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Antibacterial and Antifungal Properties of Hedyosmum cuatrecazanum Occhioni Essential Oil: A Promising Natural Alternative Studied Using Neutrosophic SuperHyperSoft Sets

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Abstract. Antimicrobial resistance is a global public health issue that, exacerbated by inappropriate antibiotic use, leads to reduced bactericidal effects, multidrug resistance, increased medical costs, prolonged hospital stays, and higher mortality rates. This study evaluates the antibacterial and antifungal activity of the essential oil of *Hedyosmum cuatrecazanum* Occhioni against various clinically relevant bacterial and fungal strains. The essential oil was extracted by hydrodistillation, yielding a 0.26% extract. Its components were characterized by gas chromatography coupled with mass spectrometry (GC-MS). The results demonstrate that the essential oil exhibits significant antibacterial activity, comparable to commercial antibiotics. *Hedyosmum cuatrecazanum* oil showed the highest antibacterial activity against *S. aureus* and antifungal activity, where *C. albicans* and *C. tropicalis* were the most susceptible. For the study, the effective relative values of the chemical components of the essential oil were modeled using Fuzzy_Extension SuperHyperSoft Sets theory, as well as their concentration. Specifically, we model indeterminacy with the use of single-valued triangular neutrosophic numbers. This is because the percentages of each chemical that makes up the essential oil vary in a certain range from one plant to another. This mathematical tool allows us to determine the percentages and concentrations in which the essential oils are most effective in treating bacteria and fungi.

Keywords: Antimicrobial resistance, *Hedyosmum cuatrecazanum Occhioni*, essential oil, antibacterial, antifungal, Neutrosophic SuperHyperSoft Sets, Fuzzy_Extension SuperHyperSoft Sets, single-valued triangular neutrosophic number.

1 Introduction

Drug discovery has its roots in nature since antiquity. Many medicines still in use today have origins in ancestral knowledge related to the properties of medicinal plants. Indeed, several plant extracts and essential oils have been repurposed, significantly expanding their therapeutic scope.

The development of new drugs continuously adapts to the needs of the current healthcare system. This approach has led to the discovery of pharmacological targets with multiple endpoints, especially in the treatment of infectious diseases, where antimicrobial resistance (AMR) is highlighted as a global health issue. AMR occurs when bacteria, viruses, fungi, and parasites no longer respond to current pharmacological treatments, resulting in difficult-to-treat infections and increasing the risk of transmission, which can be lethal.

In the Andean region of South America, the *Chloranthaceae* family is a native, relatively understudied family. *Hedyosmum* is the largest genus in the *Chloranthaceae* family, consisting of tree or shrub plants with simple, opposite, serrated, petiolate leaves and pinnate veins. These species are widely distributed in low- and high-mountain rainforests throughout South America, including Ecuador, Peru, Brazil, Bolivia, Mexico, and Central America. Within this family, *Hedyosmum cuatrecazanum, Occhioni* stands out as a tree native to the humid tropical zone, traditionally used as food.

The *Hedyosmum* genus is characterized by its main components, including sesquiterpenes, sesterterpenes, hydroxycinnamic acid derivatives, flavonoids, neolignans, among others. Additionally, this genus is a significant source of essential oils that can be extracted from various plant parts, mainly aerial parts, i.e., leaves, flowers, and fruits. Species within the *Hedyosmum* genus also have diverse traditional uses, such as sources of firewood and construction materials, as well as medicinal preparations, primarily in the form of leaf infusions. The main pharmacological effects associated with members of this genus include neuroprotective, anxiolytic, antidepressant, sedative, analgesic, antinociceptive, anticancer, antibacterial, and antiplasmodial properties.

Previous studies on essential oils from this genus, such as *Hedyosmum luteynii*, identified the most abundant constituents as α-felandrene (32.72%), (Z)-β-pinene (13.20%), (Z)-β-ocimene (10.99%), sylvane (6.51%), bicyclogermacrene (5.05%), 1,8-cineole (4.95%), α-ocimene (3.88%), and germacrene D (3.20%). These constituents differ significantly from those reported for other *Hedyosmum* species in Ecuador, Peru, Bolivia, Colombia, Venezuela, Brazil, and Costa Rica. Additionally, the analysis of the constituents of *Hedyosmum luteynii* essential oil, compared to other species in the same genus, allowed the identification of exclusive compounds such as sylvane (6.51%), cis-muurola 3-5-diene (0.45%), and amorpha-4,9-diene <7.14 -anhydro-> (0.65%).

