World Journal of Environmental Biosciences

Available Online at: **www.environmentaljournals.org**

Volume7, Issue 3: 55-62

ISSN 2277- 8047

Eco-Extraction of Essential Oil of the Species Salvia Officinalis L. Systematic Characterization and Parametric Modeling

Djermane Mohamed[1], Abdenabi Abidi[1*], Imed Cheraif[2], Toubal Abdelaziz[1], Noureddine Gherraf[3]

[1]Laboratory of Organic Synthesis, Modeling and Optimization of Chemical Processes Department of Process Engineering, University of Annaba, Annaba, Algeria,
[2]Laboratory of Biochemistry, Faculty of Medicine Monastir 5000- Tunisia,
[3]Laboratory of Natural Resources and Management of Sensitive Environments, University of Oum El Bouaghi, Algeria.

ABSTRACT

In this study, the response surface methodology (RSM) was used to optimize the hydrodistillation process of Algerian Salvia officinalis essential oil. The effects of grain size, condensing flow rate and extraction time on oil yield were studied. A 3-factor design by the Box-Behnken method was used to produce factor combinations, from the response surface analysis. A second-order polynomial expression was deduced and used to determine the best yield efficiency of extracted oil according to the optimal conditions. Analysis of variance (ANOVA) indicates that the generated second-order polynomial model was highly significant with R^2 = 0.9589 and P <0.006. Optimum oil yield conditions (0.98%) were estimated at a particle diameter of 2mm, a condensation flow rate of 1.4mL/min of and an extraction time of 210min. The essential oil extracted from the sage leaves by hydrodistillation was analyzed by GC/MS, to afford α.-Thujone, camphor, 1,8-cineole and β.-Thujone as main components.

Keywords: *Essential Oil, Salvia Officinalis L., Hydrodistillation, Response Surface.*

Corresponding author: Abdenabi Abidi
e-mail✉ abdenabi_abidi@yahoo.fr
Received: 07 February 2018
Accepted: 23 July 2018

1. INTRODUCTION

Essential oils are natural products of aromatic plants obtained by hydrodistillation or steam distillation from whole plants or certain parts such as flowers, fruits, leaves, roots, bark and seeds (Bourrain, 2013; Babar et al., 2015). These species are considered a potential therapeutic source through their broad-spectrum activities, including antifungal, antibacterial, anti-inflammatory, antiviral and antioxidant activities (Nashwa et al., 2014; Benbelaïd et al., 2014).

Salvia officinalis L. is one of the best known aromatic herbs belonging to *Labiaceae* family (*Lamiaceae*). *Salvia* is the largest genus of this family and comprises nearly 900 species (Aleksovski & Sovová, 2007). Plants of this genus grow all over the world and the present species originates from the Middle East and the Mediterranean (Ghorbani, 2017). *S. officinalis* is widely used in folk medicine for its essential oil rich in biologically active compounds. Previous studies have shown that its extracts have antioxidant, antimicrobial, anti-inflammatory, antidiabetic, anticancer, antimutagenic, cytotoxic, and virucidal properties (Akalın et al., 2015; Bouaziz et al., 2009; Alessandra et al., 2013; Pavlić et al., 2016; Fu et al., 2013). All of these properties can be very effective in developing new natural medicines to prevent, control and treat many minor health problems, as well as more serious ones such as diabetes, Alzheimer's disease and cancer (Hamidpour et al., 2014).

S. officinalis contains 0.7-5.2% (w/w) essential oil (Glisic et al., 2010). Even with this very low yield, it has significant industrial importance and market value. Therefore, it is necessary to choose the right method and optimize the extraction parameters in order to obtain a high yield and good quality oil. Different methods can be used for the extraction of essential oils namely: Distillation (water and steam), solvent extraction, supercritical fluid extraction, etc. the quality and quantity of the oil yield depends upon the conditions and the used extraction technique (Pavlić et al., 2016; Glisic et al., 2010). Distillation methods are the most used because of their practical simplicity with an interesting quality - price ratio and an eco-friendly process. Therefore, these methods are generally preferred for the extraction of essential oil from grasses (Aleksic et al., 2014; Mu'azu et al., 2012).

In quest of improving the mass yield in essential oil, studies have been conducted on the optimization of the extraction operating parameters by the use of the response surface methodology (RSM) (Galadima et al., 2012; Timung et al., 2016; Mu'azu et al., 2012; Mastura et al., 2013). This method is used in various fields such as industries, agriculture, medicine, analysis, electronics, etc. The main objective of the present work is to optimize, develop and improve the system response (Afsaneh et al., 2014; Daniel et al., 2014), for important applications in the design, development and formulation of new products. Our choice is based on the response surface

methodology, which is based on several properties, namely the optimization of the process time and the quantity of the reagents, but it also provides information on the interactions of these parameters (Vijaya et al., 2016).

