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RESEARCH ARTICLE

Theoretical Analysis of Hydrogen Bonds, Energy Distribution and Information in a 1 % *Rosa damascena* Mill. Oil Solution

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Abstract

The method of Non-equilibrium Energy Spectrum (NES) was applied in measurement of hydrogen bonds energy distribution in 1% *Rosa damscena* Mill. oil solution in deionized water. Local maxima in this spectrum were identical with these obtained in investigations of other biologically active solutions and related to particular bio effects as follows: (-0.1387 eV*;* 8.95 µm; 1117 cm^{-1}). This local maximum is typical for antibacterial, anti-tumor and anti-inflammatory effects. The local maxima at (-0.1212 eV*;* 10.23 µm; 978 cm^{-1}) and (-0.1262 eV; 9.82 µm; 1018 cm^{-1}) are typical for anti-inflammatory effects and this at (-0.1112 eV; 11.15 µm; 897 cm^{-1}) is typical for effects on the nervous system and nerve conductivity. Information theoretical analysis was performed using the values of Shannon entropy and Transformational information entropy, pointing to hydrogen bonds distribution similarities between *Rosa damscena* Mill., *V. myrtillus* L. and *Salvia divinorum* Epling. The possible chemical causes of these similarities were identified as antioxidant activity and polyphenols concentration.

Keywords

Rose oil, non-equilibrium, energy, spectrum, information, entropy

Introduction

Rose oil originated in Iran, where it was first produced and applied in the 7th century AD, subsequently showing numerous pharmacological and medicinal effects (1). The contemporary leaders in rose oil extraction with about 80% of the world's annual production are Bulgaria and Turkey, and the former is particularly renowned for its unique fragrant oil quality. In Bulgaria, more than 2000 companies extract annually about 2 tonnes of rose oil and 95% of them are exported. These businesses are located in the Rose Valley, between the towns of Karlovo and Kazanlak in South Bulgaria. Usually, 1 kg of rose oil is extracted from 3 tonnes of fresh blossoms. The oil is a key constituent of perfumes, creams, soaps and shampoos. In addition, it is used in production of rose water for drinking as well as of food additives.

In traditional medicine, *R. damascena* oil has been used to treat chest and abdominal pain, cardiovascular disease, digestive problems and also as a laxative (2). Rose oil has various beneficial effects on human health (3). The oil has been shown to have antioxidant (4) and antibacterial properties (5-7). It is known that the inflammatory diseases are among the causes of aging processes in the body (8-10), while the main constituents of rose oil have anti-inflammatory effects. The polyphenols it is rich in are gallic acid, quercetin, kaempferol and myricetin (11-13). Studies by some research teams have shown that *R. damascena* oil contains disiloxane, citronellol and heneicosan (14). All these constituents counteract body aging. *R. damascena* extract used as a dietary supplement has been found to increase life expectancy. Such studies performed on *Drosophila* flies showed its positive influence on their maximum and average lifespan (14, 15).

R. damascena oil also has a well-defined antimicrobial effect. It was found experimentally that *Penicillium notatum* is the most sensitive fungus to it with an inhibition zone of 12 to 17.5 mm, compared to *Aspergillus niger* (11 - 17 mm) (16). *Candida albicans* is the least sensitive fungus with an inhibitory zone between 10.5 and 14 mm. The most sensitive bacteria to rose oil are *Streptococcus pyogenes*, *Bacillus subtilis, Staphylococcus aureus* with an MIC of 0.25 mg/ml. *Mycobacterium phlei, Acinetobacter baumannii* with a MIC of 2 mg/ml are moderately sensitive. The minimum inhibitory concentration for *Pseudomonas aeruginosa, Proteus vulgaris, Escherichia coli, Salmonella typhimurium, Shigella flexneri* and *Klebsiella pneumonia* is 4 mg/ml.

Using gas chromatography and mass spectrometry, a detailed analysis has been made on the chemical composition of rose oils from *Rosa damascena* Mill. and *Rosa alba* L., grown in the experimental field of the Institute of Roses and Aromatic Plants in the town of Kazanlak, Bulgaria (16). They identified 60 compounds, identical in quality but with different quantitative characteristics.

