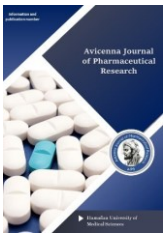
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Letter to Editor

From Colloidal Stability to Chemical Integrity: Rethinking Stability Assessment in Essential Oil Nanoemulsions

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Dear Editor,

Essential oils are multicomponent mixtures composed of volatile compounds with diverse chemical properties. The structural diversity and the interactions between the constituents contribute to a broad range of biological activities. However, low water solubility, high volatility, and susceptibility to chemical degradation limit the direct application of essential oils. Many terpenoid compounds, especially unsaturated monoterpenes and sesquiterpenes, are susceptible to oxidation, isomerization, and other structural transformations due to their double bonds and allylic hydrogens. These reactions can alter the chemical profile of essential oils during processing and storage [1]. Nanoemulsification is a common approach for improving the dispersion of essential oils in aqueous media and enhancing their stability [2]. However, the physical and colloidal stability of a nanoemulsion does not necessarily guarantee the chemical integrity of the essential oil, which is a critical consideration in these systems. In this context, chemical integrity refers to the preservation of the original chemical profile and the minimization of degradation or transformation of key constituents.

In essential oil nanoemulsion literature, stability is often evaluated based on physical and colloidal properties, including droplet size, polydispersity index (PDI), zeta potential, visual changes, and phase separation during storage [2, 3]. These parameters provide valuable information regarding the dispersion behavior and physical changes within the system; however, they cannot directly evaluate the compositional integrity of individual essential oil constituents. Different components of essential oils exhibit distinct volatility, polarity, and susceptibility to oxidation and other degradation pathways [1]. Therefore, the relative abundance of some constituents may change during storage, even when the colloidal properties of the nanoemulsion remain relatively unchanged.

In several studies of essential oil nanoemulsions, although the initial chemical composition of the essential oil is determined using analytical methods such as gas chromatography-mass spectrometry (GC-MS), changes in chemical composition after

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formulation and during storage are often not directly monitored; instead, stability evaluations are mainly based on physical and colloidal parameters. Wan et al. [2] characterized the initial composition of thyme, lemongrass, cinnamon, peppermint, and clove essential oils using GC-MS. However, the stability of nanoemulsions was evaluated only through droplet size variations and phase separation during 30 days of storage at 4 and 25°C [2]. Similarly, Pozharani et al. [3] determined the composition of three eucalyptus oils before formulation using GC-MS, while the 90-day stability of the optimized nanoemulsions was assessed based on appearance, droplet size, PDI, and zeta potential. The authors explicitly noted that time-course chemical profiling of the essential oils was not performed throughout storage [3].

Direct monitoring of essential oil constituents during storage can provide a more comprehensive evaluation of nanoemulsion performance. Cossetin et al. [4] monitored changes in essential oil constituents over 90 days of storage in nanoemulsions containing *Myristica fragrans* and *Lavandula dentata* essential oils. They demonstrated that nanoemulsification improved the retention of major constituents compared with that of free essential oils under certain storage conditions, even when physicochemical properties were not completely stable during the study period [4]. Hien and Dao [5] reported that although the droplet size of the black pepper nanoemulsion remained constant at 18 nm for six months, β-caryophyllene decreased from 21.94% to 13.90%, while caryophyllene oxide increased from 1.05% to 5.00%, and caryophylladienol also appeared during storage [5]. These findings demonstrate that a favorable droplet size alone cannot provide sufficient information regarding compositional changes and the chemical fate of the essential oil phase.

Accordingly, studies aiming to preserve essential oils or evaluate the biological activity of their formulations should incorporate direct chemical assessments alongside colloidal characterization. This consideration is particularly important when the biological activity depends on the presence or specific ratios of certain constituents. Changes such as degradation, oxidation, or transformation of these compounds during formulation or storage may affect the final performance of the system without causing noticeable alterations in colloidal properties [1, 2]. Accordingly, approaches such as GC-MS or GC-FID profiling, quantitative monitoring of marker compounds, determination of volatile compound retention, or identification of oxidation products can be applied to characterize the chemical integrity of essential oils [4, 5]. These analyses should be performed immediately after nanoemulsion preparation and at defined storage intervals to enable differentiation between changes occurring during formulation and those developing throughout storage.

The scope of stability assessment should be defined according to the objective and claim of each study. When the research aim is limited to the preservation of the physical properties of nanoemulsions, terms such as “physical stability” or “colloidal stability” provide more accurate descriptions. Conversely, when conclusions refer to “essential oil stabilization”, “protection of essential oil constituents”, or “reduced degradation”, evaluation of droplet size, PDI, and zeta potential alone is insufficient to support such claims. A clear distinction between colloidal stability and chemical integrity can prevent the overinterpretation of physicochemical findings and allow a more accurate understanding of the protective role of nanoemulsification in essential oil preservation.

Conflict of Interest

The authors declare no conflict of interest.

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