Several studies on the species *S. officinalis* have been recorded in the literature but these studies remain limited compared to the quantitative evaluation of essential oil from different parts of the plant and with respect to the optimal operating extraction parameters. Indeed, some authors such as Akalın et al. (2015) and Pavlić et al. (2016) worked on the optimization of the experimental parameters of extraction of essential oil of sage by supercritical ethanol and subcritical water respectively through the response surface method. The work in hand is intended, therefore, to study the parametric hydrodistillation optimization of essential oil from the leaves of the medicinal plant *S. officinalis* of Algerian origin using the response surface methodology (RSM), in order to study the effects of the extraction parameters, namely the particle size, the condensing flow rate, and the extraction time on the mass yield of extracted oil, and to highlight the optimal conditions necessary for the extraction to get a better performance. The composition of the oil was identified by gas chromatography coupled with mass spectrometry (GC/MS).

2. MATERIAL AND METHODS

2.1. Plant material

In this study only the leaves of *S. officinalis* were subjected to extraction. The plant was collected from a semi-arid region around the city of Ain Oualmen (33Km from Setif) in North-East of Algeria). The geographical coordinates are: latitude 35 ° 55'24 '' North, longitude 5 ° 17'51 '', an altitude of 925 m. The plant was harvested in the spring of 2016. The leaves were air-dried and room temperature under shade before being crushed and sieved through a vibrating sieve system that separates the particles according to their size.

2.2. Methods

2.2.1. Hydrodistillation

The extraction of essential oil is carried out by hydrodistillation using a Clevenger type apparatus. 100g of plant material is introduced into a glass flask (2L) to which 1500ml of water is added. The distillation is carried out, and the extraction time is measured after the appearance of the first drop of distillate at the outlet of the condenser. The recovered oil is dried with calcium chloride and stored in tightly sealed opaque glass flask at low temperature (4°C). The yield of essential oil is expressed by the following relationship (1):

$$\text{oil yield}(\%) = \frac{\text{mass of extracted oil}}{\text{mass of plant material}} \times 100 \quad (1)$$

2.2.2. GC/MS Analysis

The identification of the chemical constituents of *S. officinalis* L. essential oil was made by a gas chromatographic (HP 5890-SERIE II) equipped with a HP5 MS capillary column (30m long, 0.25mm inner diameter and 0.25µm film thickness) coupled to a mass spectrometer (HP-MSD 5972). The vector gas is helium (1ml/min). The analytical conditions were: injector and detector temperature, respectively 250°C and 280°C; oven temperature programmed at 40°C for 5min, then gradually increased to 250°C at 2°C/min, maintained isothermal at 250°C for 15min, then raised to 270°C at 10°C/min. The injected volume is 1µl (diluted to 10% in hexane). The emission energy is 70eV. The spectral analysis of the compounds was carried out by comparison authentic samples using the WILEY275 mass spectra databases.

2.2.3. Choice of Experimental plan (Box-Behnken)

Experimental plans are techniques designed to highlight the effects of various factors on a response and to optimize them in specific experimental domains. A series of tests is organized to manipulate the factors in order to describe the suitable method so as to obtain the optimal response (Hancco et al., 2011). The response surface methodology is part of the experimental designs used for optimization. It is an empirical technical modeling devoted to evaluating the relationship of a set of controlled and observed experimental factors with the results (Annadurai & Sheeja, 1998).

Of the two types of response surface plans commonly used, namely centered composite plans and Box-Behnken plans, we chose the second type. The Box-Behnken plan is a surface response method used to examine the relationship between several response variables or a set of experimental parameters (Vijaya et al., 2016). The Box-Behnken plan requires fewer implementations and design points than a central composite design, in cases of three or four variables (Chopra et al., 2007). In addition, each factor requires only three levels instead of five required for centered composite plans, unless the alpha is one, which may be more practical and easier to perform (Ragonese et al., 2002). The three-factor Box-Behnken plan requires only 6 factorial points and 6 axial points in addition to replicas at the center point, the figure 1 represents a Box-Behnken three-factor design.

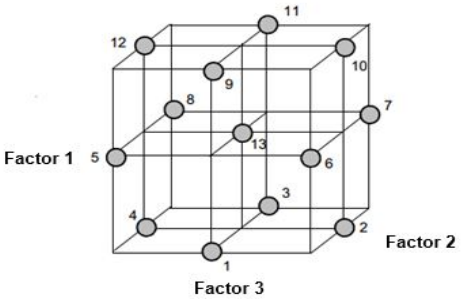

Figure 1. Box-Behnken three-factor design.

The number of experiments is given according to the equation (2):

$$N = 2k\,(k-1) + cp \quad (2)$$

Where k is the number of factors, and cp is the number of replications at the central point. So, Box-Behnken design is considered as an effective option in response surface methodology and an ideal alternative to central composite designs (Vijaya et al., 2016).

2.2.4. Experimental domains of the parameters

The optimization study was conducted on the operating parameters considered influential in hydrodistillation process

namely the particle size, the condensing liquid flow rate, and the extraction time. The choice of parameters to optimize and their experimental domains is based on literature data (Liu et al., 2009; Fadil et al., 2015; Akalın et al., 2015; Pavlić et al., 2016). The three parameters thought to affect the hydrodistillationproczss are all continuous or quantitative factors, i.e. factors which can be controlled, and which can adopt all the real numerical values in the chosen domain. The parameters and their experimental domains are shown in table 1.