This article presents the extraction of the volatile oil of *Hedyosmum cuatrecazanum* Occhioni and its characteristics evaluated as its potential antimicrobial activity, accompanied by its respective minimum inhibitory concentration. The oil was tested against clinically relevant strains, including Gram-negative bacteria such as *Klebsiella pneumoniae*, *Escherichia coli*, and *Proteus mirabilis*, as well as Gram-positive bacteria like *Staphylococcus aureus* and *Enterococcus faecalis*, and most problematic fungal strains: *Candida albicans*, *C. tropicalis*, *C. krusei*, and *C. parapsilosis*, to contribute to infection treatment and offer a potential solution in the battle against microbial resistance.

To characterize the chemical composition of the plants studied we use the Fuzzy_Extension SuperHyperSoft Set theory, specifically within the neutrosophic framework. Classical Soft Set theory was introduced by D. Molodtsov, where he defined a function on a set of parameters belonging to an attribute such that its image is the power set of the universe set [1]. More recently F. Smarandache defined HyperSoft Sets where the domain of the function is generalized to the Cartesian product of a set of attribute values, where the number of attributes can be greater than one [2, 3]. Smarandache himself introduced SuperHyperSoft Sets consisting of the Cartesian product of the power sets instead of the sets themselves [4, 5]. Finally, he provided images with evaluations in the form of fuzzy truth values or some of their extensions (intuitionistic fuzzy, neutrosophic, Pythagorean, Fermatean, Plithogenic, etc.) he called this Fuzzy_Extension SuperHyperSoft Set [6,7].

The chemical compounds we study, especially essential oils, are made up of chemical substances in undetermined percentages, which is why they must be represented in an imprecise or indeterminate way. In this article, we characterize the components and proportions that are the basis of the antibacterial and antifungal properties of *Hedyosmum. cuatrecazanum* Occhioni. To this end, we use the Neutrosophic SuperHyperSoft Sets as a variant of Fuzzy_Extension SuperHyperSoft Sets, to determine the components within the essential oil in which the bactericidal and fungicidal properties are most effective. We use single-valued triangular neutrosophic numbers to evaluate the results [8].

To meet the proposed objective, we divide the article into a Preliminaries section where we present the basic notions of Fuzzy_Extension SuperHyperSoft Sets and single-valued triangular neutrosophic numbers. In the following section, we present the details of the study carried out. The article ends with the Conclusions section.

2 Preliminaries

This section serves the purpose of remembering the basic notions of Fuzzy_Extension SuperHyperSoft Sets and neutrosophic theory.

Definition 1 ([1, 9, 10]**).** Given U is the initial universe set and E is the set of parameters. A pair (F, E) is called a *soft set* (over U) if and only if F is a mapping of E into the set of all subsets of U.

That is to say, having a set E of parameters and fixing a parameter $\varepsilon \in E$, then $F(\varepsilon) \in \mathcal{P}(U)$, where $\mathcal{P}(U)$ denotes the power set of U and $F(\varepsilon)$ is considered the set of ε-elements of the Soft Set (F, E) or the set of ε-approximate elements of the Soft Set.

It is not difficult to realize that fuzzy sets are soft sets, this is a consequence of the α-levels definition of a membership function μ_A where we have the following:

$F(\alpha) = \{x \in U \mid \mu_A(x) \geq \alpha\}$, $\alpha \in [0, 1]$. Thus, if we know the family F, then we can reconstruct the function μ_A by using the following formula:

$$\mu_A(x) = \sup_{\substack{\alpha \in [0,1] \\ x \in F(\alpha)}} \alpha$$

Thus, a fuzzy set is a (F, [0, 1]) soft set.

Given a binary operation * for subsets of the set U, where (F, A) and (G, B) are soft sets over U. Then, the operation * for soft sets is defined as follows:

$(F, A) * (G, B) = (J, A \times B)$, where $J(\alpha, \beta) = F(\alpha) * G(\beta)$; $\alpha \in A$, $\beta \in B$, and $A \times B$ is the Cartesian product of the sets A and B.

