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Optimization of Thyme Essential Oil Extraction by Microwave: An Investigation by Box–Wilson Central Composite Design (CCD)

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ABSTRACT

In this study, response surface methodology based on the Box-Wilson central composite design was employed to optimize the extraction of thyme essential oil using microwave technology. Based on prior research and operational conditions, two main factors, namely steam flow rate (Q) and microwave heating power (P), were examined to assess their impact on the yield and extraction speed. A total of 12 experiments were conducted, including central cube points and axial points, with replications at the center point to ensure robustness of the results. Experimental data were analyzed using Analysis of Variance (ANOVA) to identify significant interactions and optimize extraction conditions.

Keywords: Thyme essential oil, microwave extraction, response surface methodology, CCD, ANOVA.

1. Introduction

Optimizing key parameters in essential oil extraction can significantly enhance both the efficiency and quality of the final product. This study utilizes a rigorous approach based on the Box-Wilson design to explore the combined effects of steam flow rate and microwave power on the efficient extraction of thyme essential oil. . Previous research, such as the study by Bertouche, Sahraoui, and Boutekedjiret (2012), has demonstrated the effectiveness of different distillation techniques, including steam-distillation and steam-diffusion, under optimized conditions, highlighting the importance of method selection on yield and antioxidant activity of thyme essential oil.

2. Experimental

The experimental setup used in this study consists of a microwave-assisted steam distillation system, an innovative method that combines the traditional technique of steam extraction with the effective application of microwave energy. The experimental design employed is a central composite design, a part of the response surface methodology that allows for systematic exploration of the parameter space. . This model, well-detailed in Myers, Montgomery, and Anderson-Cook (2016). This model facilitated the variation and coding of two key variables, microwave power (200-600W) and steam flow rate (6-14 g/min). The collected data were analyzed using Analysis of Variance (ANOVA) to validate the model, identify significant interactions between the variables, and determine the optimal conditions for maximizing the yield and quality of thyme essential oil . The coefficient of determination (R2), in addition to the adjusted R2, was used for statistical assessment to quantify the accuracy and confirm the dependability of the polynomial model equation.

3. Results and Discussion

Results indicate complex interactions between steam flow rate and microwave power, with significant effects on the yield and extraction speed. The analysis facilitated the identification of specific conditions under which extraction efficiency is maximized, thereby promoting a more economical and environmentally viable method. The results derived from various experiments establish a correlation that reveals the impact of Steam Flow Rate (X_1) and Microwave Power (X_2) on the response variables, which are: essential oil yield (Y_1) and extraction speed constant (Y_2). This correlation was generated using Minitab 21 software and is

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represented by the following second-order polynomial equations:

$$Y_1=2{,}6782 - 0{,}1874\ X_1 - 0{,}0633\ X_2 + 0{,}0992\ X_1^2 - 0{,}2964\ X_2^2 - 0{,}0366\ X_1*X_2$$

$$Y_2=2{,}5240 + 0{,}6452\ X_1 + 0{,}3674\ X_2 - 0{,}3702\ X_1^2 - 0{,}2336\ X_2^2 + 0{,}2819\ X_1*X_2$$

The coefficient of determination, known as R^2, is used to validate the accuracy of the model and its fit to the data. In this study, the practical values closely matched the expected values, resulting in an R^2 value of 0.97, indicating that 97.09% of the variability in the responses could be explained by the independent variables.

4. Conclusions

This study, employing response surface methodology and a central composite design, has effectively optimized the microwave extraction of thyme essential oil. We demonstrated that steam flow rate and microwave power are key parameters that significantly influence both yield and extraction speed. The optimal conditions identified promise to enhance not only the efficiency but also the sustainability of essential oil extraction processes. With a determination coefficient of 0.97, our model accurately predicts extraction outcomes, thereby providing a solid foundation for industrial application and scaling up the results. This seminar highlights the importance of combining technological innovations with rigorous statistical methods to advance the sustainable production of natural products.

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