Table 1. Experimental domains of the studied parameters

Parameter	Symbol	Unity	Minimum	average	Maximum
Particules Size	x_1	mm	1	1.5	2
Condensation flow rate	x_2	ml/min	1.4	2.4	3.4
Extraction time	x_3	min	150	180	210

2.2.5. Experimental Matrix

The experimental plan is based on a Box-Benhken plan for three parameters and three levels. Given 3 points repeated in the center to determine the pure error, a total of 15 tests were generated in table 2, consisting of 6 factorial points and 6 axial points.

2.2.6. Mathematical model

The postulated mathematical model is a polynomial of order 2 such that the equation:

$$Y(\%) = \beta_{11}x_1^2 + \beta_{22}x_2^2 + \beta_{33}x_3^2 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_0 \quad (3)$$

With:

Y is the theoretical yield of essential oil (Response).

β_0 represents the model constant.

β_1, β_2 and β_3 are the coefficients of the linear terms.

β_{11}, β_{22} and β_{33} are the coefficients of the quadratic terms.

β_{12}, β_{13} and β_{23} are the coefficients of the interaction terms.

x_1, x_2 and x_3 are the values of the parameters.

2.2.7. Statistical analysis and parametric optimization

The Response Surface Methodology (RSM) is a useful mathematical and statistical technique for modeling and analyzing the effect of multiple quantitative variables on the response of interest. This methodology saves time and effort by reducing the number of experimental trials and providing optimized and statistically significant results (Timung et al. 2016). Optimizing extraction parameters is important for efficient extraction. Consequently, the method of (RSM) was used to evaluate the effects of the hydrodistillation parameters of S. officinalis on the mass yield in essential oil, namely: the particle size distribution, the condensation flowrate and the extraction time, in order to find the optimal conditions with a better yield. In this work, the Design-expert® software version 7.0.0 (Stat-Ease, Inc., Minneapolis) was used to design the experiments and evaluate the results.

2.2.7.1. Analysis of variance

The model has been validated by the ANOVA. The model, the regression coefficients and the non-fit test will be considered significant when the probabilities of the significance of the p-value risk are less than 0.05 (Liu et al., 2009; Wijngaard & Brunton, 2010). In addition to the analysis of the variance, we will use other tools namely the multiple determination coefficient R^2 and the coefficient of variance CV, a variance coefficient value less than 10% indicates a very high degree of precision between experimental and predicted values (Pavlić et al., 2016).

2.2.7.2. Optimization study

After the determination of the model and the proof of its validity, and to explore the optimal operating conditions which lead to the desired response by a better optimization, we used the response surfaces that can be generated within the experimental domain from the model equation. These surfaces explain the variations of our response according to two parameters while maintaining the third constant, i.e. the graphical representation of the results (estimated model) to be able to derive optima.

Then, to find the exact optimal operating conditions with a certain percentage of compromise, we use the function "Desirability". This function, which makes it possible to give an exact optimal adjustment, varies between 0 and 1. Indeed, the value 0 is assigned when the factors lead to an unacceptable (undesirable) response and that of 1 when the response represents the maximum desired performance for the considered factors (Fadil et al., 2015)

3. RESULTS AND DISCUSSION

3.1. Experimental yield

The estimation of the mass yield of essential oil obtained by hydrodistillation reveals a value between 0.41-0.9 percent (table 2). The reading in the experimental results shows that the high yield (0.9%) was obtained for a particle size, a condensation flow rate and an extraction time of 2mm, 1.4ml/min and 180min respectively. A good yield of 0.84% was estimated at: 2mm, 2.4ml/min and 210min respectively. However, we recorded a relatively low yield (0.41%) at 1.5mm; 3.4 ml/min and 150min.

Table 2. Experimental matrix and experimental yield values

Exp	x_1 : Particle size (mm)	x_2 :Condensation flow rate(ml/min)	x_3: Extraction time(min)	Y : Experimental yield (%)
1	1	1.4	180	0.59
2	2	1.4	180	**0.9**
3	1	3.4	180	0.68
4	2	3.4	180	0.67
5	1	2.4	150	0.59
6	2	2.4	150	0.69
7	1	2.4	210	0.67
8	2	2.4	210	**0.84**
9	1.5	1.4	150	0.56
10	1.5	3.4	150	**0.41**
11	1.5	1.4	210	0.71
12	1.5	3.4	210	0.46
13	1.5	2.4	180	0.6
14	1.5	2.4	180	0.62
15	1.5	2.4	180	0.62

On the other hand, the obtained yield is in general in agreement with those reported in different localities (table 3).

Table 3. Essential oil yields of *Salvia officinalis* extracted by hydrodistillation.

Pays	Yields	Reference
Algeria (Setif)	0.41-0.9%	Our study
Algeria (Bejaia)	0.97%	Adrar et al. 2015
France	2.05%	
Tunisia	1.8%	
Portugal	2.9%	
Romania	2.3%	
Italy	0.55-2.20%	Alessandra et al. 2013

3.2. Kinetics of hydrodistillation

The kinetics of extraction consists in following the evolution of the cumulative extracted oil mass as a function of time. For this purpose and in order to assess this variation, sufficient time is left until the total extraction of the essential oil. The amount of oil extracted after 180 min and up to 240 min is about 0.3% of the total amount of oil extracted (figure 2). Based on the concept of minimizing extraction time and reducing energy consumption, the time required for the hydrodistillation is set as 180min.