Definition 2 ([2, 3, 11, 12]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be n distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $(F, A_1 \times A_2 \times \ldots \times A_n)$, where: $F: A_1 \times A_2 \times \ldots \times A_n \to \mathcal{P}(U)$ is called a *HyperSoft Set* over U.

Definition 3 ([2, 3, 11, 12]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be n distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $(F, \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n))$, where:

$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n) \to \mathcal{P}(U)$ is called a *SuperHyperSoft Set* over U.

Definition 4 ([4, 5, 13-15]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be n distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $(F, \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n))$, where:

$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n) \to \mathcal{P}\left(U\left(x(d^0)\right)\right)$ is called a *Fuzzy_Extension SuperHyperSoft Set* over U.

Where $x(d^0)$ is the fuzzy or any fuzzy extension degree of appurtenance of the element x to the set U. Fuzzy extension means Fuzzy Set or Intuitionistic Fuzzy Set, Pythagorean Fuzzy Set, Fermatean Fuzzy Set, Neutrosophic Fuzzy Set, Plithogenic Fuzzy Set, etc.

Before concluding, let us recall some fundamental definitions of neutrosophic sets:

Definition 5 ([8]). The *Neutrosophic set N* is characterized by three membership functions, which are the truth-membership function T_A, indeterminacy-membership function I_A, and falsity-membership function F_A, where U is the Universe of Discourse and $\forall x \in U$, $T_A(x), I_A(x), F_A(x) \subseteq]^-0, 1^+[$, and $^-0 \leq \inf T_A(x) + \inf I_A(x) + \inf F_A(x) \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$.

See that according to the definition, $T_A(x), I_A(x)$, and $F_A(x)$ are real standard or non-standard subsets of $]^-0, 1^+[$ and hence, $T_A(x), I_A(x)$ and $F_A(x)$ can be sub-intervals of $[0, 1]$. $^-0$ and 1^+ belong to the set of hyperreal numbers.

Definition 6 ([8, 16, 17]). The *Single-Valued Neutrosophic Set* (SVNS) A over U is $A = \{< x, T_A(x), I_A(x), F_A(x) > : x \in U\}$, where $T_A: U \to [0,1]$, $I_A: U \to [0,1]$ and $F_A: U \to [0,1]$. $0 \le T_A(x) + I_A(x) + F_A(x) \le 3$.

The *Single-Valued Neutrosophic Number* (SVNN) is symbolized by
$N = (t, i, f)$, such that $0 \le t, i, f \le 1$ and $0 \le t + i + f \le 3$.

Definition 7 ([8, 16, 17]). The *single-valued triangular neutrosophic number,* $\tilde{a} = \langle (a_1, a_2. a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$, is a neutrosophic set on $\mathbb{R}$, whose truth, indeterminacy, and falsity membership functions are defined as follows:

$$T_{\tilde{a}}(x) = \begin{cases} \alpha_{\tilde{a}\left(\frac{x-a_1}{a_2-a_1}\right), a_1 \le x \le a_2} \\ \alpha_{\tilde{a},}\ x = a_2 \\ \alpha_{\tilde{a}\left(\frac{a_3-x}{a_3-a_2}\right), a_2 < x \le a_3} \\ 0, \text{otherwise} \end{cases} \quad (1)$$

$$I_{\tilde{a}}(x) = \begin{cases} \frac{(a_2 - x + \beta_{\tilde{a}}(x-a_1))}{a_2-a_1}, a_1 \le x \le a_2 \\ \beta_{\tilde{a},}\ x = a_2 \\ \frac{(x - a_2 + \beta_{\tilde{a}}(a_3-x))}{a_3-a_2},\ a_2 < x \le a_3 \\ 1, \text{otherwise} \end{cases} \quad (2)$$

$$F_{\tilde{a}}(x) = \begin{cases} \frac{(a_2 - x + \gamma_{\tilde{a}}(x-a_1))}{a_2-a_1}, a_1 \le x \le a_2 \\ \gamma_{\tilde{a},} x = a_2 \\ \frac{(x - a_2 + \gamma_{\tilde{a}}(a_3-x))}{a_3-a_2},\ a_2 < x \le a_3 \\ 1, \text{otherwise} \end{cases} \quad (3)$$

Where $\alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \in [0,1]$, a_1, $a_2, a_3 \in \mathbb{R}$ and $a_1 \le a_2 \le a_3$.

