Solvent free microwave extraction of Elletaria cardamomum L.: A multivariate study of a new technique for the extraction of essential oil

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Abstract

The solvent-free microwave extraction (SFME) of cardamom essential oil (Elletaria cardamomum L.) was studied. A multivariate study based on a central composite design (CCD) was used to evaluate the influence of three major variables affecting the performance of the solvent-free microwave extraction of cardamom seed. The yield and the composition of the essential oils from the dry cardamom seeds obtained by SFME were determined, and compared with those obtained by the traditional hydro-distillation (HD). Statistical treatment of the results provided by the CCD revealed that the selected parameters: extraction time, irradiation power and moisture content of the seeds were significant. The essential oils were analysed by gas chromatography–mass spectrometry (GC–MS). Essential oils provided by SFME are dominated by the oxygenated fraction which is the more valuable and composed of highly odoriferous aromatic compounds. Cardamom seeds treated by SFME and HD were observed by scanning electronic microscopy (SEM). Micrographs provide more evidence of the destruction of cardamom seeds treated by SFME, in contrast to conventional hydro-distillation.

Keywords: Microwave; Extraction; Cardamom; Essential oil; Multivariate study

1. Introduction

Cardamom (Elleteria cardamomum L.), known as the Queen of Spices, is the traditional native spice from the humid Asian areas. It is a tall, perennial herbaceous belonging to the Zingiberaceae family. It takes 3–4 years to start bearing the yellow-grey capsules containing many small black seeds. Fruits are gathered just before they are ripe in order to conserve the seeds inside the capsule, and then distilled to obtain the essential oil with an average yield from 2% to 5%. Apart from India, countries like Sri Lanka, Tanzania, Papua New Guinea, Costa Rica, El Salvador and Guatemala, which is now one of the largest cardamom-exporting countries, also produce cardamom (Mehra, 2001).

Cardamoms seeds are widely used for flavouring purposes in food, especially in the Nordic countries Sweden and Norway, the United Kingdom, and in Asia. Medically, they are used for flatulent indigestion, and to stimulate the appetite. The seeds are also prescribed in Ayurvedic medicine for coughs, colds, bronchitis, and asthma. Furthermore, according to some researchers, cardamom oil seems to have antibacterial, antiseptic, carminative and antispasmodic properties (Al-Zuhair, El-Sayeh, Ameen, & Al-Shoora, 1996). Moreover, some studies have considered the potential effects of essential oils from spices, including cardamom,
against insect pests, including stored-product insects (Huang, Lam, & Ho, 2000).

The major components of cardamom oil are 1,8-cineole, α-terpinyl acetate, and then linalool, limonene or myrcene of lesser importance. Cardamom oil is usually olfactory described as a sweet, spicy, warm, lightly camphorated and citrusy. (Boisvert & Hubert, 1998; Robert, 1986; Westland, 1986).

Essential oil of cardamom has usually been isolated by either traditional hydro-distillation or steam-distillation. Losses of some volatile compounds, long extraction times, degradation of unsaturated or ester compounds through thermal or hydrolytic effects are the principal disadvantages of these extraction methods (Khajeh, Yamini, Sefidkon, & Bahramifar, 2004; Tuan & Ilangantileke, 1997).

Recently, an original method for extracting natural products by using microwave energy has been developed in our laboratory (Chemat, Smadja, & Lucchesi, 2003; Chemat, Smadja, & Lucchesi, 2004). Solvent free microwave extraction (SFME) is based on the combination of microwave heating and distillation, and is performed at atmospheric pressure. This method involves placing vegetable material in a microwave reactor. The internal heating of the in situ water within the plant material distends it and makes the glands and oleiferous receptacles burst. This process thus frees essential oil which is entrained by the in situ water of the plant material by azeotropic distillation. The vapour then passes through a condenser outside the microwave cavity where it condensed. The distillate is collected continuously in the receiving flask. The excess of water was refluxed and recycled to the extraction vessel by cohabation in order to restore the moisture of the plant material. The essential oil is collected directly and dried without added any solvent extraction step. Solvent free microwave extraction has been used to obtain essential oils from different raw materials. The SFME is neither a modified microwave assisted extraction (MAE) which uses organic solvents, or a modified hydro-distillation (HD) which uses a large quantity of water. Recently, Lucchesi, Chemat, and Smadja (2004a, 2004b) analysed the essential oils of three aromatic herbs (basil, garden mint, and thyme) and three spices (ajowan, cumin, and star anise).

