Effects of Different Drying Conditions on Key Quality Parameters of Pink Peppercorns (Schinus terebinthifolius Raddi)

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Received 18 April 2017; Revised 3 June 2017; Accepted 2 July 2017; Published 1 August 2017

Academic Editor: Ángel Calín-Sánchez

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Pink peppercorns, also called pink pepper, are among the most sophisticated condiments in the international cuisine, adding a slightly spicy and sweet taste to food. In recent years, their consumption has shown significant growth in the international market. This culinary spice is obtained from ripe fruits of Schinus terebinthifolius Raddi, a species native to South America. In this work, a methodology for the assessment of pink peppercorn quality under various drying conditions was defined. Experiments were performed in a pilot tray dryer, which ensured integrity of the product. A central composite rotatable design with 11 experiments was devised to study the influence of drying air temperature (35–75°C) and air velocity (0.3–0.9 m/s) on product quality, assessed by moisture content, color (CIELAB system), and volatile compounds. The essential oils of fresh and dried fruits were extracted by hydrodistillation and analyzed by gas chromatography coupled to mass spectrometry. Air temperature had the greatest influence on the quality parameters under study, while air velocity had no statistically significant effect. Considering all quality criteria, temperatures between 40 and 55°C provided the best compromise, yielding an adequate moisture content in the dried product without dramatic degradation of color and essential oil.

1. Introduction

Drying is still the most popular method for preservation of agricultural products (e.g., fruits, vegetables, herbs, and spices), ensuring microbial safety of various biological materials. Nonetheless, this method has several disadvantages and limitations. For example, contact between the dried material and hot air causes degradation of key flavor compounds and nutritional substances, and there is a risk of volatilization of volatile compounds during the drying operation. In addition, undesirable changes in product color, possibly due to Maillard reactions, can be observed in the processed material [1–3]. Both locally and internationally, numerous researchers have attempted to study the influence of drying on the quality of various products, corroborating the importance of additional studies in this area [2–8]. These reports include those on Australian nectarines [4], lemon myrtle leaves (Backhousia citriodora) [5], oregano (Origanum vulgare) [2], lemon verbena (Lippia citriodora) [6], curry leaves (Murraya koenigii L. Spreng.) [7], and lemon peels (Citrus limon cv. lunari) [8].

Pink peppercorns, also called pink pepper, are among the most sophisticated condiments in the international cuisine, adding a slightly spicy and sweet taste to food. In recent years, their consumption has shown significant growth in the international market. This culinary spice is obtained from ripe fruits of Schinus terebinthifolius Raddi, a species native to South America. In the food industry, these fruits are usually sold in dried form and should have a bright red color and a spherical shape in the absence of broken shells.
It should be noted that *S. terebinthifolius* is not related to the pepper family (Piperaceae); rather, this plant belongs to the Anacardiaceae family, being a relative of cashew and mango [9]. Besides its use as a condiment, *S. terebinthifolius* has great commercial potential owing to its medicinal, cosmetic, and pharmaceutical properties [10–12].

In Brazil, production of pink peppercorns is carried out empirically, and the drying step is a crucial operation. *S. terebinthifolius* fruits are dried to inhibit microbial growth and quality decay, thus adding value to the fruits. Another benefit of drying is reduced weight; the removal of large amounts of water from the material makes transport more economical. Nonetheless, if drying is not performed properly, the quality and marketability of the pink peppercorn are affected. In the production of pink peppercorns, appearance (color and integrity) and flavor are among the most important quality criteria. Thus far, few studies have addressed the effect of different drying conditions on key quality and marketability of the pink peppercorn are determined using

\[
\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}.
\]  