Definition 8 ([8, 16, 17]). Given $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$ and $\tilde{b} = \langle (b_1, b_2, b_3); \alpha_{\tilde{b}}, \beta_{\tilde{b}}, \gamma_{\tilde{b}} \rangle$ two single-valued triangular neutrosophic numbers and λ any non-null number in the real line. Then, the following operations are defined:

1. Addition: $\tilde{a} + \tilde{b} = \langle (a_1 + b_1, a_2 + b_2, a_3 + b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \rangle$,
2. Subtraction: $\tilde{a} - \tilde{b} = \langle (a_1 - b_3, a_2 - b_2, a_3 - b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \rangle$,
3. Inversion: $\tilde{a}^{-1} = \langle (a_3^{-1}, a_2^{-1}, a_1^{-1}); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$, where $a_1, a_2, a_3 \neq 0$.
4. Multiplication by a scalar number:
$$\lambda\tilde{a} = \begin{cases} \langle (\lambda a_1, \lambda a_2, \lambda a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle, \lambda > 0 \\ \langle (\lambda a_3, \lambda a_2, \lambda a_1); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle, \lambda < 0 \end{cases}$$
5. Division of two triangular neutrosophic numbers:
$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \left\langle \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \right\rangle, a_3 > 0 \text{ and } b_3 > 0 \\ \left\langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \text{ and } b_3 > 0 \\ \left\langle \left(\frac{a_3}{b_1}, \frac{a_2}{b_2}, \frac{a_1}{b_3}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \text{ and } b_3 < 0 \end{cases}$$
6. Multiplication of two triangular neutrosophic numbers:
$$\tilde{a}\tilde{b} = \begin{cases} \langle (a_1 b_1, a_2 b_2, a_3 b_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \rangle,\ a_3 > 0 \text{ and } b_3 > 0 \\ \langle (a_1 b_3, a_2 b_2, a_3 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \rangle, a_3 < 0 \text{ and } b_3 > 0 \\ \langle (a_3 b_3, a_2 b_2, a_1 b_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \vee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \vee \gamma_{\tilde{b}} \rangle, a_3 < 0 \text{ and } b_3 < 0 \end{cases}$$

Where, $\wedge$ is a t-norm and $\vee$ is a t- conorm.

3 Results

This section is devoted to presenting the results obtained and mathematically modeling the problem. Some details of the study are given below.

3.1 Details of the experiment

Sample Collection: The extraction of essential oil was carried out using the aerial parts of *Hedyosmum cuatrecazanum* Occhioni. The collection of plant material was authorized by the Ministry of Environment, Water, and Ecological Transition of Ecuador. The aerial parts of *Hedyosmum cuatrecazanum* Occhioni were manually collected between April and August 2023 in the natural forest of Jacarón, located in the Juan de Velasco parish, Colta canton, Chimborazo province, Ecuador. The soils are formed from volcanic ashes, with high organic content, pH between 5.5 and 6.5; classified as dysstrandepts within the Inceptisols order, corresponding to young soils with limited development that exhibit high organic matter accumulation and base saturation below 50%.

A specimen sample was deposited at the Herbarium of the "Escuela Superior Politécnica del Chimborazo", Ecuador following botanical identification.

Essential Oil Extraction: The aerial parts of *Hedyosmum cuatrecazanum* (stem, leaves, fresh flowers) were used. After weighing and repeated cycles of washing with distilled water, the samples were ground to increase the contact surface and improve extraction efficiency. Essential oil extraction was performed using the hydrodistillation method. The obtained oil was stored refrigerated at 4 °C in sterile aliquots until analysis.

Bacterial Strains: The bacteria used in this study were obtained from the American Type Culture Collection. The assay included Gram-negative bacteria *Escherichia coli*, *Proteus mirabilis*, and *Klebsiella pneumoniae*, as well as Gram-positive bacteria: *Staphylococcus aureus* and *Enterococcus faecalis*.

Fungal Strains: The fungal strains of the *Candida* genus—*C. albicans*, *C. glabrata*, *C. krusei*, *C. tropicalis*, and *C. parapsilosis*—were provided by the microbiology laboratory collection at the University of Cuenca, Ecuador.