In this paper, the SFME of *Elleteria cardamomum* L. has been studied in order to understand in depth and to optimize this new technique of extraction. A central composite design (CCD) has been developed to specify the importance of the three major factors affecting the SFME. The yields and the composition of each sample of essential oils resulting from the experiments of the CCD have been analysed and compared.

2. Materials and methods

2.1. SFME apparatus and procedure

SFME was carried out with a Milestone DryDIST® (2004) microwave apparatus. The multimode microwave reactor has a twin magnetron (2 × 800 W, 2450 MHz) with a maximum delivered power of 1000 W in 10 W increments. A rotating microwave diffuser ensures homogeneous microwave distribution throughout the plasma coated PTFE cavity (35 cm × 35 cm × 35 cm). The temperature was monitored by a shielded thermocouple (ATC-300) inserted directly into the corresponding container. Temperature was controlled by feedback to the microwave power regulator. The SFME apparatus is described in Fig. 1.

In a typical SFME procedure, 100 g of small, black cardamom seeds were moistened prior extraction by soaking
in water then draining the excess of water. This step is essential to give them the initial moisture. Moistened seeds were next placed in the reactor. The essential oil is collected, dried with anhydrous sodium sulphate and stored at 4 °C until analysis.

2.2. Hydro-distillation apparatus and procedure

One hundred gram of dry whole cardamom was submitted to hydro-distillation with a Clevenger-type apparatus according to the European Pharmacopoeia (Conseil de l’Europe, 1996) and extracted with 1 L of water for 6 h, until no more essential oil was obtained. The essential oil was collected, dried under anhydrous sodium sulphate and stored at 4 °C until used.

2.3. Gas chromatography–mass spectrometry identification

The essential oils were directly analysed by gas chromatography coupled to mass spectrometry (GC–MS) (Hewlett-Packard computerized system comprising a 5890 gas chromatograph coupled to a 5971A mass spectrometer) and stored at 4 °C until used.

2.4. Experimental design

A Box-Wilson central composite design, commonly called a central composite design (CCD) has been established to study the performance of the solvent-free microwave extraction. A multivariate method was chosen to optimise the number of experiments and allow identification of interactions between variables. This CCD comprises a three-level full factorial design (+1, −1, 0), superimposed by the centre points (coded 0), and the star points (+α, −α). The star points allow estimation of the curvature in the model and establish new extremes for the low and high settings for all factors. The precise value of α depends on certain properties desired for the design and on the number of factors involved. In this study the design point describes a circle circumscribed about the factorial square. Typically, for three factors, the central composite circumscribed (CCC) design points describe a sphere around the factorial cube.

Each of the three variables studied (namely time, power and humidity of the matrix) had levels set at five separate coded levels: −α (−1.68), −1, 0, +1, +α (1.68) as shown in Table 1. These values were used to create a CCC design and the interpretation of data obtained was analysed by two statistical experimental design computer programs, Statgraphics Plus™ (2000) and Nemrod™ (2003).

2.5. Dielectric properties measurements

The relative permittivity ε′ and the dielectric loss factor ε″ of both the whole cardamom fruit and seeds only were measured using a sample holder of dimensions 72×34×20 mm in WR 284 waveguide. Both wet and dry seeds were tested. This waveguide measurement system is a two port measurement and was done in the frequency band 2.6–3.3 GHz. On inversion, the data yield a bulk permittivity value that is a function of the packing of the seeds, the moisture content of the packed sample and the inherent permittivity of the individual seeds. In the extraction of the properties, care was taken to assess whether higher order modes could occur (which could possibly corrupt the measurement) and whether the sample length was an even half wavelength multiple, as this gives maximum uncertainty in the measurement.