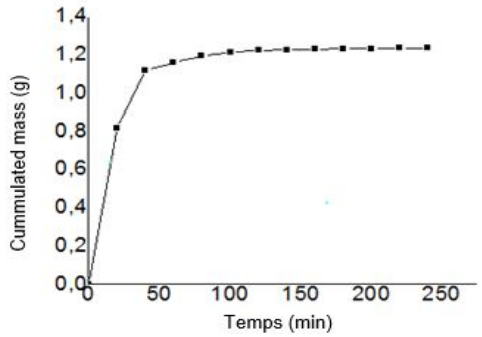

Figure 2. Variation of the cumulated mass of the essential oil as a function of the extraction time

3.3. Chemical composition of the essential oil:

The qualitative and quantitative GC/MS analysis led the identification of 34 compounds representing 99.99% of the crude oil. The chromatogram is shown in figure 3.

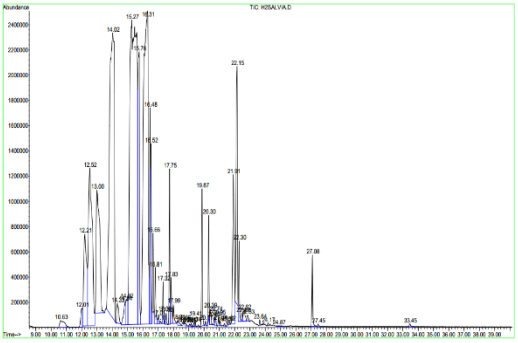

Figure 3. Chromatogram of analysis of the essential oil of *Salvia officinalis* by GC/MS

The results revealed that the oil is rich in oxygenated monoterpenes (table 4). In fact, 15 compounds of this family were detected representing (78.64%) of the mixture, 11 hydrocarbon monoterpenes with a rate of 15.44%, 4 oxygenated sesquiterpenes (4.68%) and 4 hydrocarbon sesquiterpenes (1.23%). The predominance of oxygenated monoterpenes is well known in the even with changing extraction methods and harvest techniques literature (Alessandra et al., 2013; Rus et al., 2015; Glisic et al., 2010; Aleksovski & Sovová, 2007; Bouaziz et al., 2009).

Table 4. Chemical composition of *S. officinalis* essential oil extracted by hydrodistillation

N°	Compound	RT (min)	KI	Composition (%)
	Monoterpenehydrocarbons			15.44
1	cis-salvene	6.223	855	0.23
2	α-thujene	6.359	935	1.8
3	α-Pinene	6.657	940	3.94
4	Camphene	7.196	954	2.21
5	Sabinene	7.422	976	1.34
6	β-pinene	7.735	997	0.38
7	α-Phellandrene	7.975	1005	0.25
8	*p*-Cymene	8.129	1025	2.62
9	Limonene	8.216	1032	2.06
10	γ-Terpinene	8.837	1063	0.39
11	α-terpinolene	9.057	1089	0.22
	Oxygenatedmonoterpenes			78.64
12	1.8-Cineole	8.294	1033	16.27
13	2-nonanone	9.497	1094	0.77
14	Nonanal	9.693	1105	0.42
15	α.-Thujone	9.857	1117	28.36
16	β.-Thujone	10.031	1120	6.2
17	dihydro-Linalool	10.178	1134	0.47
18	Camphor	10.67	1144	21.53
19	Borneol	11.044	1168	1.76
20	Terpinen-4-ol	11.276	1180	1
21	α-Terpineol	11.601	1190	0.36
22	Methyl chavicol	11.694	1205	0.66
23	Cuminicaldehyde	12.299	1251	0.52
24	Pulegone	12.891	1259	0.08
25	Bornylacetate	13.039	1288	0.07
26	2-undecanone	13.332	1295	0.17
	Sesquiterpenehydrocarbons			1.23
27	β.-Bourbonene	14.098	1393	0.07
28	β-Caryophyllene	15.86	1427	0.62
29	α.-Humulene	16.464	1461	0.47
30	allo-Aromadendrene	16.596	1478	0.07
	Oxygenatedsesquiterpenes			4.68
31	Spathulenol	18.587	1576	0.87
32	Caryophylleneoxide	18.692	1586	0.65
33	Veridiflorol	18.835	1590	2.72
34	13-Epimanool	19.124	1961	0.44
	Total %			99.99

Another qualitative reading in the constituents of oxygenated monoterpenic compounds shows that α.-Thujone is the major compound (28.36%), followed by camphor (21.53%), 1,8-

cineole (16.27%). and β.-Thujone (6.2%). these 4 compounds account for more than 72% of the total oil. The remaining compounds represent individual percentages of less than 4%. The same chemotype has been observed in the literature (Aleksovski & Sovová, 2007; Longaray et al., 2007; Rus et al., 2015).