The subscript “0” in (1) refers to the color parameters of pink peppercorns obtained from the local market. The Sauter mean diameter \(d_p\) was calculated to represent the mean diameter of *S. terebinthifolius* fruits, according to

\[
d_p = \frac{1}{\sum_{i=1}^{n} (x_i/D_i)}, \tag{2}
\]

where \(x_i\) is the mass fraction of particles with mean diameter \(D_i; D_1\) is the mean diameter of particles retained between one test sieve and the subsequent one. A vibratory sieve shaker (Bertel®, 302 model) and mesh sieves 1/4", 3.5, 4, 5, 6, and 7 (Tyler series, USA) were used. To determine the apparent density of a fruit (\(\rho_a\)), *S. terebinthifolius* fruits were regarded as spheres (\(\Phi_p = 1\)); the spherical volume (\(V_p\)) was calculated as a function of the Sauter mean diameter. The mass of a fruit (\(m_p\)) was determined from the weight of 1000 fruits (\(W_{1000}\)), which was measured using a digital scale (SHIMADZU® AUY220; 0.0001 g accuracy) according to the method described by ISTA [15]. Bulk density (\(\rho_{bulk}\)) of *S. terebinthifolius* fruits was determined by weighing the contents of a cylindrical container of known volume. The measurement was conducted using a 2-L graduated cylinder. Porosity (\(\varepsilon\)), or void fraction, was estimated from the apparent and bulk densities, as described by Rapusas et al. [16].

2.3. Drying, Hydrodistillation, and Chromatographic Analyses. In general, the experimental procedure consisted of two stages: firstly *S. terebinthifolius* fruits were dried, and secondly morphological and physicochemical parameters were characterized, and volatile compounds were extracted from the dried product. The drying of *S. terebinthifolius* fruits was carried out in a pilot thin-layer dryer (tray dryer), described by Silva et al. [13]. The dryer receives atmospheric air from a fan, and air flow is adjusted by a manual valve. The air heating system consists of four electrical resistors connected to a temperature control system. A fixed bed thickness of 1 cm was used in the experiments. Relative humidity (RH) was measured continuously throughout the experiments using a thermohygrometer (Umni®). In each drying assay, drying kinetics and rate (see (3)) were analyzed.

\[
DR = \frac{M_{t_i} - M_i}{t_i - t_{i-1}}, \tag{3}
\]

where \(M_i\) is dry basis moisture content at any time point \(t_i\) and \(M_{i-1}\) is moisture content prior to \(M_i\). Details of the
experimental methodology for drying have been described previously [13]. A central composite rotatable design (CCRD) with 11 experiments (Table 1) was devised to study the influence of drying air temperature and velocity on product quality in terms of final moisture content, Sauter mean diameter, density (apparent and bulk), porosity, weight of 1000 fruits, and color (CIELAB system). The data were processed in STATISTICA® software. The influence of drying on the essential oil of *S. terebinthifolius* fruits was also evaluated.

Extraction of essential oil was accomplished by hydrodistillation in a Clevenger apparatus. Before each extraction, fruits were ground in a hand mill (BOTINI®, model B03). After that, the crushed fruits and 1L of distilled water were mixed in a 2-L round-bottom flask. The system was heated (at level 4 power) using a 2-L heating mantle (Fisaton®, model 202, 480 W). After hydrodistillation, the distillate (oil and water) was transferred to a separatory funnel, and the essential oil was extracted three times with anhydrous dichloromethane (Synth®). Two phases were obtained: an aqueous phase and an organic phase containing oil and dichloromethane. The organic phase was collected and dried over anhydrous sodium sulfate (Exodo Científica®). Dichloromethane was evaporated using a rotary evaporator (Buchi®, model R-200) under vacuum at 40°C. Next, the mass of essential oil was determined, and the extraction yield on a dry basis (*Y*) was calculated according to

\[ Y = \frac{m_o}{m_d} \times 100, \]  

where \( m_o \) is the mass of essential oil, and \( m_d \) is the dry mass of the raw material fed into the extractor. Quality attributes were determined and compared with those of fresh fruits. For example, the yield ratio (**YR**) was calculated using

\[ {YR} = \frac{Y}{Y_f}, \]  

where \( Y \) and \( Y_f \) are the extraction yields of the essential oil extracted from dried and fresh fruits of *S. terebinthifolius*, respectively.

