared and hot-air drying strategies, respectively, are more suitable and recommended for obtaining a higher yield of the main components of essential oil. Despite the advantages and various uses of citral, its high amount causes the concentration of its aroma and flavor, which is useful for use in the perfumery industry and the production of soaps, cosmetics, and flavoring for soft drinks (Kumar et al. 2015). In order to determine the best method to obtain a higher amount of neral and Geranial, variance analysis and mean comparisons were performed using the LSD test. Figure 8 and Fig. 9 show mean comparisons of the effect of the drying method on the yields of neral and Geranial obtained from the essential oil of lemongrass, respectively.

There was a significant difference (p < 0.05) between the yield of neral obtained from the essential oil of lemongrass leaves dried under different drying methods. According to the results of the comparisons (Fig. 8), the highest yield of neral belongs to infrared drying having radiation intensity of 0.8w/cm² (45.25%) and also hot air drying at the temperature of 60°C (44.56%), respectively. As previously mentioned, the lengthy drying process causes more evaporation and reduces the amount of essential oil, and also causes a waste of energy and time. Therefore, considering that the drying method with hot air at 60 °C has a longer drying time (two and a half hours) compared to the infrared drying having the radiation intensity of 0.6w/cm² (an hour and a half), it could be concluded that drying of lemongrass leaves in the infrared drying with radiation intensity of 0.6 w/cm² is more suitable and recommended for saving time and obtaining a higher yield of neral obtained from the essential oil. These results are in agreement with those obtained by Hanaa et al. (2012).

There was a significant difference (p < 0.05) between the yield of geranial obtained from the essential oil of lemongrass leaves dried under different drying methods. According to the results of the comparisons (Fig. 9), the highest yield of geranial belongs to infrared drying having radiation intensity of 0.8w/cm² (51.56%), and also infrared drying having the radiation intensity of 0.5w/cm² (50.43%), respectively, but there is no significant difference between them. Therefore, considering that the drying method with infrared having the radiation intensity of 0.5w/cm² has a longer drying time (almost three hours) compared to the infrared drying having the radiation intensity of 0.8w/cm² (almost one hour), it could be concluded that drying of lemongrass leaves in the infrared drying with radiation intensity of 0.8 w/cm² is more suitable and recommended for saving time and obtaining a higher yield of geranial obtained from the essential oil. Hanaa et al. (2012) reported that the yield of geranial in drying lemongrass by oven at 45°C for 7 hours is equal to 24.37, which is consistent with the values obtained in this study.

Declarations

Ethical Approval

This is an observational study and no ethical approval is required.

Competing interests

Roghayeh Setareh is a graduate student at University of Tabriz. Khosro Mohammadi-Ghermezgoli, Hossein Ghaaffari-Setoubadi and Saeideh Alizadeh-Salteh report a relationship with University of Tabriz that includes: employment and speaking and lecture fees.

Authors’ contributions

All authors contributed to the study conception and design. Material preparation were performed by Khosro Mohammadi-Ghermezgoli and Saeideh Alizadeh-Salteh. Data collection and analysis were performed by Khosro Mohammadi-Ghermezgoli and Roghayeh Setareh.
Hossein Ghaffari-Setoubadi developed the hybrid Drying apparatus. The GC/Mass analysis and essential oil-related tables and figures were prepared by Saeideh Alizadeh-Salteh and Roghayeh Setareh. The first draft of the manuscript was written by Roghayeh Setareh and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

**References**


Figures

Figure 1

The lemongrass
Figure 2

The chopped samples

Figure 3

Schematic diagram of hybrid drying system
Figure 4

Curves of hot-air drying of lemongrass leaves at different temperatures

Figure 5

Curves of infrared drying of lemongrass leaves at the different intensities of infrared radiation
Figure 6

Curves of hybrid drying of lemongrass leaves. \( d_{hi} \): Drying by hot air and infrared drying concurrently, \( d_{fi} \): Drying by infrared drying first, until 50% of the moisture content of the product was removed, and then drying by hot air drying, \( d_{fh} \): Drying by hot air drying first, until 50% of the moisture content of the product was removed, and then drying by infrared drying.

Figure 7

Bars represent the essential oil yield (%). The letters indicate statistical significance groups. Treatment means with the same letters are not significantly different.
Mean comparisons of the effect of the drying method on the yield of essential oil of lemongrass

IR 1: infrared drying with radiation intensity of 0.5 w/cm². IR 2: infrared drying with radiation intensity of 0.6 w/cm². IR 3: infrared drying with radiation intensity of 0.8 w/cm². Air 1: hot air drying at the temperature of 40°C. Air 2: hot air drying at the temperature of 50°C. Air 3: hot air drying at the temperature of 60°C. Air+IR: Simultaneous drying by hot air and infrared drying. Air (first): drying by hot air drying first, until 50% of the moisture content of product was removed, and then drying by infrared drying. IR (first): Drying by infrared drying first, until 50% of the moisture content of product was removed, and then drying by hot air drying

Figure 8

Mean comparisons of the effect of the drying method on the yield of neral obtained from the essential oil of lemongrass

IR 1: infrared drying with radiation intensity of 0.5 w/cm². IR 2: infrared drying with radiation intensity of 0.6 w/cm². IR 3: infrared drying with radiation intensity of 0.8 w/cm². Air 1: hot air drying at the temperature of 40°C. Air 2: hot air drying at the temperature of 50°C. Air 3: hot air drying at the temperature of 60°C. Air+IR: Simultaneous drying by hot air and infrared drying. Air (first): drying by hot air drying first, until 50% of the moisture content of product was removed, and then drying by infrared drying. IR (first): Drying by infrared drying first, until 50% of the moisture content of product was removed, and then drying by hot air drying
Mean comparisons of the effect of the drying method on the yield of Geranial obtained from the essential oil of lemongrass

IR 1: infrared drying with radiation intensity of 0.5 w/cm². IR 2: infrared drying with radiation intensity of 0.6 w/cm². IR 3: infrared drying with radiation intensity of 0.8 w/cm². Air 1: hot air drying at the temperature of 40°C. Air 2: hot air drying at the temperature of 50°C. Air 3: hot air drying at the temperature of 60°C. Air+IR: Simultaneous drying by hot air and infrared drying. Air (first): drying by hot air drying first, until 50% of the moisture content of product was removed, and then drying by infrared drying. IR (first): Drying by infrared drying first, until 50% of the moisture content of product was removed, and then drying by hot air drying.