3.4. Physicochemical properties of extracted essential oil

The essential oil of *S. officinalis* L. is colorless with a specific odor similar to that of camphor and an acid number of 1,122. The refractive index was measured at 20°C using a branded refractometer (ABBE) having a temperature indicator. The relative density, refractive index and pH were 0.914, 1.465 and 4.36 respectively and were similar to literature data (New Directions Aromatics Inc., 2016), as indicated table 5.

Table 5. Physicochemical properties of essential oil

Properties	Presentstudy	New Directions Aromatics Inc., 2016
Aspect	Colorlessliquid	Pale yellow to golden yellow liquid
Odor	Camphor	Herbaceouscharacteristic
Density (g/ml) at 20°C	0.9140	0.9100-0.9300
Réfraction Index de à 20°C	1.465	1.470
pH	4.36	ND
acid Index	1.122	ND

ND: undetermined

3.5. Statistical validation of the model

Variance Analysis (ANOVA) is a statistical tool that is widely used in model validation and comparison as well as in data analysis. This method uses variance measures to assess the significance of factors and models. The interest of this analysis is to be able to test in an absolute way the influence of the factors on the variations of a given answer. Our results were statistically tested by analysis of variance (ANOVA), the analysis showed that the experimental data were very adapted to the second order polynomial model.

The results displayed in the analysis of variance table (table 6) indicate that the model is significant since the probability of significance of the risk-value is less than 0.05, so there is only 0.58% chance that the model becomes invalid because of the noise. In addition, the model does not represent an adjustment lack since the probability of the risk significance of terms "default of adjustment " (p-value = 0.0444) is also less than 0.05. So, we can say that the model is well adjusted. Therefore, the model can be used to navigate the entire space of the experimental domain. The variance analysis also indicates that the terms of the model x_1, x_2, x_3, as well as x_1x_2, and x_1^2 are significant terms (p-value <0.05). Nevertheless, the rest of the terms are statistically insignificant: x_1x_3, x_2x_3, x_2^2, and x_3^2.

Table 6. Analysis of variance (ANOVA) for the quadratic model

variance Source	Sum of squares	Ddl	Middle square	p-value
Model	0.21	9	0.023	0.0058*
x_1 : particle size	0.041	1	0.041	0.0050*
x_2 : condensation flow rate	0.036	1	0.036	0.0063*
x_3 : Extraction time	0.023	1	0.023	0.0156*
x_1x_2	0.026	1	0.026	0.0128*
x_1x_3	1.225E-003	1	1.225E-003	0.4456
x_2x_3	4.500E-003	1	4.500E-003	0.2902
x_1^2	0.062	1	0.062	0.0020*
x_2^2	4.001E-003	1	4.001E-003	0.1950
x_3^2	7.616E-003	1	7.616E-003	0.0940
residues	8.942E-003	5	1.788E-003	
adjustmentFailure	8.675E-003	3	4.892E-003	0.0444*
pure Error	4.667E-004	2	1.333E-004	
Total	0.22	14		
R^2	0.9589			
CV (%)	6.6			

* Significant Terms, *p*-value <0,05

A coefficient of variation (CV) of 6.6% indicates a very high degree of precision between the experimental and predicted values (Akalın et al., 2015). On the other hand, for a good adjustment of a model, the R^2 value should be a minimum of 0.80 (Guan & Yao, 2008). The coefficient of determination R^2=0.9589% is sufficient. This value gives good compatibility between the experimental and predicted values of the adapted model.

The representative curve of the expected yield values as a function of the experimental yields is shown in figure 4, where it can be seen from the graph that the cloud of points is not far from the equation line (y=x) with a coefficient of determination R^2=0.9589, which indicates that the model has a good descriptive quality.

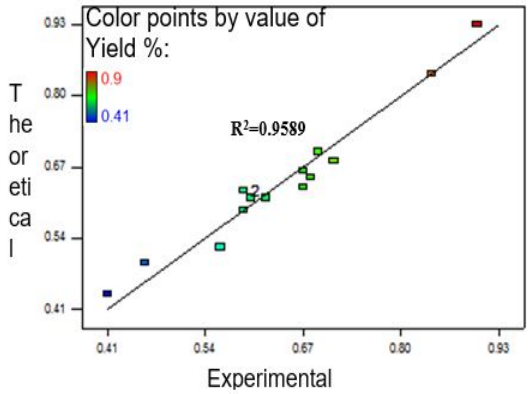

Figure 4. Representation of theoretical yield according to the experimental one

3.6. Study of the interactions of the parameters

For our model, and as shown in table 6, there is only one interaction whose effect is statistically significant. These are

the terms x_1 and x_2 relating respectively to the interaction of the particle size and the condensation flow rate. This means that the effect of particle size is not the same on the response when the condensation flow rate is changed.

3.7. Mathematical model

The experimental yield is used to determine the values of the regression coefficients of the polynomial (table 7).