Measurement of Antibacterial Activity: Antibacterial activity was assessed using the disk diffusion method on agar. Strains that showed inhibition zones against the oil were subjected to minimum inhibitory concentration (MIC) determination.

Measurement of Antifungal Activity: A colony of each species (*C. albicans*, *C. tropicalis*, *C. krusei*, and *C. parapsilosis*) was streaked onto Sabouraud agar plates, which were then incubated at 37°C for 24 hours. Subsequently, a sample of the pre-inoculum from each *Candida* species was collected and placed in a tube with 0.89% sterile saline solution.

3.2 Modeling with Neutrosophic SuperHyperSoft Sets

One of the characteristics of the plants studied is that each of them individually has a chemical composition and properties that do not comply with the exact percentages from one plant to another, even when it is the same species. This does not mean that the effectiveness of the antibacterial and fungicidal properties is lost between one plant and another. However, there are values at which effectiveness is lost. On the other hand, it is necessary to determine the concentration of essential oil that is optimally needed for use as a medicine, which cannot be determined exactly with a numerical value. For this end, we study the values of the attributes that essential oils must satisfy to be effective, and for them, these values include the indeterminacy given in the form of a single-valued triangular neutrosophic number, which on the other hand provides accuracy to the proposed values.

Soft Sets are a useful tool for modelling uncertainty, and SuperHyperSoft Sets in particular will allow for a non-exact representation of the essential oil's required characteristics. Additionally, greater possibilities of expression will be obtained if the use of SuperHyperSoft Sets is compared to HyperSoft Sets since with the previous, cases that meet two or more different values of a single attribute can be considered simultaneously. This is impossible with the former tools. Additionally, each essential oil will be assigned a neutrosophic value of medicinal effectiveness, calculated from its chemical components and concentration.

The attributes to be measured determined in this study are the following as shown in Table 1:

Table 1: Attributes to be measured in the chemical composition of the essential oils studied. The sets of possible values are real numerical values representing the relative values of substances.

Attribute	Name	Relative value (%)
a_1	Eugenol	0-100
a_2	Citronellol	0-100
a_3	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7trimethyl-4-methylene-,[1ar(1a α,4a α,7 β,7a β,7b α)]	0-100
a_4	Aromandendrene	0-100
a_5	Cyclohexene, 3-(1,5-dimethyl-4-hexenyl)-6methylene-, [S-(R*, S*)]	0-100
a_6	benzene 2-methoxy-4-methyl-1-(1-methylethyl)-	0-100
a_7	6-Octen-1-ol, 3,7-dimethyl-, acetate	0-100
a_8	2-Acetylcyclopentanone	0-100
a_9	3H-3a,7-Methanoazulene, 2,4,5,6,7,8-hexahydro1,4,9,9-tetramethyl-,[3aR	0-100
a_{10}	Terpineol	0-100
a_{11}	Caryophyllene	0-100
a_{12}	Terpinen-4-ol	0-100
a_{13}	3-Undecen-5-yne, (Z)-	0-100
a_{14}	Phenol, 2-methoxy-4-(2-propenyl)-,acetate	0-100
a_{15}	Linalool	0-100
a_{16}	3-Methyl-4-isopropylphenol	0-100
a_{17}	Cedran-diol, (8S,14)-	0-100
a_{18}	Eucalyptol	0-100
a_{19}	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)-	0-100
a_{20}	Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-4a,8dimethyl-2-(1-methylethenyl)-, [2R(2 α,4a α,8a β)]	0-100
a_{21}	a1Cyclopropane carboxamide, 2-cyclop ropyl-2methyl-N-(1-cyclopropylethyl)	0-100
a_{22}	Pregnane-3,20-dione	0-100
a_{23}	Pregn-5-en-20-one, 3,21-bis(acetyloxy)-, (3 β)-	0-100
a_{24}	2,6-Octadien-1-ol, 3,7-dimethyl-,acetate	0-100
a_{25}	Benzeneethanol, α-phenyl	0-100
a_{26}	1,6-Octadiene, 3,7-dimethyl-	0-100
a_{27}	Azulene, 1,2,3,3a,4,5,6,7-octahydro-1,4-dimethyl-7(1-methylethenyl)-, [1R(1 α,3a β,4 α,7 β)]	0-100
a_{28}	(+)-2-Bornanone	0-100
a_{29}	Cyclohexene, 4-methylene-1-(1-methylethyl)-	0-100
a_{30}	3,4-Pentadienal, 2,2-dimethyl-	0-100
a_{31}	o-Cymene	0-100
a_{32}	1,6-Octadiene, 3,7-dimethyl-	0-100

