Review Article

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Color and composition of beauty products formulated with lemongrass essential oil: Cosmetics formulation with lemongrass essential oil

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Abstract: Diversification of products that are derived from essential oils carries important implications in reducing agricultural waste and promoting the medicinal materials industry. In this study, we formulated a shampoo and a body wash product incorporated with lemongrass (*Cymbopogon citratus*) essential oils (LEOs) and evaluated their color stability and the LEO compositional change. We first determined the color change and chemical composition of bare LEO under different storage conditions. Afterward, the washing product base was formulated, and its formulation process was optimized to minimize the color change by varying a wide range of parameters including pH, the inclusion of preservatives and antioxidants, LEO/antioxidant

ratio, and emulsification temperature. The base product was then used in body wash and shampoo formulation following our previously reported procedure. The results indicated that direct incorporation of the LEO into the cosmetic products resulted in better color stability and citral retention in comparison with emulsion formation. In addition, shampoo and body wash products showed no detectible presence of compounds resulting from citral decomposition such as 3,7-dimethyl-1,3,6-octatriene, *p*-mentha-1,5-dien-8-ol, and *p*-cymene-8-ol. The current findings are expected to aid in diversifying LEO-derived commodities and justifying scalability of the cosmetics production process with a focus on the incorporation of naturally derived ingredients.

Keywords: *Cymbopogon citratus*, essential oils, shampoo, body wash, color stability, cosmetic formulation

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1 Introduction

Lemongrass (*Cymbopogon citratus*) is a common plant ingredient that is used widely in daily applications and in folk medicine [1–4]. The main product derived from the lemongrass plant, lemongrass essential oil (LEO), is also a commodity that is widely used in the food industry due to its predominant content of citral in its composition, which confers the LEO with potent antibacterial activity and pleasant, favorable aroma [5–8]. Additionally, the LEO is also a common material in the manufacture of medicinal products such as antifungal agents, antidepressants, and indigestion remedies.

Despite that, the increasingly rapidly growing area of lemongrass has brought about excess output on both the raw material and LEO, causing difficulty in solving the surplus LEO and calling for diversification of products that are mainly or partially derived from LEO. Apart from medicinal products, products that are manufactured

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with LEO as a major component are quite limited in Vietnam, mostly comprising insect repellent products and a relaxation agent. As a result, new and novel attempts to incorporate LEO into consumers' products such as personal care and home products are essential to the valorization of lemongrass and contribute to ease the burden of lemongrass output in the upcoming years [9,10].

The main challenge in introducing LEO into consumer products is that the citral component in LEO is highly susceptible to conversion by acid catalysts and oxidative degradation, especially in the presence of light and heat, leading to the formation of the intensity change of flavor [11,12]. The decomposition of citral is more expedited at a higher temperature, light, and available oxygen in this compound and may produce other compounds such as p-cymene, p-cymene-8-ols, p-mentha-1,5-dien-8-ol, p-menthadien-8-ol, α ,p-dimethylstyrene, p-methylacetophenone, and p-cresol, which may further alter the aroma intensity of LEO [12-18]. To address this issue, various measures have been devised to prevent or mitigate the decomposition of citral, including the use of spraydrying technique, the formation of oil-in-water emulsions, and the manufacture of micelles and reverse micelles to stabilize citral in the oil phase [19-21]. However, such techniques are more labor-intensive and require modern instruments, thus considerably escalating manufacturing costs and in turn affecting consumers' acceptance due to the high price sensitivity of demands for home products.

Driven by the aforementioned trusts, this study aims to evaluate the stability of LEO in the formulation of various cosmetic products. We first evaluated the color change and chemical composition of LEO under different storage conditions. Then, the formulating process of a washing product base was optimized to minimize the color change in the base. The best product base was then used in the formulation of two cosmetic products, including body wash and shampoo, following our previously reported procedure. Finally, the two products were then evaluated for the LEO volatile composition and color change. The findings are expected to aid in diversifying LEO-derived commodities and justifying the scalability of the cosmetics production process with a focus on the incorporation of naturally derived ingredients.

2 Materials and methods

2.1 Materials

LEO was obtained by steam distillation of the leaves of emongrass (Cymbopogon citratus) harvested from Tan Phu

Dong district, Tien Giang province, Vietnam (Coordinates 10°15′N 106°39′E). The extraction apparatus was of industrial scale and operated under the following conditions: extraction time, 3 h; material quantity, 639–710 kg per batch. The highest LEO vield was 0.273% (v/w).