Table 7. Regression coefficients of the polynomial

Coefficient	Value	Coefficient	Value
β_0	−1.04027	β_{22}	−0.032917
β_1	−1.23850	β_{33}	$-5.04630.10^{-5}$
β_2	0.48050	β_{12}	−0.16000
β_3	0.020208	β_{13}	$1.16667.10^{-3}$
β_{11}	0.51833	β_{23}	$-8.33333.10^{-4}$

The used mathematical model is given by the following equation (4):

$$Y(\%) = 0.51833x_1^2 - 0.032917x_2^2 - 5.04630.10^{-5}x_3^2 - 0.16000x_1x_2 + 1.16667.10^{-3}x_1x_3 - 8.33333.10^{-4}x_2x_3 - 1.23850x_1 + 0.48050x_2 + 0.020208x_3 - 1.04027 \quad (4)$$

3.8. Optimization of parameters

The objective of this study is to improve the yield of essential oil of *S. officinalis* extracted by hydrodistillation, through the optimization of operating parameters affecting the extraction process. By carrying out the experimental plan, we experimentally recorded a maximum yield with a value of 0.9%. The objective will therefore be to determine the optimum operating parameters that lead to a better yield than the experiment. In other words, we will look for the optimal operating conditions that lead to the maximum accessible value.

3.8.1. Response surfaces

The influence of the parameters studied on the oil yield can be graphically illustrated by the representation of the response surfaces in a three-dimensional space (3D). These surfaces make it possible to show the variation of the oil yield according to two factors while keeping the third constant. Figure 5 shows the response surface diagrams for the effect of mutual interactions of the parameters on the oil yield which can be observed from the nature of the curvature of the response surfaces.

The figures 5(a) and (b) highlight the effect of the extraction time on the essential oil yield, where they show that the increase in the extraction time results in an increase in the oil yield whatever is the particle size and the condensation flow rate. In addition, from Figures 5 (a) and (c) the increase in particle size results in a large increase in yield. On the other hand, and contrary to the first two parameters, the increase in yield is noticed with the decrease in condensing flow rate (Figures. 5. (b) and (c)). After the interpretation of the 3 surfaces, it is found that the oil yield is proportional with the extraction time and the particle diameter, and inversely proportional to the condensation flow rate.

The Analysis of the response surfaces permitted us to know the domains of variation of the parameters that enable to reach the desired yield. Thus, obtaining an optimum yield of 0.98% (the maximum accessible value) requires an extraction time: 210min, a condensation rate (1.4ml/min) and a particle size of 2mm. The study of desirability will enable us to define precisely the optimized values of the three studied parameters.

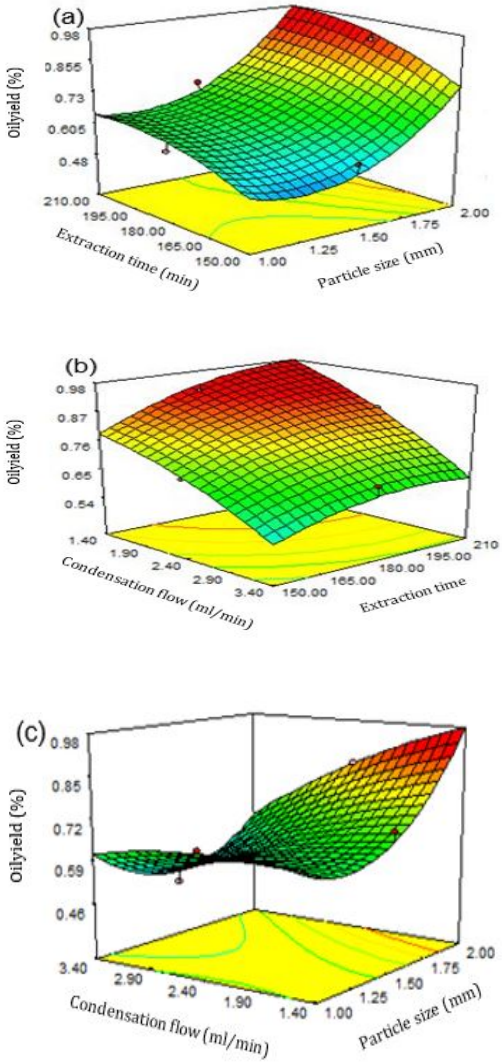

Figure 5. Response surfaces to show the effect of the hydrodistillation parameters on the oil yield: (a) extraction time and particle size; (b) condensation flow rate and extraction time; (c) condensation flow rate and particle size

3.8.2. Desirability study

The objective of our study is to maximize the yield of essential oil so as to reach the maximum available value. Figure 6 indicates that the achievement of the maximum yield value is possible with desirability of the order of 1, while providing, as operating conditions, an extraction time of 210min, a condensation flow rate of 1.4ml/min and finally a particle size of 2mm.

These results indicate that the desired yield requires an increase in the extraction time to the red terminal at the right of the variation range of this parameter 210min. Obviously,

time has a direct influence on the hydrodistillation operation, and its impact on this operation has been proven by several authors (Fadil et al., 2015).

The increase of the yield is also noticed with the increase of the particle size. This is perhaps due to the localization of the producing glands of the metabolites in the tissues of this plant. Indeed, for *lamiaceae*, essential oils are stored in specialized histological structures, often located on the surface of the plant such as secretory hairs (Fadil et al., 2015), and therefore do not require a strong grinding to extract them.