Quantitative and qualitative analyses of the essential oil were carried out using gas chromatography coupled to mass spectrometry (GC-MS). The samples were analyzed on a gas chromatograph (Agilent Technologies, HP-6890, USA) equipped with a mass spectrometer (Agilent Technologies, HP5975, USA) operating in electron impact mode (70 eV). A HP-5MS® capillary column (30 m × 250 μm, 0.25 μm phase thickness) was used. The carrier gas was helium, and the flow rate was 1 mL/min. Injector and detector temperatures were 220 and 250°C, respectively. Oven temperature was programmed with a ramp from 60 to 240°C at a rate of 3°C/min. Prior to GC-MS analysis, samples were solubilized in ethyl acetate (10 mg/mL). The injection volume was 1 μL; injection was performed in split mode at a ratio of 1:30. Individual constituents were identified by comparison of their linear retention index (RI) [17] and mass spectra with published data [18]. The retention index was calculated using a homologous series of n-alkanes, \( C_8 – C_{22} \). The relative percentages obtained from chromatogram peak areas served as indicators of the amounts of volatile components [19].

![Figure 1: Dimensionless physical parameters (relative to fresh fruits) as a function of moisture content of *S. terebinthifolius* fruits. *M*: moisture content on dry basis; \( \rho_{bulk} \): bulk density; \( W_{1000} \): weight of 1000 fruits; \( \rho_p \): apparent density.](image)

### 3. Results and Discussion

In this work, the quality of pink peppercorns under different drying conditions was evaluated. Experiments were designed (Table 1) to study the influence of drying air temperature (35–75°C) and air velocity (0.3–0.9 m/s) on product quality, measured primarily by means of moisture content, color, and volatile compounds. Tables 2–4 show the results for all parameters analyzed in this study. Considering all quality criteria, drying air temperature had the greatest influence on the quality parameters of pink peppercorns under study; drying air velocity had no significant effects. These results suggest that resistance to moisture movement at the surface of the fruits was negligible compared with internal resistance [20]. Accordingly, the effects of drying air temperature are discussed in detail hereafter.

#### 3.1. Effects on Moisture Content.

Appropriate moisture content in pink peppercorns is necessary to avoid microbial growth and product degradation. Therefore, low moisture contents are recommended (\( M^* < 12% \)) [21]. As shown in Table 2, the final moisture content on a wet basis ranged from 2.1% (75°C and 0.6 m/s) to 13.6% (35°C and 0.6 m/s). Thus, a drying air temperature of 35°C resulted in a moisture content above 12%. Furthermore, drying at lower temperatures required longer operation time. As shown in Table 1, the equilibrium drying time (\( t_e \)) ranged from 4 h (75°C and 0.6 m/s) to 14 h (35°C and 0.6 m/s). Thus, the increase in temperature from 35 to 75°C, and the consequent decrease in relative humidity (from 31% to 5%), increased the drying rate and reduced the drying time and moisture content of *S. terebinthifolius* fruits. As shown in Table 2, an increase in temperature also resulted in a decrease in density (apparent and bulk) and in the weight of 1000 fruits, as expected. These changes were due to changes in fruit moisture content. This phenomenon can be seen in Figure 1, which depicts the nonlinear dependence of these physical parameters on the moisture content of *S. terebinthifolius* fruits.
Table 1: Operating conditions for drying of *S. terebinthifolius* fruits.

| Assay | *T* (°C)*a* | *V* (m/s)*a* | RH (%) | *M₀* (d.b.) | *M*ₐ (%) | *t*ₑ (min) |
|-------|--------------|--------------|--------|-------------|----------|------------|
| 1     | 40.9 (−1)    | 0.39 (−1)    | 22     | 1.62        | 61.8     | 690        |
| 2     | 69.1 (+1)    | 0.39 (−1)    | 6      | 1.62        | 61.8     | 270        |
| 3     | 40.9 (−1)    | 0.81 (+1)    | 23     | 1.62        | 61.8     | 705        |
| 4     | 69.1 (+1)    | 0.81 (+1)    | 7      | 1.63        | 62.0     | 300        |
| 5     | 35.0 (−1.41) | 0.60 (0)     | 31     | 1.62        | 61.8     | 840        |
| 6     | 75.0 (+1.41) | 0.60 (0)     | 5      | 1.64        | 62.1     | 240        |
| 7     | 55 (0)       | 0.30 (−1.41) | 11     | 1.64        | 62.1     | 495        |
| 8     | 55 (0)       | 0.90 (+1.41) | 13     | 1.64        | 62.1     | 510        |
| 9     | 55 (0)       | 0.60 (0)     | 12     | 1.63        | 62.0     | 495        |
| 10    | 55 (0)       | 0.60 (0)     | 13     | 1.62        | 61.8     | 510        |
| 11    | 55 (0)       | 0.60 (0)     | 13     | 1.62        | 61.8     | 480        |

*T*: drying air temperature; *V*: air velocity; RH: air relative humidity; *M₀*: initial moisture content on dry basis of *S. terebinthifolius* fruits; *M*ₐ*: initial moisture content on wet basis; *t*ₑ: final drying time; *a* coded values in parentheses.