2.2 Formulation of simulated product base incorporated with LEO

Formulation of the product base was realized by using base oil, emulsifier, or the lack thereof. The simulated product base was formulated by using four ingredients including LEO, preservatives, additives (base oil, emulsifier, or none), antioxidants, and water. The LEO (and additive) mixture was first mixed with preservatives and antioxidants. The afforded mixture was introduced into heated water (70-80°C) under stirring. The resulting mixture was then allowed to naturally cool and homogenized.

The formulation process was first investigated with respect to different base oils (PEG-40 hydrogenated castor oil (PEG-400), paraffin oil, and none), varying emulsification temperature (room temperature to 90°C), and different emulsifiers (Tween 80, Tween 20, PEG 40, and none). After determining the appropriate formulation technique, the process was then further optimized by experimenting at different pH values (4-7), different preservatives (sodium benzoate, sodium lactate, DMDM hydantoin (DMDM-H)), antioxidants (butylated hydroxyanisole (BHA), and butylated hydroxy toluene (BHT)), and antioxidant/LEO ratio (0.5:1-2.5:1).

2.3 Formulation of body wash and shampoo products incorporated with LEO

The body wash formulation process was carried out by using the product base following a previous report [20]. Briefly, the product base was separately formulated with the composition and conditions that were determined in previous investigations. Then, another mixture consisting of the main detergent, detergent adjuvant, thickener, foaming agent, humectant, preservative, and skin emollient was prepared separately before being introduced into the mixture. Afterward, NaCl 25% and citric acid 30% were added to the mixture. Finally, the body wash was cooled and poured into a bottle for further evaluation.

The shampoo product was formulated similarly to the body wash formulation, except that the BHT/LEO ratio in the washing base was fixed at 0.5:1 (w/w) [19].

2.4 Determination of pH and the color change

The MP220 pH meter (Mettler Toledo) was used to determine the pH of the sample. The product samples were diluted 100 times before the pH measurement for accurate determination.

The color of the samples was measured by using a CR-400 colorimeter (Konica Minolta, Japan). The liquid product was stored in a glass cuvette placed in a dark chamber for the measurement. The color of the product was determined by the color space $L^*a^*b^*$. The $L^*a^*b^*$ color space is spherical with three axes: L, a, b. The a-axis runs from $-a^*$ (green) to $+a^*$ (red) and the b-axis runs from $-b^*$ (light green) to $+b^*$ (vellow). The brightness axis L^* is valid from 0 (black at the bottom) to 100 (white at the top).

The color differences between samples or time points are determined as follows:

$$\Delta L = L_2 - L_1$$

$$\Delta a = a_2 - a_1$$

$$\Delta b = b_2 - b_1$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

where *L*, *a*, and *b* represent lightness, *a*-axis, and *b*-axis, respectively, Subscripts 2 and 1 represent after and before color change, respectively, and ΔE is the color change indicator.

2.5 Determination of chemical composition

LEOs present in the product samples were first recovered by using hydrodistillation before the samples were used to determine the chemical composition. Briefly, 100 g of the sample was first introduced in water in the ratio of 1:4 (w/w). Hydrodistillation was carried out at a temperature of 120°C until no essential oil could be recovered from the apparatus.

Gas chromatography-mass spectrometry (GC-MS) was adopted to determine the composition of LEO. About 25 μ L of the essential oil was diluted in 1.0 mL of n-hexane and dehydrated with Na₂SO₄ salt. The equipment used was GC Agilent 6890 N (Agilent Technologies, Santa Clara, CA, USA), with MS 5973, HP5-MS column, and column head pressure of 9.3 psi. GC-MS was installed under the following conditions: He carrier gas; flow rate, 1.0 mL/min; split line, 1:100; injection volume, 1.0 µL; and injection temperature, 250°C. The initial temperature was kept at 50°C for 2 min; the oven temperature increased to 80°C at a speed of 2°C/min, from 80 to 150°C at a speed of 5°C/min, from 150 to 200°C at a speed of 10°C/min, from 200 to 300°C at a speed of 20°C/min, and maintained at 300°C for 5 min.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussion

3.1 Color and compositional changes of LEO during storage

The obtained LEO via hydrodistillation was light yellow in color with a characteristically strong citrusy and lemony aroma. The color changes of different LEO samples are detailed in Table 1. At ambient temperature, the color of LEO tended to become darker as the storage time prolonged, yielding the ΔE values of 0.82 and 3.63 for LEO stored after 1 week and 1 month, respectively. However, visual examination of LEO samples revealed that these color changes are indiscernible due to the insignificant

Table 1: Color changes of LEO under different storage and extraction conditions

Index	Initial LEO	LEO after 1 week at ambient temperature	LEO after 1 month at ambient temperature	LEO after 1 week at 45°C	LEO after 1 month at 45°C	Redistilled LEO after 1 month at 45°C		
L	61.98	62	61.99	61.79	60.09	62.48		
а	-7.82	-7.89	-8.4	-8.9	-8.21	-3.87		
b	22.57	23.39	26.15	30.47	42.13	10.54		
Δ <i>E</i>	_	0.82	3.63	7.15	16.09	20.57		

change in the intensity of the *L* index. By contrast, storage at elevated temperature seemed to cause more pronounced darkening in samples, reflected by significantly higher ΔE values compared to their respective values of LEO measured at ambient temperature. The role of heat in accelerating citral transformation has been documented by Peacock and Kuneman [22]. On the other hand, the redistilled LEO displayed a much lighter vellow in color, less pungent aroma than other samples, and was obtained in a lower yield due to the mass loss of around 35.91% of the total essential oil. According to Weerawatanakorn et al. [23], aromatherapy compounds are susceptible to chemical changes that occur in different types of interactions, including oxidation, hydrolysis, thermal destruction, photochemical, and polymerization of unsaturated compounds, adversely affecting the overall fragrance quality of the product. Therefore, the storage temperature of 45°C was selected as the base condition in the subsequent experiment measuring compositional changes in product formulations (Figure 1).

The major compounds that were present in the initial LEO sample are summarized in Table 2. In total, 11 volatile compounds were identified, accounting for 99.79% of the total LEO content, of which the percentage of citral amounted to 86.90%, followed by β -myrcene (5.656%), and nerol (3.887%). Other components lower than 1% included 6-methyl-5-hepten-2-one, β-linalool, β-citronellol, geraniol acetate, β-caryophyllen, α-bergamotene, and selina-6-en-4-ol. The composition of LEO in the present sample is similar to that of a previous study where LEO extracted from the lemongrass materials of the same origin showed citral and β-myrcene contents of 79.33 and 16.65%, respectively [21]. The abundance of citral is in line with the result of another review that indicated that LEO contained at least 75% citral and other minor ingredients such as nerol, geraniol, citronellal, terpinolene, geranyl acetate, myrecene, and terpinol methylheptenone [24]. The beneficial effect of citral on the skin membrane was elaborated by a previous study where citral-rich LEO was found to exhibit potent antifungal activities against several yeasts of Candida species and did not cause skin irritation [25]. Furthermore, Modak and Mukhopadhaya [26] also demonstrated the antiobesity effects of citral in a rat model and suggested that the effect could be attributable to the influence of citral on energy production, thus reducing fat accumulation. The role of citral in the food industry was also highlighted by a previous finding suggesting that citral-containing nanoemulsion exhibited potent antibacterial and antibiofilm activity against Listeria monocytogenes, a common foodborne pathogen [27] (Figure 2).

The compositional stability of LEO was further evaluated by performing GC-MS analysis of LEO samples stored for a week, for a month at 45°C, and the redistilled LEO sample. In comparison with citral contents of the initial LEO, the 1-month LEO sample stored at 45°C showed a moderately reduced percentage in α- and β-citral contents, reaching 44.214 and 35.026% respectively. This LEO sample also indicated the presence of three new compounds that had not been previously detected in the initial LEO, including 3,7-dimethyl-1,3,6-octatriene (0.395%), p-1,5-menthadien-8-ol (0.768%), and p-cymen-8-ol (1,154%). However, after being redistilled, the three compounds were no longer detected in the LEO. These results imply that the oxidation of citral occurred during storage due to exposure to heat and light and are consistent with the results of Weerawatanakorn et al. [23] and Ueno et al. [28], which found that the oxidation products of citral, including p-menthadien-8-ol, α ,p-dimethylstyrene, p-cymene, p-methylacetophenone, and p-cresol, resulted in a loss of flavor in the LEO.