Attribute	Name	Relative value (%)
a_{33}	Humulene	0-100
a_{34}	Bicyclo[3.1.0]hex-2-ene, 2-methyl-5-(1methylethyl)	0-100
a_{35}	3,4-Pentadienal, 2,2-dimethyl-	0-100
a_{36}	Geraniol	0-100

Note that the sets A_i with $i \in \{1,2,\cdots,36\}$ corresponding to each a_i are defined as $A_i = [0, 100]\%$. Also note that the use of SuperHyperSoft Sets allows these values to be represented as $\{[0, 2],\ [4, 5]\}$ sets of relative values in the range of 0% to 2% or 4% to 5% for a specific substance. This is not possible with HyperSoft Sets.

Additionally, we have another SuperHyperSoft Set with attributes that represent the concentration of *Hedyosmum essential cuatrecazanum* Occhioni oil, this is summarized in Table 2.

Table 2: Attributes representing the concentration of essential oil necessary to combat nine germs.

Attribute	Concentration of essential oil to combat germs	Name of germ (type)
b1	$[0.062 \times 10^6, 10^6]$ µg/ml	*Enterococcus faecalis* (Gram-positive Bacteria)
b2	$[0.062 \times 10^6, 10^6]$ µg/ml	*Staphylococcus aureus* (Gram-positive Bacteria)
b3	$[0.062 \times 10^6, 10^6]$ µg/ml	*Klebsiella pneumoniae* (Gram-negative bacteria)
b4	$[0.062 \times 10^6, 10^6]$ µg/ml	*Proteus mirabilis* (Gram-negative Bacteria)
b5	$[0.062 \times 10^6, 10^6]$ µg/ml	*Escherichia coli* (Gram-negative Bacteria)
b6	$[0.062 \times 10^6, 1]$ g/ml	*C. albicans* (Candida Species)
b7	$[0.062 \times 10^6, 1]$ g/ml	*C. tropicalis* (Candida Species)
b8	$[0.062 \times 10^6, 1]$ g/ml	*C. krusei* (Candida Species)
b9	$[0.062 \times 10^6, 1]$ g/ml	*C. parasilopsis* (Candida Species)

To summarize, we have two SuperHyperSoft Sets: the first one is formed by the attributes $a_1, a_2, \dots, a_{36}$ that appear in Table 1, with the values in the sets $A_i = [0, 100]\%$. This SuperHyperSoft Set is formed by the pair $(F, \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \dots \times \mathcal{P}(A_{36}))$, where:

$$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \dots \times \mathcal{P}(A_{36}) \rightarrow \mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right).$$

On the other hand, we have the SuperHyperSoft Set $(G, \mathcal{P}(B_1) \times \mathcal{P}(B_2) \times \dots \times \mathcal{P}(B_9))$, where:

$$G: \mathcal{P}(B_1) \times \mathcal{P}(B_2) \times \dots \times \mathcal{P}(B_9) \rightarrow \mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right).$$

These are sets for the attributes $b_1, b_2, \dots, b_9$ where $B_i = [0.062 \times 10^6, 10^6]$ µg/ml for $i \in \{1,2,3,4,5\}$; while $B_i = [0.062, 1]$ g/ml for $i \in \{6,7,8,9\}$.

The elements of the universe set are the $x \in U$, an essential oil extracted from the *Hedyosmum cuatrecazanum* Occhioni with a chemical composition having the substances appearing in Table 1 and in a concentration as shown in Table 2. $\mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right)$ is the neutrosophic evaluation of the elements of the universe set concerning anti-germ effectiveness.