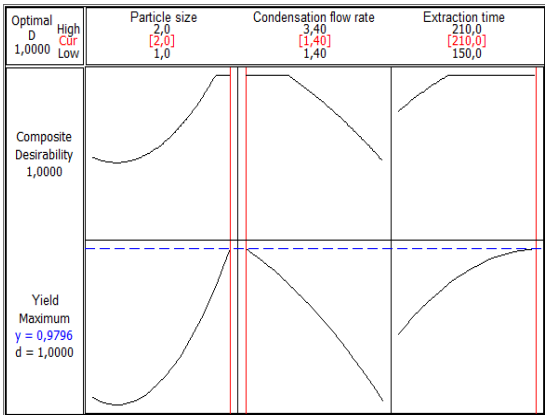

Figure 6. Prediction profile of optimal hydrodistillation conditions of *Salvia officinalis*

The last parameter (condensation flow rate) has an inverse effect on the essential oil yield. The latter reaches its maximum when the condensing flow rate is in the lower limit of the variation range of this factor (1.4ml/min). This phenomenon can be explained by the fact that a large increase in the heating temperature increases the condensation flowrate and, therefore, minimizes the residence time of the condensate in the condenser and does not allow time for the essential oils to be separated from the liquid.

4. CONCLUSION

The results of the study revealed that the essential oil of *Salvia officinalis* can be easily extracted using the hydrodistillation technique. The physicochemical properties of extracted oil were determined. analysis of this oil by GC/MS identified 34 constituents representing 99.99% of the crude oil, the majority of which is α.-Thujone (28.36%), followed by camphor. (21.53%), 1,8-cineole (16.27%) and β.-Thujone (6.2%).

The expected essential oil yield expressed by the second-order polynomial model depends on the linear terms β_1, β_2 and β_3, the quadratic terms β_{11}, β_{22} and β_{33} relating to the particle size, the condensation flowrate and the extraction time respectively, β_{12}, β_{13} and β_{23} interaction terms relating to the particle size/condensing flowrate interaction, particle size/extraction time and the condensation flow rate/extraction time interaction. The high regression coefficients of the R^2=0.9589 response with the model value *p*-value=0.0058 showed that the developed model is well suited to the experimental data, including the optimal (maximum) value of the expected yield Y=0.98% is obtained by the combination of the following operating conditions: particle size (2mm), condensation flow rate (1.4 ml/min) and extraction time (210min).

REFERENCES

1. Adrar N, Oukil N, Bedjou F. (2015). Antioxidant and antibacterial activities of Thymus numidicusand Salvia officinalis essential oils alone or in combination. Industrial Crops and Products.http://dx.doi.org/10.1016/j.indcrop.2015.12.007.
2. Afsaneh M and Mina A. (2014). Application of response surface methodology: design of experiments and optimization: a mini review. Indian Journal of Fundamental and Applied Life Sciences 4: 2434-2439.
3. Akalın M. K, Tekin K, Akyüz M, Karagöz S. (2015). Sage oil extraction and optimization by response surface methodology. Industrial Crops and Products 76: 829–835.
4. AleksicV andKnezevic P. (2014). Antimicrobial and antioxidative activity of extracts and essential oils of MyrtuscommunisL. Microbiological Research 169: 240–254.
5. Aleksovski S.A andSovová. H. (2007). Supercritical CO2extraction ofSalvia officinalisL.J. of Supercritical Fluids 40: 239–245.
6. Alessandra R, Carmen F, Daniela R, Felice S, Sebastiano D, Venera C, Sergio R, Maurizio B. (2013). Chemical composition and anticancer activity of essential oils of Mediterraneansage (Salvia officinalisL.) grown in different environmental conditions. Food and Chemical Toxicology 55: 42–47.
7. Annadurai G andSheeja, R.Y. (1998). Use of Box-Behnken design of experiments for the adsorption of verofix red using biopolymer. Bioprocess Engineering 18: 463–466.
8. Babar Ali, Naser A. A, Saiba S, Aftab A, Shah A. K, Firoz A. (2015). Essential oils used in aromatherapy: A systemic review. Asian Pac J Trop Biomed 5(8): 601–61.
9. BenbelaïdF, Khadir A, Abdoune M. A, Bendahou M, Muselli A, Costa J. (2014). Antimicrobial activity of some essential oils against oral multidrug resistant Enterococcus faecalis in both planktonic and biofilm state. Asian Pacific Journal of Tropical Biomedicine 4(6): 463-472.
10. Bouaziz M, Yangui T, Sayadi S, Dhouib A. (2009). Disinfectant properties of essential oils fromSalviaofficinalisL. cultivated in Tunisia. Food and Chemical Toxicology 47: 2755–2760.
11. BourrainJ. -L. (2013). Allergies aux huiles essentielles: aspects pratiques. Revue française d'allergologie 53: 30-32.
12. Chopra S, Gayathri V. P, Sanjay K. M. (2007). Release modulating hydrophilic matrix systems of losartanpotassium: Optimization of formulation usingstatistical experimental design. European

Journal of Pharmaceutics and Biopharmaceutics 66: 73–82.