Table 2: Physical parameters of *S. terebinthifolius* fruits (fresh and dried under the operating conditions of Table 1).

| Assay | *M*ₑ (d.b.) | *M*ₑ* ( %) | ρ*bulk* (g/mL) | *W*₁₀₀₀ (g) | *d*ₚ (mm) | ρ*ₚ* (g/mL) | *ε* (—) |
|-------|-------------|-------------|----------------|-------------|-----------|-------------|---------|
| 1     | 0.1030      | 9.34        | 0.277          | 2706        | 4.92      | 0.433       | 0.360   |
| 2     | 0.0378      | 3.64        | 0.260          | 2500        | 4.92      | 0.401       | 0.351   |
| 3     | 0.1180      | 10.5        | 0.280          | 2711        | 4.91      | 0.438       | 0.362   |
| 4     | 0.0528      | 5.01        | 0.259          | 25.01       | 4.90      | 0.407       | 0.364   |
| 5     | 0.1570      | 13.6        | 0.299          | 29.30       | 4.96      | 0.460       | 0.350   |
| 6     | 0.0216      | 2.12        | 0.232          | 25.31       | 4.96      | 0.397       | 0.365   |
| 7     | 0.0574      | 5.43        | 0.263          | 24.82       | 4.90      | 0.403       | 0.348   |
| 8     | 0.0778      | 7.22        | 0.260          | 25.30       | 4.96      | 0.395       | 0.342   |
| 9     | 0.0586      | 5.54        | 0.269          | 25.42       | 4.92      | 0.407       | 0.339   |
| 10    | 0.0684      | 6.40        | 0.259          | 24.04       | 4.90      | 0.391       | 0.337   |
| 11    | 0.0854      | 7.87        | 0.269          | 25.43       | 4.92      | 0.407       | 0.339   |

| Fresh fruits | 1.62 | 61.8 | 0.543 | 54.57 | 4.96 | 0.852 | 0.358 |

*M*ₑ: equilibrium moisture content on dry basis, determined at the final stage of drying; *M*ₑ*: equilibrium moisture content on wet basis; *ρ**bulk*: bulk density; *W*₁₀₀₀: weight of 1000 fruits; *d*ₚ*: Sauter mean diameter; *ρ*ₚ*: fruit apparent density; *ε*: porosity.

Table 3: Color parameters (CIELAB system) of *S. terebinthifolius* fruits (dried under the operating conditions of Table 1).

| Assay | *L** | *a** | *b** | Δ*E* |
|-------|------|------|------|------|
| 1     | 25.72| 34.17| 22.45| 3.16 |
| 2     | 23.90| 26.97| 16.42| 6.91 |
| 3     | 26.52| 32.65| 21.62| 1.41 |
| 4     | 24.70| 27.95| 18.04| 5.01 |
| 5     | 26.41| 32.19| 21.03| 0.70 |
| 6     | 21.12| 26.61| 17.43| 8.19 |
| 7     | 26.50| 30.91| 19.00| 1.74 |
| 8     | 26.49| 30.90| 19.04| 1.72 |
| 9     | 25.83| 32.01| 20.24| 0.77 |
| 10    | 26.16| 31.53| 19.89| 0.78 |
| 11    | 25.23| 30.77| 18.41| 2.68 |

*Commercial pink peppercorn* | 26.59| 31.94| 20.40| — |

*L**: darkness/whiteness; *a*: greenness/redness; *b*: blueness/yellowness; Δ*E*: total color difference.