In general, exposure to both heat and light and extended preservation have led to the degradation of citral content and color quality. Some compounds such as p-menthadien-8-ol and p-cymene were generated in



Figure 1: Color change of LEO at different time points: (a) initial LEO; (b) after 1 week at room temperature; (c) after 1 month at room temperature; (d) after 1 week at 45°C; (e) after 1 month at 45°C; and (f) redistilled LEO.

Table 2: Chemical compositions of LEO under different storage and extraction conditions

No.	RT (min)	Compounds	Content (%)							
			Initial LEO	LEO after 1 week at 45°C	LEO after 1 month at 45°C	Redistilled LEO after 1 month at 45°C				
1	9.771	6-Methyl-5-hepten-2-one	0.805	1.149	1.314	1.529				
2	9.907	β-Myrcene	5.656	6.025	10.867	3.887				
3	12.427	3,7-Dimethyl-1,3,6- octatriene	_	_	0.395	_				
4	16.097	β-Linalool	0.754	0.664	0.805	1.024				
5	19.799	<i>p</i> -Mentha-1,5-dien-8-ol	_	_	0.768	_				
6	20.667	p-Cymene-8-ol	_	0.288	1.154	_				
7	22.727	β-Citronellol	0.499	0.547	0.572	0.681				
8	23.166	β-Citral	39.031	38.699	35.026	38.697				
9	23.710	Nerol	3.887	3.583	3.612	4.402				
10	24.337	α-Citral	47.868	47.588	44.214	46.802				
11	28.050	Geraniol acetate	0.602	0.361	0.525	1.610				
12	28.980	β-Caryophyllen	0.296	0.339	0.324	0.357				
13	29.482	α-Bergamotene	0.267	0.309	0.234	0.449				
14	33.884	Selina-6-en-4-ol	0.115	0.200	0.189	0.313				
Citral	content		86.899	86.287	79.240	85.499				

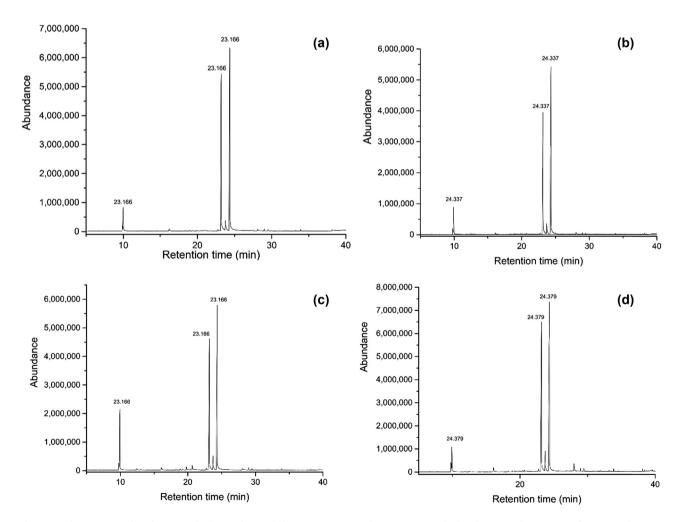


Figure 2: Chromatography of essential oil samples at different storage conditions: (a) initial; (b) after 1 week at 45; (c) after 1 month at 45; and (d) redistilled LEO.

the process, necessitating further investigation in preserving valuable compounds in LEOs when it is being formulated in cosmetic products.

3.2 Color of the product base during formulation

3.2.1 Effects of base oil, emulsifier, and emulsification temperature

Incorporation of LEO into cosmetic products is usually realized through two main approaches: direct mixing and via the formation of emulsions. In the first investigation (effect of base oil on the product color), formulation conditions consisted of the following: LEO content, 3%; BHT, 1.5%; PEG-40, 15%; sodium benzoate, 0.6%; sodium lactate, 2%; DMDM-H, 0.6%; and emulsification temperature, 70°C. All formulated product bases showed an aroma almost identical with that of the LEOs after short and constant storage conditions (7 days at 45°C).