The relative permittivity ε′ and the dielectric loss factor ε″ of the neat cardamom essential oil were measured over the frequency range 45 MHz–3 GHz with an HP-8510 automatic network analyzer (ANA) and coaxial probe technique. This method is a single port, broadband technique and is well suited to loss materials. The S11-parameter was measured over the desired frequency range using the ANA. The inversion algorithm used to treat the data was based on techniques by Stuchly and Stuchly (1980) and Marcuvitz (1986). Sample measurement was done by immersing the probe in the essential oil. Details on the probe can be found in Rimbi (2003).

2.6. Scanning electron micrographs (SEM)

The specimens were freeze-dried, fixed on the specimen holder with aluminium tape and then sputtered with gold. All the specimens were examined by a TOPCON ABT60, under vacuum condition and accelerating voltage of 15 kV, with a spot size 5 and a working distance of 15 mm.

<table>
<thead>
<tr>
<th>Level</th>
<th>Time (min)</th>
<th>Power (W)</th>
<th>Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>−α</td>
<td>10.0</td>
<td>140</td>
<td>30</td>
</tr>
<tr>
<td>−1</td>
<td>23.0</td>
<td>190</td>
<td>38</td>
</tr>
<tr>
<td>0</td>
<td>42.5</td>
<td>265</td>
<td>50</td>
</tr>
<tr>
<td>+1</td>
<td>62.0</td>
<td>340</td>
<td>62</td>
</tr>
<tr>
<td>+α</td>
<td>75.0</td>
<td>390</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 1

Values of the variables at five levels used with the design
3. Results and discussion

3.1. Preliminary study

A preliminary study consisting of various experiments was carried out in order to study the role of the factors involved in SFME of essential oil from cardamom. The main factors are the state of the cardamom (with or without capsule), the moisture of the matrix, the extraction time, and the irradiation power.

The sample moisture and the condition of cardamom relate directly to the plant. The first factor can be easily controlled and modified depending on whether the whole fruit (capsule and seed) is used or only the seeds. However, experiments have shown that it is difficult to reach moisture content higher than 70% whatever the condition of cardamom. Secondly, the yield of essential oil obtained by SFME, from the whole fruit with moisture content greater than 65%, was around 1% depending on the operating conditions, whereas the yield of essential oil from seeds only under the same operating conditions was around 3%. As a result of this, in this study only the seeds of *Elettaria cardamomum* L. were treated and the moisture content of the matrix was one of the three factors of the CCD. Indeed, the moisture content under a microwave treatment is critical, since water is an excellent absorber of microwave energy. This strong absorption provides the increase of the temperature inside the sample and then the rupture of the essential oils cells by the in situ water, followed by the evaporation of water vapour.

The irradiation power is directly related to the sample size. The power must be sufficient to reach the boiling point of the water (100 °C) which determine the temperature of the extraction. However, the power should not be too high or this will result in loss of volatile compounds.

Finally, the extraction time must be optimised to maximise the yield of the extraction without affecting the quality of the oil. Moreover, the extraction time of SFME must be lower than the one of the hydro-distillation in order for the new technology to be viable.

3.2. Central composite design results

Table 2 shows the response obtained in the CCD experiments and the overall design. The yield was the mass of essential oil extracted relative to the mass of dry cardamom seeds. Analysis of variance (ANOVA) was performed on the design to assess the significance of the model with the initial summary of the model statistics given by Table 3. The \( F \)-ratio in this table is the ratio of the mean square error to the pure error obtained from the replicates at the design centre. The significance of the \( F \)-value depends on the number of degrees of freedom (DF) in the model, and is shown in the \( P \)-value column (95% confidence level). Thus, the effects lower than 0.05 in this column are significant. This is emphasized by the standardized Pareto chart in Fig. 2, which reveals three significant coefficients affecting the extraction (within the chosen limits), namely extraction time, irradiation power and sample moisture. The lack