The drying kinetics for all operational conditions listed in Table 1 are presented in Figures 2 and 3. As noted, drying kinetics were not a linear function of time, and moisture content decreased exponentially with drying time; the last step was represented by an almost horizontal line, which marked the end of the drying process (equilibrium moisture content). As shown in Figures 2 and 3, the effects of air velocity on drying kinetics and rate were small compared with the large effects of air temperature. The increase in drying rate at higher temperatures is related to increased moisture diffusivity at higher temperatures. Accordingly, the drying kinetics of *S. terebinthifolius* fruits showed only the falling-rate period of drying. At this stage, mass transfer was limited by diffusion as described by Fick’s second law of diffusion. These results are due to the fact that, in biological materials, water molecules tend to be tightly held by the materials [22]. This behavior is consistent with previously published literature on the drying of *S. terebinthifolius* fruits [13] and other fruits and seeds [23–25].
### Table 4: Chemical composition (GC-MS data) and the yield of essential oil from S. terebinthifolius fruits (fresh and dried under the operating conditions of Table 1).

| Compound        | RI<sub>lit</sub><sup>a</sup> | RI<sub>cal</sub><sup>b</sup> | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | Fresh fruits |
|-----------------|-------------------------------|-------------------------------|----|----|----|----|----|----|----|----|----|----|----|-------------|
| α-Pinene        | 932                           | 933                           | 3.65 | 3.52 | 5.12 | 2.84 | 4.87 | 1.49 | 5.15 | 3.61 | 3.72 | 5.06 | 2.86 | 5.36 |
| Sabinene        | 969                           | 973                           | 2.24 | 2.14 | 1.89 | 1.78 | 2.20 | 1.28 | 2.32 | 2.03 | 1.52 | 2.12 | 1.50 | 2.45 |
| β-Mycene        | 988                           | 991                           | 12.14 | 10.90 | 11.61 | 11.03 | 12.16 | 8.12 | 11.03 | 11.73 | 11.21 | 11.66 | 10.91 | 12.75 |
| α-Phellandrene  | 1002                          | 1006                          | 18.48 | 17.84 | 16.35 | 16.59 | 19.64 | 14.26 | 19.31 | 18.69 | 17.34 | 17.61 | 17.16 | 20.46 |
| δ-3-Carene      | 1008                          | 1012                          | 18.41 | 16.81 | 18.37 | 16.08 | 18.60 | 13.67 | 17.54 | 17.00 | 17.43 | 17.82 | 17.04 | 19.14 |
| n.i.<sup>c</sup> | —                             | 1017                          | 0.38 | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| p-Cymene        | 1020                          | 1025                          | 1.36 | 0.68 | 2.04 | 1.21 | 0.90 | 0.69 | 0.66 | 0.83 | 1.26 | 1.09 | 1.09 | 0.73 |
| Limonene        | 1024                          | 1029                          | 17.77 | 16.30 | 17.42 | 16.49 | 17.91 | 15.19 | 16.75 | 17.43 | 17.12 | 15.90 | 17.37 | 18.28 |
| n.i.<sup>c</sup> | —                             | 1058                          | 0.46 | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| Terpinolene     | 1086                          | 1089                          | 1.38 | 1.26 | 1.19 | 1.29 | 1.33 | 1.35 | 1.24 | 1.33 | 1.32 | 1.20 | 1.44 | 1.31 |
| n.i.<sup>c</sup> | —                             | 1178                          | 0.74 | 0.61 | 0.74 | 0.58 | 0.52 | 0.62 | 1.00 | 0.64 | 1.04 | 0.68 | —   | —   |
| n.i.<sup>c</sup> | —                             | 1337                          | —   | —   | —   | —   | —   | —   | 0.61 | —   | —   | —   | —   | —   |
| Caryophyllene   | 1417                          | 1418                          | 4.50 | 4.72 | 4.27 | 5.20 | 3.99 | 5.83 | 4.08 | 4.71 | 4.66 | 4.52 | 4.32 | 3.73 |
| Germacrene D    | 1484                          | 1480                          | 8.04 | 8.91 | 7.13 | 9.19 | 6.83 | 10.90 | 7.32 | 8.34 | 6.47 | 7.91 | 8.17 | 6.25 |
| n.i.<sup>c</sup> | —                             | 1495                          | —   | —   | —   | —   | —   | 0.71 | —   | —   | —   | —   | —   | —   |
| δ-Cadinene      | 1522                          | 1523                          | 0.93 | 1.05 | 1.10 | 1.33 | 1.01 | 1.45 | 1.03 | 1.19 | 1.65 | 1.34 | 1.78 | 0.94 |
| Elemol          | 1548                          | 1550                          | 1.38 | 1.83 | 1.02 | 1.82 | 1.05 | 6.52 | 3.50 | 1.58 | 1.37 | 1.55 | 2.67 | 0.90 |
| Germacrene B    | 1559                          | 1555                          | 0.64 | 0.75 | 0.79 | 0.57 | 0.99 | 0.66 | 0.72 | —   | 0.67 | 0.76 | —   | —   |
| γ-Eudesmol      | 1630                          | 1631                          | 4.01 | 5.70 | 5.83 | 5.97 | 3.99 | 6.07 | 3.48 | 4.94 | 5.77 | 4.90 | 4.27 | 3.29 |
| β-Eudesmol      | 1650                          | 1650                          | 1.19 | 1.75 | 1.54 | 1.85 | 0.96 | 2.23 | 1.29 | 1.47 | 1.74 | 1.60 | 1.38 | 0.90 |
| α-Eudesmol      | 1652                          | 1653                          | 2.42 | 3.16 | 3.28 | 3.80 | 2.03 | 3.15 | 2.47 | 2.67 | 3.62 | 3.19 | 2.38 | 1.96 |
| n.i.<sup>c</sup> | —                             | 1654                          | —   | —   | —   | —   | —   | 1.27 | —   | —   | —   | —   | —   | —   |
| n.i.<sup>c</sup> | —                             | 1667                          | —   | 0.79 | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| n.i.<sup>c</sup> | —                             | 1676                          | 0.81 | 1.24 | 1.09 | 1.40 | 0.98 | 2.81 | 1.64 | 1.12 | 1.59 | 1.21 | 1.83 | 0.86 |
| n.i.<sup>c</sup> | —                             | 1776                          | —   | 0.65 | —   | 0.73 | —   | 0.85 | —   | —   | 0.68 | —   | —   | —   |
| Monoterpenes (%)<sup>d</sup> | 76.1                         | 69.5                          | 74.7 | 67.9 | 79.2 | 56.6 | 74.5 | 73.3 | 72.4 | 73.1 | 71.4 | 81.2 | —   |
| Yield (%)<sup>e</sup> | 5.24                         | 4.87                          | 5.48 | 4.38 | 5.38 | 4.66 | 5.52 | 5.64 | 4.67 | 5.33 | 4.90 | 5.56 | —   |

