Optimization of essential oil yield in *Lippia alba* leaves using Response Surface Methodology (RSM)

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Introduction

Essential oils (EOs) are effective and sustainable alternatives to chemical pesticides for controlling storage pests.

Lippia alba essential oil has demonstrated insecticidal and antifungal activity which can be explored against pests responsible for cereal post-harvest losses of up to 20% in Sub-Saharan Africa.

Well adapted to Senegal's agroecological conditions and requiring low water input, *Lippia alba* is a promising candidate for modernizing traditional post-harvest storage technologies using its essential oil.

This study focuses on producing *Lippia alba* and optimizing its essential oil yield using Response Surface Methodology (RSM), aiming for maximum yield with consistent essential oil composition.

Methods

1. Plant cultivation

Fig.2 Three plots ensured phenological differentiation, (UGB Farm, Sanar, Senegal)

2. Design of experiment

Table 1 Full Factorial Design (FFD)

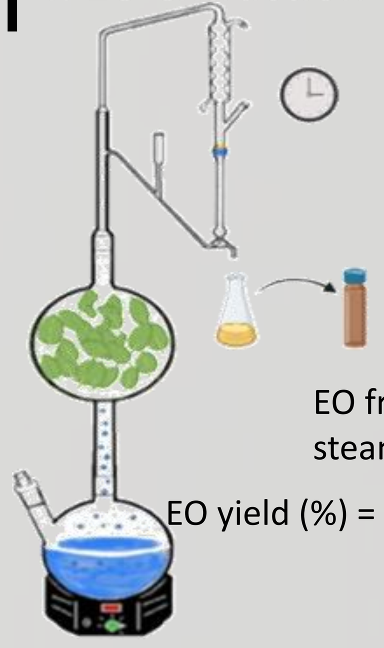
Parameters	Levels (coded)		
	Minimum (+1)	Medium (0)	Maximum (+1)
Phenological stage	Vegetative	Flowering	Fructification
Drying time (days)	0	3	6
Distillation time(hours)	1	2	3

3. Sample Preparation

Leaves harvest at 3 stages — Drying (shade, ambient T°C) — Leaf packaging

Vegetative · Flowering · Fructification · Drying conditions followed the FFD · Vacuum-sealed and labeled leaves

4. EO extraction



EO from 20 g leaves by steam distillation

EO yield (%) = (EO (g) / Plant (g)) x 100

5. Data analysis

Data were analyzed using Response Surface Methodology (RSM) with Minitab 21

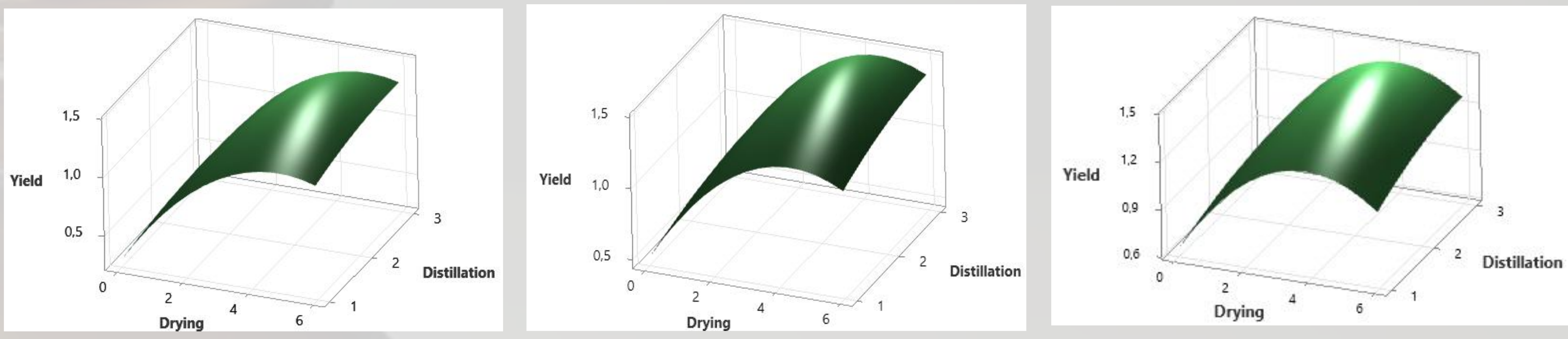
Results and discussion

Table 2 : Analysis of variance

Source	Degree of Freedom	Mean of square	F-Value	P-Value
Model	11	0,97861	119,89	0,000
Linear	4	1,93558	237,12	0,000
Drying	1	7,12211	872,51	0,000
Distillation	1	0,21624	26,49	0,000
Phenology	2	0,20198	24,74	0,000
Square	2	1,22784	150,42	0,000
Drying²	1	2,42443	297,01	0,000
Distillation²	1	0,03125	3,83	0,054
2-Way Interaction	5	0,11334	13,89	0,000
Drying*Dist	1	0,01925	2,36	0,129
Drying*Phenology	2	0,26788	32,82	0,000
Dist*Phenology	2	0,00586	0,72	0,491
Error	69	0,00816		
Lack-of-Fit	15	0,00948	1,22	0,289
Pure Error	54	0,00780		
Total	80			

Table 3 : Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0,09	95,03%	94,24%	93,36%



Hold value : Phenology vegetative · Hold value : Phenology flowering · Hold value : Phenology fructification

Fig. 3: Surface plots of EO yield vs. distillation and drying at each phenological stage

Table 4 : Result of optimum condition

Results	Phenology	Drying time (days)	Distillation time (hours)	EO yield (%)
Predictive model	Flowering	4	3	1,465
Experimentation	Flowering	4	3	1,457

- Based on the ANOVA, the model p-value was < 0.05, indicating statistical significance.
- Adjusted regression coefficient (adj-R^2 = 94.24%) demonstrated high predictive accuracy.
- Lack-of-fit with a p-value > 0.05 confirms that the fitted model is reliable and reproducible.
- Linear and square terms of the regression model for the drying factor were significant ($p \leq 0.05$).
- Drying*phenology interaction was significant ($p < 0.05$).
- Essential oil yield was greater than 1.2% after 4–5 days of drying and 2–3 hours of distillation (Fig. 3). Similarly, Minitab's optimization tool predicted a maximum yield of 1.46% with 4 days of drying and 3 hours of distillation, which is very close to the experimental result (Table 3).

Conclusion and perspectives

The mathematical model accurately predicted the results, as shown by a high R^2 value and significant p-values. Among the tested factors, drying time had the strongest effect on essential oil yield.

The highest yield of EO was obtained with four days of drying, harvesting at the flowering stage, and three hours of distillation.

Further GC-MS analysis will reveal the chemical composition and help identify the best conditions for maximizing limonene content, ensuring both high yield and consistent quality.

References

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