Additionally, we propose the SuperHyperSoft Set $(H, (\mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \dots \times \mathcal{P}(A_{36})) \times (\mathcal{P}(B_1) \times \mathcal{P}(B_2) \times \dots \times \mathcal{P}(B_9)))$ as if $x \in U$ with the appurtenance $(T_\alpha, I_\alpha, F_\alpha)$ for the chemical composition parameters and appurtenance $(T_\beta, I_\beta, F_\beta)$ for the concentration parameters, then $(T_\delta, I_\delta, F_\delta)$ is obtained for the composition of the two $H(\alpha_1,\alpha_2,\cdots,\alpha_{36},\beta_1,\beta_2,\cdots,\beta_9)=F(\alpha_1,\alpha_2,\cdots,\alpha_{36})\cap G(\beta_1,\beta_2,\cdots,\beta_9)$. Thus, we have that $T_\delta=min(T_\alpha,T_\beta), I_\delta=max(I_\alpha,I_\beta)$, $F_\delta=max(F_\alpha,F_\beta)$. Note that in turn, $T_\alpha,T_\beta,I_\alpha,I_\beta,F_\alpha,F_\beta$, depend accordingly on the values for the parameters $\alpha_1,\alpha_2,\cdots,\alpha_{36}$ and $\beta_1,\beta_2,\cdots,\beta_9$. Equations 1, 2, and 3 are used for the experimental values shown below in Table 3. These values are maximum when the ideal conditions are reached in which the compound is most effective.

Table 3: Effective antibacterial and antifungal values of the essential oil in its chemical composition.

Attribute	Name	Effective Relative Value (%)
a_1	Eugenol	12.82±1
a_2	Citronellol	11.60±1
a_3	1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7trimethyl-4-methylene-,[1ar(1a α,4a α,7 β,7a β,7b α)]	10.10±1
a_4	Aromandendrene	7.14±1
a_5	Cyclohexene, 3-(1,5-dimethyl-4-hexenyl)-6methylene-, [S-(R*, S*)]	5.23±1
a_6	benzene 2-methoxy-4-methyl-1-(1-methylethyl)-	4.02±0.5
a_7	6-Octen-1-ol, 3,7-dimethyl-, acetate	3.57±0.5
a_8	2-Acetylcyclopentanone	3.23±0.5
a_9	3H-3a,7-Methanoazulene, 2,4,5,6,7,8-hexahydro1,4,9,9-tetramethyl-,[3aR	2.88±0.5
a_{10}	Terpineol	2.59±0.5
a_{11}	Caryophyllene	2.56±0.5
a_{12}	Terpinen-4-ol	2.47±0.5
a_{13}	3-Undecen-5-yne, (Z)-	2.46±0.5
a_{14}	Phenol, 2-methoxy-4-(2-propenyl)-,acetate	2.36±0.5
a_{15}	Linalool	1.87±0.1
a_{16}	3-Methyl-4-isopropylphenol	1.83±0.1
a_{17}	Cedran-diol, (8S,14)-	1.81±0.1
a_{18}	Eucalyptol	1.63±0.1
a_{19}	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)-	1.58±0.1
a_{20}	Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-4a,8dimethyl-2-(1-methylethenyl)-, [2R(2 α,4a α,8a β)]	1.57±0.1
a_{21}	a1Cyclopropane carboxamide, 2-cyclop ropyl-2methyl-N-(1-cyclopropylethyl)	1.54±0.1
a_{22}	Pregnane-3,20-dione	1.50±0.1
a_{23}	Pregn-5-en-20-one, 3,21-bis(acetyloxy)-, (3 β)-	1.27±0.1
a_{24}	2,6-Octadien-1-ol, 3,7-dimethyl-,acetate	1.22±0.1
a_{25}	Benzeneethanol, α-phenyl	1.14±0.1
a_{26}	1,6-Octadiene, 3,7-dimethyl-	1.14±0.1
a_{27}	Azulene, 1,2,3,3a,4,5,6,7-octahydro-1,4-dimethyl-7(1-methylethenyl)-, [1R(1 α,3a β,4 α,7 β)]	1.08±0.1
a_{28}	(+)-2-Bornanone	1.05±0.1
a_{29}	Cyclohexene, 4-methylene-1-(1-methylethyl)-	0.97±0.05
a_{30}	3,4-Pentadienal, 2,2-dimethyl-	0.97±0.05
a_{31}	o-Cymene	0.95±0.05

a_{32}	1,6-Octadiene, 3,7-dimethyl-	0.92±0.05
a_{33}	Humulene	0.92±0.05
a_{34}	Bicyclo[3.1.0]hex-2-ene, 2-methyl-5-(1methylethyl)	0.75±0.03
a_{35}	3,4-Pentadienal, 2,2-dimethyl-	0.72±0.03
a_{36}	Geraniol	0.57±0.02