<sup>a</sup>Retention index [18]; <sup>b</sup>calculated retention index (average value); <sup>c</sup>not identified; <sup>d</sup>relative percentage obtained from the peak area of the chromatograms; <sup>e</sup>extraction yield according to (4).
3.2. Product Integrity. Pink peppercorns should have a bright red color and a spherical shape in the absence of broken shells. Thus, it was possible to evaluate the integrity of *S. terebinthifolius* fruits after drying based on their diameter. As shown in Table 2, the fruits remained intact after the drying process under all conditions investigated, which was possible because of the use of a dryer in a fixed bed (tray dryer). In addition, no shrinkage of the material was observed during drying. Aside from the integrity and moisture content of pink peppercorns, monitoring of parameters such as color and volatile content is necessary to ensure quality of the product. In the next sections of this paper, the effects of drying on these parameters are discussed in detail.

3.3. Effects on Color. The color of pink peppercorns is highly important for commercial acceptability. Pink peppercorns are characterized by a bright red color. This color may be due to phenolic compounds [26] or carotenoids in *S. terebinthifolius* fruits [27]. Nonetheless, specific studies are needed to determine a definitive relationship between these compounds and the color of *S. terebinthifolius* fruits. Table 3 shows the results of the colorimetric analysis (CIELAB system) of *S. terebinthifolius* fruits that were dried under the operating conditions listed in Table 1; as expected for pink peppercorns, the dried fruits had a dark red color (low $L^*$ and positive $a^*$).