<table>
<thead>
<tr>
<th>Run order</th>
<th>Time (min)</th>
<th>Power (W)</th>
<th>Humidity (%)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.56</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.55</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.49</td>
</tr>
<tr>
<td>4</td>
<td>−1</td>
<td>+1</td>
<td>−1</td>
<td>0.89</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.55</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.45</td>
</tr>
<tr>
<td>7</td>
<td>−1</td>
<td>−1</td>
<td>+1</td>
<td>1.29</td>
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<td>8</td>
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</tr>
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<td>0</td>
<td>0</td>
<td>+2</td>
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</tr>
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<td>10</td>
<td>−1</td>
<td>+1</td>
<td>+1</td>
<td>1.24</td>
</tr>
<tr>
<td>11</td>
<td>+1</td>
<td>−1</td>
<td>+1</td>
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</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>−2</td>
<td>0.88</td>
</tr>
<tr>
<td>13</td>
<td>−1</td>
<td>−1</td>
<td>−1</td>
<td>0.71</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.53</td>
</tr>
<tr>
<td>15</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>2.21</td>
</tr>
<tr>
<td>16</td>
<td>+2</td>
<td>0</td>
<td>0</td>
<td>2.27</td>
</tr>
<tr>
<td>17</td>
<td>+1</td>
<td>−1</td>
<td>−1</td>
<td>1.49</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
<td>+2</td>
<td>0</td>
<td>1.74</td>
</tr>
<tr>
<td>19</td>
<td>+1</td>
<td>+1</td>
<td>−1</td>
<td>1.61</td>
</tr>
<tr>
<td>20</td>
<td>−2</td>
<td>0</td>
<td>0</td>
<td>0.65</td>
</tr>
</tbody>
</table>

\( R^2 = 86.56\%; R^2 \text{ (adjusted for DF)} = 74.46\%.

Table 3

Summary of the ANOVA model statistics

<table>
<thead>
<tr>
<th>Effect</th>
<th>Sum of squares</th>
<th>DF</th>
<th>Mean squares</th>
<th>( F )-ratio</th>
<th>( P )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: time</td>
<td>1.86567</td>
<td>1</td>
<td>1.86567</td>
<td>27.27</td>
<td>0.0004</td>
</tr>
<tr>
<td>B: power</td>
<td>1.08892</td>
<td>1</td>
<td>1.08892</td>
<td>15.92</td>
<td>0.0026</td>
</tr>
<tr>
<td>C: humidity</td>
<td>0.72068</td>
<td>1</td>
<td>0.72068</td>
<td>10.53</td>
<td>0.0088</td>
</tr>
<tr>
<td>AB</td>
<td>0.13005</td>
<td>1</td>
<td>0.13005</td>
<td>1.90</td>
<td>0.1980</td>
</tr>
<tr>
<td>AC</td>
<td>0.05445</td>
<td>1</td>
<td>0.05445</td>
<td>0.80</td>
<td>0.3933</td>
</tr>
<tr>
<td>BC</td>
<td>0.06125</td>
<td>1</td>
<td>0.06125</td>
<td>0.90</td>
<td>0.3664</td>
</tr>
<tr>
<td>AA</td>
<td>0.00199</td>
<td>1</td>
<td>0.00199</td>
<td>0.03</td>
<td>0.8678</td>
</tr>
<tr>
<td>BB</td>
<td>0.48389</td>
<td>1</td>
<td>0.48389</td>
<td>7.07</td>
<td>0.0239</td>
</tr>
<tr>
<td>CC</td>
<td>0.00264</td>
<td>1</td>
<td>0.00264</td>
<td>0.04</td>
<td>0.8482</td>
</tr>
<tr>
<td>Total error</td>
<td>0.68416</td>
<td>10</td>
<td>0.06841</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5.08992</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The significance of the cross-product terms suggests the absence of interaction between variables in the zone studied.