Table 3 shows the color changes of simulated product base formulated at different temperatures, base oils (PEG-400, paraffin oil, and none), and emulsifiers (Tween 80, Tween 20, PEG-40, and none). Generally, two samples that were devoid of base oils or emulsifiers showed the lowest ΔE values, of 0.96 and 0.87, respectively, indicating that base oils and emulsifiers play a key role in inducing color changes in the product base formulations with LEO [29-31]. Further examination of the formulated bases showed that the LEO layering phenomenon emerged

Table 3: Color change of the washing product base after 7 days of storage at 45°C formulated at different base oils and emulsification conditions

Base oil	Emulsification temperature (°C)	Emulsifier	ΔΕ
PEG-400	70	PEG-40	2.35
Paraffin oil	70	PEG-40	4.17
None	70	PEG-40	0.96
None	Room	PEG-40	1.54
None	50	PEG-40	1.58
None	60	PEG-40	1.13
None	70	PEG-40	1.26
None	80	PEG-40	1.75
None	90	PEG-40	1.83
None	60	Tween 80	1.98
None	60	Tween 20	4.31
None	60	PEG-40	1.73
None	60	None	0.87

in the sample incorporated with paraffin. After 7 days of preservation at 45°C, bases formulated with PEG-400 and paraffin exhibited moderate discoloration toward yellow and revealed instability. Overall, the direct mixing of LEO into product bases seemed to result in little change in color in comparison with the emulsion route. Therefore, direct mixing of LEO would be done in subsequent experiments.

3.2.2 Effects of formulation conditions on the product base color

Influence of other mixing conditions including pH (4–7), preservative (sodium lactate, sodium benzoate, and DMDM-H), antioxidant (BHT and BHA), and antioxidant/LEO ratio (0.5:1-2.5:1 w/w) on the product color was investigated in the next series of experiments. In the experiment where the pH value was varied, the color change was more pronounced at pH 7, while the products obtained at pH 4 and 5 displayed comparatively lower ΔE , of 2.49 and 2.22, respectively. This could be explained by the susceptibility to the decomposition of citral at high pH and its stability in acidic environments [14]. Apparently, at pH 5, the product color changed to a minimal degree and thus was selected as the condition for further investigation. Regarding color change with respect to the added preservatives, the base product incorporated with sodium benzoate displayed higher ΔE (1.75) when compared with those added with sodium lactate (0.76) or with DMDM-H (0.77). Therefore, DMDM-H and sodium lactate were used for further experiments (Table 4).

The antioxidants are important ingredients that assist in preventing and slowing down the oxidation process of other chemicals in the formulation. They reduce the effects of oxidation processes by binding to each other radical molecules, reducing their decomposition power [32]. In the following experiments, the product color was investigated with regard to the type of antioxidant and its content. Two common antioxidants, namely BHA and BHT, were incorporated into the base formulation. The sample incorporated with BHA and stored at 45°C demonstrated a marked color quality change and major layering in the bottle. On the contrary, samples incorporated with BHT showed minor ΔE fluctuations and less color degradation than BHA-containing samples. This is in part due to the higher thermal stability of BHT structure in comparison with BHA [33]. Thus, BHT was selected as the antioxidant in the following experiment. Regarding the change of product color with respect to the antioxidant/LEO ratio, a higher ratio seemed to be associates with a more yellowish

Table 4: Color change of the washing product base after 7 days of storage at 45°C formulated at different process conditions

pH value	Preservatives	Antioxidants	Antioxidant/LEO ratio (w/w)	ΔΕ
pH 4	Sodium benzoate	ВНТ	1:1	2.49
	Sodium lactate			
	DMDM-H			
pH 5	Sodium benzoate	BHT	1:1	2.22
	Sodium lactate			
	DMDM-H			
pH 6	Sodium benzoate	ВНТ	1:1	2.56
	Sodium lactate			
	DMDM-H			
pH 7	Sodium benzoate	ВНТ	1:1	2.67
	Sodium lactate			
	DMDM-H			
pH 5	Sodium benzoate	ВНТ	1:1	0.76
pH 5	Sodium lactate	BHT	1:1	1.75
pH 5	DMDM-H	BHT	1:1	0.77
pH 5	Sodium benzoate	ВНТ	1:1	1.94
	DMDM-H			
pH 5	Sodium benzoate	ВНА	1:1	2.93
	DMDM-H			
pH 5	Sodium benzoate	BHT	0.5:1	0.85
	DMDM-H			
pH 5	Sodium benzoate	BHT	1:1	0.84
	DMDM-H			
pH 5	Sodium benzoate	ВНТ	1.5:1	1.60
	DMDM-H			
pH 5	Sodium benzoate	BHT	2:1	3.75
	DMDM-H			
pH 5	Sodium benzoate	BHT	2.5:1	5.94
	DMDM-H			