As shown in Table 3, the $L^*$ parameter ranged from 26.52 (40.9°C and 0.81 m/s) to 21.12 (75°C and 0.6 m/s), indicating decreasing luminosity with increasing drying temperature. The $a^*$ parameter ranged from 34.17 (40.9°C and 0.39 m/s) to 26.61 (75°C and 0.6 m/s), indicating decreasing redness with increasing drying temperature. The $b^*$ parameter ranged from 22.45 (40.9°C and 0.39 m/s) to 16.42 (69.1°C and 0.39 m/s), indicating decreasing yellowness with increasing drying temperature. Thus, as shown in Pareto diagrams (Figure 4), increasing the drying air temperature resulted in a statistically significant negative effect on the color parameters, with a confidence level of 95%. Therefore, drying of *S. terebinthifolius* fruits resulted in color degradation, suggesting that higher temperatures cause more pronounced degradation of pigments. These results may be due to either browning reactions or degradation of carotenoid and phenolic compounds at high temperatures. Nevertheless, specific studies are needed to identify a definitive relation between these phenomena and color losses. Unfortunately, information on the nonenzymatic browning of pink peppercorns is still scarce in the literature. Lee et al. [28] suggest that nonenzymatic browning in dried red peppers is due to Maillard reactions. In addition, the loss of red color may have been caused by oxidation of carotenoids in drying air. Klieber [29] states that carotenoids are vulnerable to the
effects of heat, light, and high oxygen tension. According to Malchev et al. [30], the degradation rate increases as the drying temperature increases.

Comparison of the data from the pink peppercorns produced in this work with data obtained from commercial pink peppercorns (Table 3) suggests that low temperatures should be used for drying (35 to 55°C). As shown in Table 3, the total color difference was lower (0.70 to 3.16) for this drying temperature range. In fact, the maximal temperature of 55°C ensured adequate coloration (0.77 < ΔE < 2.68)
and suitable moisture content \( (M^* < 12\%) \). This drying temperature was close to the temperature of 60 °C mentioned by De Carvalho et al. [31] for drying of S. terebinthifolius fruits for the production of pink peppercorns. Nonetheless, if the objective is extraction of volatile compounds, it is necessary to determine whether these drying conditions are sufficient to avoid losses of these compounds during drying.

### 3.4. Effects on Volatile Compounds

GC-MS analysis (Table 4) enabled detection of 25 compounds in the essential oil from S. terebinthifolius fruits. As shown in Table 4, 16 compounds were identified, representing, on average, approximately 98% of the chemical composition of the essential oil. The main compounds were \( \alpha \)-phellandrene \((14.26–20.46\% \)) , \( \delta \)-3-carene \((13.67–19.14\% \)) , limonene \((15.19–18.28\% \)) , \( \beta \)-myrcene \((8.12–12.75\% \)) , and 

#### Figure 5: Pareto diagrams for process responses. (a) Extraction yield on dry basis; (b) monoterpenic content of the essential oil from S. terebinthifolius fruits. \( T(L) \): linear temperature effect; \( T(Q) \): quadratic temperature effect; \( V(L) \): linear velocity effect; \( V(Q) \): quadratic velocity effect.

These results are similar, with slight variations, to those obtained by Barbosa et al. [32] and Cole et al. [12]. This variation observed in the same species collected at different locations (ecotypes) can often be explained by the high complexity of the chemical composition of essential oils, which depends on several factors, such as the location of harvest, climatic conditions, genetic variability (chemotype), pretreatment of the raw material (e.g., grinding, drying), and extraction process [3, 19, 33].

Figure 5 depicts Pareto diagrams showing the standardized effects of drying air temperature and velocity on the yield and monoterpenic content of essential oil from S. terebinthifolius fruits, showing that air temperature had statistically significant negative effects on these parameters. These data indicate that an increase in air temperature manifests itself in a decrease in the extraction yield and monoterpenic content, with a confidence level of 95%. Consequently, these results indicate a relationship between the volatilization of some volatile compounds from S. terebinthifolius fruits and the parameters of the drying process. It is worth mentioning that, in the literature, there are no studies that have addressed the influence of drying on essential oils from S. terebinthifolius fruits.

According to Figiel et al. [2], there are several different factors that can affect the loss of volatile compounds during the drying process, for instance, the temperature reached, interactions between the volatiles and water vapor, or the hydrophobicity of the volatiles. Pinheiro [34] reported that the loss of volatile compounds during drying is based on the steam distillation operation (when a mixture of two immiscible liquids is distilled). Accordingly, during drying, some volatile components may have been carried away with water vapor within the fruit to the dryer outlet. In fact, Figiel et al. [2] found that, during vegetable drying, decreases in volatile concentration were strongly associated with the amount of water being evaporated. According to those authors, water acts as a solvent enabling diffusion of volatile compounds within the dried material, and water vapor acts as a carrier that enhances transfer of volatiles from the material being dried to the surroundings. In addition, during convective drying, volatile compounds are substantially exposed to oxidation processes due to the large volume of air flowing through the drying bed.