The second-order polynomial of the response surface obtained is as follows:

\[
Yield\ of\ essential\ oil\ extracted\ by\ SFME(\%) = 1.5183 + 0.3713T + 0.3093P + 0.2311H + 0.1284TP - 0.0829TH + 0.0865PH - 0.0036T^2 - 0.2132P^2 - 0.0058H^2,
\]

where \(T\) denotes extraction time (min), \(P\) irradiation power (W) and \(H\) percentage of humidity of the matrix (%). The response surface for this polynomial is represented in Fig. 3 where a maximum at the positive extremes is clearly shown.

Extraction time is the major factor affecting the yield of the SFME. As time increases, the yield increases almost linearly. Irradiation power and humidity affect also the yield in the same way as the extraction time.

SFME extraction of cardamom seeds has been done at the optimal values of variables. The optimal yield of essential oil obtained by SFME was 2.70% which is relatively closed to theoretical optimal yield obtained by CCD, 2.80%.

### 3.3. Optimal conditions

The optimal values of the variables affecting the SFME given by the software are the following: extraction time: 75 min, power: 390 W and humidity level: 67%. As expected, and according to the response surface, the efficiency of the extraction in terms of yield in essential oil increases by increasing all the three factors. Those optimal values correspond practically to the extremes values chosen to define the experimental domain.

Indeed, as it appeared in the preliminary study, SFME extraction can be continued until no more essential oil is extracted, as in hydro-distillation. However, extraction time of SFME must be lower than that of HD to be interesting in terms of time and energy savings. The irradiation power determines the rate of evaporation of water or the azeotropic mixture (water and essential oil) during SFME. The greater the rate of evaporation, the greater the yield of essential oil extracted. The humidity level of the matrix under microwave heating is crucial as it was emphasised by the preliminary study. Water absorbs microwaves, and then heats, allowing giving an extraction temperature close to 100°C. This heated in situ water creates areas of compression in the seed, surrounded by areas of lower pressure, making the glands and oleiferous receptacles burst, then the oil flows to the exterior.

### 3.4. Composition of the essential oil

Each sample of essential oil from cardamom obtained during the CCD experiments was analysed and compared (Table 4). To carry out this study, the six major compounds of the cardamom essential oil have been identified, namely: 1,8-cineole, \(\alpha\)-terpinyl acetate, linalool, linalyl acetate, \(\alpha\)-terpineol, and terpin-4-ol in order of importance. These six compounds represent almost 90% of the aromatic compounds of the essential oil from cardamom and all of them are oxygenated compounds.

As we expected, it was observed that the compositions of the samples vary with the experimental conditions. 1,8-Cineole and \(\alpha\)-terpinyl acetate are the major aromatic
compounds of the cardamom essential oil, but they can be present in different amount. These varied between 35% and 52% for 1,8-cineole, and between 19% and 30% for α-terpinyl acetate, depending on the extraction parameters of the SFME. As is shown in Fig. 4a and b, the fractions of 1,8-cineole and α-terpinyl acetate show opposite trends with extraction time. At the same irradiation power (250 W) and the same moisture content (50%), the fraction of 1,8-cineole decreases whereas the fraction of α-terpinyl acetate increases. The same behaviour is observed for lower moisture content and microwave power. However, when the power was increased (340 W), for the same moisture content, the trends are reversed; the concentration of 1,8-cineole increases. The same behaviour is observed for lower moisture content and microwave power. However, when the power was increased (340 W), for the same moisture content, the trends are reversed; the concentration of 1,8-cineole increases whereas the fraction of α-terpinyl acetate decreases.

Fig. 4c illustrates the difference in yields of the two major aromatic components of the cardamom essential oil. Experiment 1 corresponds to the shortest extraction time 23 min (−1), the lowest irradiation power 190 W (−1) and the lowest moisture content 38% (−1), while experiment 8 corresponds to the longest extraction time 62 min (+1), the highest irradiation power 340 W (+1) and the highest moisture content 62% (+1). In comparison, HD is characterized by a long extraction time (6 h), high humidity level (~99%). Overall, the 1,8-cineole fraction seems to decrease according with time, power and moisture content whereas α-terpinyl acetate acetate seems to increase.