product texture. However, the change was marginal and could not be visually discernible. To be specific, at BHT/ LEO ratios of 0.5:1 and 1:1, the ΔE values of the base product were 0.85 and 0.84, respectively. At higher BHT/ LEO ratios of 1.5:1, 2:1, and 2.5:1, the color change progress was more accelerated, reaching ΔE values of 1.6, 3.75, and 5.94, respectively. The observed color degradation is largely attributable to increased reactivity of the atmospheric oxygen atoms having an uneven number of electrons in the outer shell resulting in the chemical reactions occurring within the base. The addition of BHT could contribute to better color stability via a mechanism that is similar to that of vitamin E. To be specific, BHT could donate one hydrogen atom to the oxygen atoms with uneven electron distribution, forming hydroperoxide [33]. However, excessive addition of BHT may generate redundant electrons than that required for radical oxygen to stabilize, adversely affecting the product quality. From these results, the BHT/ LEO ratio of either 0.5:1 or 1:1 was used in subsequent investigations.

3.3 Color and compositional changes of LEO in formulated body wash and shampoo products

The body wash and shampoo products incorporated with LEO were stored for a month at 45°C. Sensorial examination of the samples shows that, compared with the initial sample, the preserved products exhibit moderate color change to light yellow and the aroma quality was comparable with those before storing. The ΔE values of the body wash and shampoo after 1 month of storage were 1.13 and 0.85, respectively [34–37] (Figure 3).

To elaborate on the degradation of the chemical composition of LEO after storage, different LEO samples were analyzed by GC-MS. LEO was first recovered from the products through a hydrodistillation process. Table 5 summarizes the compositions and contents of the compounds in the bare LEO and LEO recovered from the product base, body wash, and shampoo under different storage times and temperatures. LEO isolated from the



Figure 3: Initial (1) and 1-month body wash product (2); initial (3) and 1-month shampoo product (4).

washing base, after 1 week and 1 month of storage, was devoid of decomposition products of citral such as 3,7dimethyl-1,3,6-octatriene, p-1,5-menthadien-8-ol, and p-cymen-8-ol. Other compounds such as isogeranial, geraniol, cyclohexane, caryophyllene, α-bergamotene, butylated hydroxytoluene, caryophylene oxide, *m*-camphorene, and p-camphorene accounted for less than 1% of the total content in the LEO sample recovered from the product base. These results confirm the capability of the emulsification

technique for preserving the composition of essential oils in the formulation of washing bases.

Regarding the citral content, the highest citral content was observed in the initial bare LEO and LEO after 7 days of storage at 45°C (86.89 and 86.28%, respectively), closely followed by citral content in LEO recovered from the body wash product (85.81 and 85.31% respectively). Further comparison of the citral content in various products to that of the Initial bare LEO revealed that the simulated product base stored after 1 month at 45°C exhibited the highest citral reduction (around 9.7%). Meanwhile, the corresponding values for the shampoo and body wash product were only 4.9 and 1.8%, respectively, suggesting that direct LEO incorporation into the base may result in shampoo and body products with minimized citral degradation. Some new ingredients in shampoo and body wash with concentrations below 1% included isogeranial, geraniol, cyclohexane, caryophyllene, caryophylene oxide, *m*-camphorene, and *p*-camphorene.