13. Daniel G, Verônica M. (2014). The use and importance of design ofexperiments (DOE) in process modelling in foodscience and technology. Mathematical and Statistical Methods in Food Science and Technology, First Edition. John Wiley & Sons.
14. Fadil M, A. Farah, B. Ihssane, T. Haloui, S. Rachiq. (2015). Optimization of parameters influencing the hydrodistillation of Rosmarinus officinalis L. by response surface methodology. J. Mater. Environ. Sci 6 (8): 2346-2357.
15. Fu Z, Hang W, Xiaofei H, Zhaolin S, Chunchao H. (2013). The Pharmacological Properties of Salvia Essential Oils. Journal of Applied Pharmaceutical Science 3 (07): 122-127.
16. Galadima M. S, Ahmed A.S, Olawale A.S, BugajeI. M. (2012). Optimization of Steam Distillation of Essential Oil of Eucalyptus tereticornis by Response Surface Methodology. Nigerian Journal of Basic and Applied Science 20(4): 368-372.
17. Ghorbani A, Esmaeilizadeh M. (2017). Pharmacological properties ofSalvia officinalis and its components.http://dx.doi.org/10.1016/j.jtcme.2016.12.014. Journal ofTraditional and Complementary Medicine.
18. Glisic S, Jasna I, Mihajlo R, Dejan S. (2010). Extraction of sage (Salvia officinalisL.) by supercritical CO2: Kinetic data, chemical composition and selectivity of diterpenes. J. of Supercritical Fluids52: 62–70.
19. Guan X and Yao H. (2008). Optimization of Viscozyme L-assisted extraction of oat branprotein using response surface methodology. Food Chemistry 106: 345–351.
20. Hamidpour M, Hamidpour R, Hamidpour S, Shahlari M. (2014). Chemistry, Pharmacology, and Medicinal Property of Sage (Salvia) to Prevent and Cure Illnesses such as Obesity, Diabetes, Depression, Dementia, Lupus, Autism, Heart Disease, and Cancer. Journal of Traditional and Complementary Medicine 4 (2): 82 88.
21. Hancco V, Poilâne C, Chen J. (2011). In 17èmes Journées Nationales sur les Composites, PoitiersFuturoscope, France.
22. Liu S, Yang F, Zhang C, Ji H, Hong H, Deng C. (2009). Optimization of process parameters for supercritical carbon dioxide extraction ofPassifloraseed oil by response surface methodology. J. of Supercritical Fluids 48: 9–14.
23. Longaray Delamare A. P, Moschen-Pistorello I. T, Artico L, Atti-Serafini L, Echeverrigaray S. (2007). Antibacterial activity of the essential oils ofSalvia officinalisL. andSalvia trilobalL. cultivated in South Brazil. Food Chemistry 100: 603–608.
24. Mastura A. M, Najwa M, Khatimah M. (2013). Supercritical Fluid Extraction of Citronella Oil from Cymbopogonnardusand its Optimization. IEEE Business Engineering and Industrial Applications Colloquium (BEIAC).
25. Mu'azu K, Mohammed-Dabo I.A, Waziri S.M. (2012). Development of Mathematical Model for the Prediction of Essential Oil Extraction from Eucalyptus Citriodora Leave. Journal of Basic and Applied Scientific Research. 2(3): 2298-2306.
26. Nashwa T, Hassan H. M, Sameh M.M. A, Radwan I.A, Hammouda O, El-Gendy A. O. (2014). Comparative chemical and antimicrobial study ofnine essential oils obtained from medicinal plantsgrowing in Egypt. Journal of basic and applied sciences 3: 149-156.
27. Pavlić B, Vidović S, Vladić J, Radosavljević R, Cindrić M, Zeković Z. (2016). Subcritical water extraction of sage (Salvia officinalisL.) by-Products-Process optimization by response surface methodology. J. of Supercritical Fluids 116: 36–45.
28. Ragonese R, Macka M, Hughes J, Petocz P. (2002). The use of the Box – Behnken experimental design in the optimization and robustness testing of a capillary electrophoresis method for the analysis of ethambutol hydrochloride in a pharmaceutical formulation. Journal of Pharmaceutical and Biomedical Analysis 27: 995–1007.
29. Rus C. F, Pop G, Alexa E, Şumălan R. M, Copolovici D. M. (2015). Antifungal activity and chemical composition of Salvia officinalis L. essential oil. Research Journal of Agricultural Science 47:2.
30. Timung R, Barik C. R, Purohit S, Vaibhav V. G. (2016). Composition and anti-bacterial activity analysis of citronellaoil obtained by hydrodistillation: Process optimization study. Industrial Crops and Products 94: 178–188.
31. Vijaya Ch.S. V andMaravajhala V. (2016). Response surface methodology during optimization studies - an overview. Journal of Scientific Research in Pharmacy 5(9): 124-129.
32. Wijngaard H. H and Brunton N. (2010). The optimization of solid–liquid extraction of antioxidants from apple pomace by response surface methodology. Journal of Food Engineering 96: 134–140.