The dimensionless extraction yield and monoterpenic content (relative to fresh fruits) for each assay (Table 1) are shown in Figure 6. The relative value was calculated in accordance with (5), with a relative value closer to 1.0 being more ideal in terms of drying performance. Figure 6 shows that the extraction yield and monoterpenic content are close to 1.0 when drying is performed at mild temperatures (assays 1, 3, and 5). In contrast, drying at higher temperatures (assays 2, 4, and 6) decreases the extraction yield and monoterpenic content, as compared with values obtained from fresh fruits. Therefore, drying at higher temperatures may reduce the extraction yield and monoterpenic content of the essential oil from S. terebinthifolius fruits.

#### 3.5. Optimal Drying Conditions

The coded models and the results of analysis of variance (ANOVA) are shown in Table 5. In this work, coded statistical models (quadratic polynomial equation) were used to predict responses in moisture content, total color difference, and monoterpenic content as a function of drying air temperature. The adjustment quality of these models was evaluated by ANOVA; the experimental data were analyzed in STATISTICA software at a fixed significance level of 0.05. The data presented in Table 5 show that \( F_{cal,1} \)
As mentioned above, the maximal temperature of 55°C was close to the temperature of 60°C mentioned by De Carvalho et al. [31] for the drying of S. terebinthifolius fruits for production of pink peppercorns. Karam et al. [3] reported that low drying temperatures generally have a positive influence on the quality of biological materials but require long processing times, which in turn have detrimental effects on product quality and increase costs. The authors emphasized that drying at temperatures of 55°C or 60°C can be considered an optimal compromise for the quality of dehydrated fruits/vegetables; under these temperature conditions, acceptable color and nutrient retention, relatively short drying time, and limited structural damage are achieved.

4. Conclusion

In the production of pink peppercorns, drying is undoubtedly the most important step. If drying is not performed properly, the quality of pink peppercorns decreases, affecting marketability. Appearance and flavor are among the most important quality criteria for pink peppercorns. In this work, a methodology for the assessment of pink peppercorn quality under different drying conditions was defined. The results

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**Figure 6:** Dimensionless parameters (relative to fresh fruits) for each assay (from 1 to 11, under operating conditions of Table 1).

**Table 5:** Coded models and results of analysis of variance (ANOVA).

| Model | Regression/residual | Lack of fit/pure error | $R$ |
|-------|---------------------|------------------------|-----|
| $M^* = 6.48 - 3.43T + 0.675T^2$ | $F_{cal,1}$ | $F_{tab,1}$ | $F_{cal,2}$ | $F_{tab,2}$ | 0.9553 |
| $\Delta E = 1.80 + 2.24T + 1.65T^2$ | $22.40$ | $4.459$ | $1.072$ | $19.33$ | 0.9211 |
| $MC = 73.3 - 5.67T - 2.23T^2$ | $20.27$ | $4.459$ | $12.64$ | $19.33$ | 0.9139 |

$M^*$: moisture content on wet basis; $T$: coded temperature according to Table 1; $\Delta E$: total color difference; MC: monoterpenes content; $F_{cal}$: $F$ distribution (calculated); $F_{tab}$: $F$ distribution (tabulated); $R$: correlation coefficient.
showed that drying in a tray dryer ensures integrity of the product. Air temperature had the greatest influence on the chemical and physical parameters that were investigated in this study, while air velocity had no statistically significant effects. Considering all the quality criteria, drying temperatures between 40 and 55°C ensured the best compromise, in terms of adequate reduction of moisture without dramatic degradation of color and essential oil. Further work is needed to devise a sensory analysis of pink peppercorns. Therefore, these results show the importance of monitoring drying conditions during the production of pink peppercorns. This approach enabled a better understanding of the phenomena involved and evaluation of the behavior of this material during the drying operation. In addition, this study can serve...
as a basis for improving the quality of pink peppercorn product and thus meeting the quality requirements imposed by consumers.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

Acknowledgments
The authors thank CNPq for financial support.

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