The decrease in citral content or other ingredients is due to the prolonged exposure to high temperatures during the LEO recovery process. The increase of β-myrcene content in the base and the shampoo sample may be

Table 5: Chemical compositions of bare LEO, LEO recovered from the base sample, shampoo, and body products

No	RT (min)	Compounds	Lemongrass oil		Base sample		Shampoo		Body wash		
			Initial	7 days	1 month	7 days	1 month	Initial	1 month	Initial	1 month
1	9.813	6-Methyl-5-hepten-2-one	0.805	1.149	1.314	2.575	1.598	1.243	1.572	0.866	1.026
2	9.928	β-Myrcene	5.656	6.025	10.86	7.097	9.932	5.498	8.597	4.256	4.543
3	12.427	3,7-Dimethyl-1,3,6-octatriene	_	_	0.395	_	_	_	_	_	_
4	16.16	β-Linalool	0.754	0.664	0.805	1.818	0.775	0.959	0.808	0.839	0.788
5	18.942	Unknown name	_			0.727	0.232	0.197	0.224	-	0.179
6	19.799	<i>p</i> -Mentha-1,5-dien-8-ol	_	_	0.768	-	-	_	_	-	_
7	20.667	<i>p</i> -Cymene-8-ol	_	0.288	1.154	_	_	_	_	_	_
8	20.761	Isogeranial	_	_	_	0.505	-	0.295	0.826	-	0.347
9	22.727	β-Citronellol	0.499	0.547	0.572	0.241	0.696	0.62	0.603	0.552	0.599
10	23.166	β-Citral	39.031	38.699	35.026	38.74	35.996	38.779	38.49	38.124	37.715
11	23.71	Nerol	3.887	3.583	3.612	2.601	4.306	4.294	4.249	3.831	4.277
12	23.773	Geraniol	_			0.4	0.429	_	_	0.543	0.424
13	24.337	α-Citral	47.868	47.588	44.214	41.60	42.459	45.893	44.15	47.686	47.596
14	28.05	Geraniol acetate	0.602	0.361	0.525	1.125	0.889	0.45	0.851	0.329	0.784
15	28.227	Cyclohexane	_	_	_	-	0.409	_	0.366	0.369	0.784
16	29.419	Caryophyllene	_	_	_	0.598	_	0.412	0.621	_	0.655
17	29.482	α-Bergamotene	0.267	0.309	0.324	-	0.27	0.368	0.321	0.376	0.31
18	31.636	Butylated hydroxytoluene	_	_	_	_	0.198	_	_	1.735	_
19	33.226	Caryophylene oxide	_	_	_	0.125	_	0.123	0.091	_	0.089
20	33.884	Selina-6-en-4-ol	0.115	0.2	0.189	-	0.444	0.308	0.344	0.28	0.203
21	38.14	<i>m</i> -Camphorene	_	_	_	0.289	0.266	0.314	_	0.245	0.121
22	38.433	<i>p</i> -Camphorene	_	_	_	0.181	_	0.157	_	_	_
23	39.552	Unknown name	_	_	_	0.094	_	0.079	_	_	_
Citr	al content	(%)	86.899	86.287	79.24	80.34	78.455	84.672	82.64	85.81	85.311
% C	itral decrea	ase compared to initial		-0.704	-8.814	-7.549	-9.717	-2.563	-4.903	-1.253	-1.827

Note: The values shown in bold in Table are due to (1) being the main ingredient in Lemon grass essential oil, (2) there is a marked variation in content under different storage conditions.

attributable to its low molecular weight, making the compound to be more susceptible to evaporation and in turn more detectable during the GC-MS process. Alternatively, the increased β -myrcene content could be attributed to the rearrangement processes that transform surplus contents such as citral, geraniol, and citronella [38]. The emergence of substances such as geraniol, camphorene, and caryophylene oxide, which were previously absent in the bare LEO, could be explained by the inability of GC-MS to detect the constituents at very low concentrations.

Data availability statement: The data that support the findings of this study are available from the Nguyen Tat Thanh University but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Nguyen Tat Thanh University

4 Conclusion

In this study, we attempted the incorporation of LEO into the formulation of a washing product base, shampoo, and body wash product. The process was optimized to minimize color changes and citral degradation in the final products. The incorporation of LEO into two cosmetic products via direct mixing, rather than emulsion forming with base oils or emulsifiers, gave products better color stability. The best color stability of the product base could be achieved by using the following formulation conditions: pH, v5; preservatives, sodium lactate, and DMDM-H; antioxidant, BHT; LEO/BHT ratio, 0.5:1 or 1:1 (w/w); temperature, 70°C. The obtained shampoo and body wash also displayed negligible citral decomposition in comparison with the bare LEO.

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Conflict of interest: The authors declare no conflict of interest.

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