The results in Table 3 indicate the principal values of the single-valued triangular neutrosophic number functions that are used to evaluate any essential oil. For example, eugenol with value 12.82 ±1, means that the single-valued triangular neutrosophic number is formed as $\langle(a_1, a_2, a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}}\rangle$ where $a_2 = 12.82$, $a_1 = 12.82 - 1 = 11.82$ and $a_3 = 12.82 + 1 = 13.82$, for $\alpha_{\tilde{a}} = 1, \beta_{\tilde{a}} = 0, \gamma_{\tilde{a}} = 0$.

This same idea extends to the concentration of essential oil that is effective as a natural medicine. See Table 4.

Table 4: Effective antibacterial and antifungal values of the essential oil in its concentration as a natural medicine.

Attribute	Concentration of essential oil suitable for combating germs	Name of germ (type)
b_1	$0.062 \times 10^6 \pm 10^7$	*Enterococcus faecalis (*Gram-positive Bacteria*)*
b_2	$0.125 \times 10^6 \pm 10^7$	*Staphylococcus aureus (*Gram-positive Bacteria*)*
b_3	$0.125 \times 10^6 \pm 10^7$	*Klebsiella pneumoniae* (Gram-negative bacteria)
b_4	$0.125 \times 10^6 \pm 10^7$	*Proteus mirabilis* (Gram-negative Bacteria)
b_5	$0.25 \times 10^6 \pm 10^7$	*Escherichia coli* (Gram-negative Bacteria)
b_6	0.25±0.01	*C. albicans (*Candida Species*)*
b_7	0.25±0.01	*C. tropicalis (*Candida Species*)*
b_8	0.50±0.02	*C. krusei (*Candida Species*)*
b_9	1.50±0.07	*C. parasilopsis (*Candida Species*)*

Let us illustrate someway the usefulness of the proposed model. Suppose that the essential oil was extracted from 10 specimens of *Hedyosmum cuatrecazanum* Occhioni in an Ecuadorian laboratory, let us denote them by $x_1, x_2, \cdots, x_{10}$. A study of the chemical composition of each of the 36 compounds summarized in Table 1 is carried out.

These results in the laboratory on the relative values were evaluated in the corresponding single-valued triangular neutrosophic numbers of Equations 1, 2, and 3, with the parameters that appear in Table 3. As in the example we had analyzed, it is used ⟨(11.82,12.82,13.82); 1,0,0⟩ to evaluate Eugenol, therefore each essential oil sample will have a value $(T_{i1}, I_{i1}, F_{i1}) \in [0,1]^3$ for each oil sample with $i = 1, 2, \ldots, 10$, where the index 1 means that it is the first compound eugenol. This triple of neutrosophic values means to how degree the essential oil sample satisfies the conditions of effectiveness as a bactericide and fungicide. The lowest x_i neutrosophic value is then obtained, that is, for x_i the values (T_{ij}, I_{ij}, F_{ij}) $j = 1,2, \ldots, 36$ are achieved, and from them, the aggregation is calculated which is the value $(min_j\{T_{ij}\}, max_j\{I_{ij}\}, max_j\{F_{ij}\})$. This value results in the single-valued Neutrosophic number meaning the effectiveness of the ith sample of essential oil.

4. Conclusion

Hedyosmum cuatrecazanum Occhioni essential oil is a natural antibacterial and antifungal source. The relative values of 36 chemical substances present in the active ingredient were experimentally determined so that these properties are manifested. The concentration of essential oil necessary for it to be sufficiently effective was also determined, and tested on nine germs between bacteria and *candida* *species*. For mathematical modeling, the neutrosophic SuperHyperSoft Sets, allow us to deal with the uncertainty of the present percentages of the different components of the essential raw material. This complete analysis makes it possible to classify the essential oil extracted from any plant and to verify its quality for use as a natural medicine, both for its chemical composition and for its concentration.

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