Substantially higher amounts of oxygenated compounds and lower amounts of monoterpane hydrocarbons are present in the essential oil of cardamom extracted by SFME in comparison with HD. Monoterpene hydrocarbons are less valuable than oxygenated compounds in terms of their contribution to the fragrance of the essential oil. Conversely, the oxygenated compounds are highly odoriferous and, hence, the most valuable. The greater proportion of oxygenated compounds in the SFME essential oils is probably due to the diminution of thermal and hydrolytic effects, compared with hydro-distillation which uses a large quantity of water and is time and energy consuming. Water is a polar solvent, which accelerates many reactions, especially reactions via carbonation as intermediates.

Essential oils are composed from a variety of compounds divided into two main groups: hydrocarbons and oxygenated compounds. For cardamom, the essential oil is mainly constituted from oxygenated compounds such as 1,8-cineol and α-terpinyl acetate. How does the microwave energy effect differ for these two different aromatic compounds? It would be reasonable to believe that the more polar compounds, the more readily the microwave irradiation is absorbed, the better interaction between wave and matter, and the higher aromatic component content obtained. This would appear to correspond well to what is observed in the case of 1,8-cineol which is more polar versus α-terpinyl acetate.

3.5. Dielectric properties of the cardamom seeds and cardamom essential oils

Table 5 summarizes the various ε’ and ε" values together with the loss tangent, tan δ, and the penetration depth, Dp. This is defined as the depth at which the microwave drops to 1/e of its value at the surface. When dry, both whole cardamom and the seeds alone show relatively low loss (i.e., they are poor absorbers of microwave energy). When
moist, both become good absorbers, as would be expected due to the presence of water. The dielectric properties of the essential oils obtained by both SFME and HD were similar, although close inspection of the results over the full frequency band suggested that the slight difference could be significant. The small differences in these values could be due to the greater content of oxygenated compounds for the essential oil obtained by SFME.

3.6. Structural changes after extraction

The various extraction methods produced distinguishable physical changes in the cardamom seeds. Fig. 5a is a micrograph of the untreated seeds, which can be compared...
with structures of the treated seeds in Fig. 5b and c. After 1 h of solvent free microwave extraction at 100 °C, Fig. 5c shows that cells and cell walls have been affected to different degrees. We observed a huge perforation on the external surface of the particle and some starch is dispersed. The husk is clearly damaged. A part of this protective cover appeared very similar to the untreated ones. Some parts are still filled, however the albumen is also damaged.

The changes observed for solvent free microwave extraction in Fig. 5 were markedly different from those observed by hydro-distillation, showing clearly that the cells are broken and damaged during SFME. Similar effects were pointed out by Pare and Belanger (1997) and Chen et al. (1995) for the microwave extraction of rosemary leaves in hexane. When the glands were subjected to more severe thermal stresses and localized high pressures, as in the case of microwave heating, the pressure build-up within the glands could have exceeded their capacity for expansion, and caused their rupture more rapidly than in conventional extraction.

4. Conclusion

The potential of the SFME technique has been compared with the conventional hydro-distillation method, for the extraction of essential oil from cardamom seeds. The performance of the solvent free microwave extraction was studied with a statistical method based on the response surface methodology in order to identify and quantify the variables which may maximize the yield of essential oil. The three variables chosen, namely extraction time, power and moisture content all have a positive influence on the yield of oil using the SFME method.

Analysis of the extract highlighted differences in the composition of the essential oil, which depended on the extraction method (SFME or HD) and on the experimental conditions. For SFME, it was found that the 1,8-cineole fraction decreased with time, power and moisture content while the opposite was true for cis-terpinyl acetate. The HD composition confirmed this trend; for the HD extract, the fraction of cis-terpinyl acetate was greater. Thus, the experimental parameters such as extraction time, irradiation power or moisture content can be optimized for the particular aim of the SFME: either to obtain a high yield of essential oil, or to obtain essential oils of differing composition. SEM images of the untreated cardamom, cardamom subjected to SFME and cardamom after hydro-distillation emphasize the difference between the two extraction methods used. Microwaves seem to cause the rupture of the cells and the glands more rapidly than in conventional hydro-distillation.

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References