The main components in the *R. damascena* Mill. oil composition are: Citronellol (48.24%), Geraniol (13.06%), Nonadecane (7.78%), Nerol (4.19%), Nonadecene (2.23%), Caryophyllene oxide (1.79%), Heneicosane (1.77%), E, E - Farnesol (1.56%), Methyl eugenole (1.29%). The other constituents are in concentrations below 1%. The main components in the R. alba oil with concentrations higher than 1% are: Citronellol (30.94%), Geraniol (8.76%), Nonadecane (11.83%), Heneicosane (8.08%), Nonadecene (5.92%), Nerol (4.96%), Caryophyllene oxide (3.76%), E, E - Farnesol (2.32%), Tricosane (1.22%), Eicosane (1.22%).

The citronellol/geraniol ratio is important for the quality of the aroma, as well as the content of rose oxides, aldehydes and esters of terpeneols. Using gas chromatographic-mass spectral (GC-MC) analysis of *R. damascena* oil originating from the Institute of Roses and Essential Oils in the town of Kazanlak, Bulgaria identified in it 40 compounds altogether and 38 compounds altogether in the *R. alba* oil (17).

Rose water also contains rose oil, but in lower concentration. It is obtained by water-steam distillation of fresh rose flowers, collected in late May and early June. It has been used since ancient times on the skin for cleansing, toning, moisturizing, refreshing, softening and soothing at allergies and rashes, and as an anti-inflammatory agent (18). The properties of other rose products are similar. Such is the rose concrete (orange-red wax-like mass), which is extracted from fresh, unsteamed blossoms of Bulgarian oil-bearing roses. It contains all the constituents that are also found in rose oil, but phenylethyl alcohol predominates - about 70%. Rose concrete is used in the cosmetic and perfume industry, as well as for production of rose absolute.

Rose absolute is obtained from rose concrete by extraction with ethyl alcohol. It is a reddish liquid with a fine rose aroma. Rose absolute contains all the rose oil ingredients. The content of phenylethyl alcohol is the highest - about 70%, followed by citronellol, geraniol and nerol. It is used in perfumery and cosmetics (19).

The aim of the present work is to extend the existing body of research with a measurement and information theoretical analysis of the distribution of hydrogen bonds energy in 1% *Rosa damascena* Mill Oil Solution. It was shown that the local maxima in this distribution correspond to those found in solutions of other medicinal plants as indicators of particular health effects. The novel metric of transformational information entropy was applied for analysis of similarity with other medicinal plants in terms of overall beneficial effects.

Materials and Methods

One percent *Rosa damascena* Mill. solution in deionized water (pH=7.62; ORP=+165 mV) was investigated. Rose oil had been produced in the town of Kazanlak situated in the Rose Valley in Bulgaria (Certificate No 135/15.06.2017) according to the following standards: ISO 11024: 1998; 9842: 2003; BDS: 11024: 2000; 9842: 2006; 510/2006 – Protection of Geographical Indications and Designations of Occurrence of Agricultural Products and Foods. Its characteristics are presented in Table 1.

The distribution of hydrogen bonds energy in the investigated solution was measured with an optical method invented by Antonov, based on the non-equilibrium process of droplets evaporation (20-25). Its output is the so-called Non-equilibrium Energy Spectrum (NES), described by the function f(E) where the energy E is expressed in eV. Ten sample droplets and ten deionized water control droplets evaporated simultaneously on a thin BoPET film over a glass plate in a hermetic chamber. During the measurements, the temperature inside the chamber was fixed at 23±1 ^{0}C. All investigated droplets were irradiated by parallel beams of monochromatic light (⊠ = 580±7 nm) that fell perpendicularly to the BoPET film and the glass plate (Fig.1). Wetting angles Θ in the range from 72.3 to 0 degrees and corresponding to hydrogen bonds energy in the range E=-0.08– -0.1387 eV were measured every 10 min for 3 hrs until complete evaporation.

Table 1. Characteristics of Bulgarian rose oil according to Bulgarian State Standard (BDS) and ISO

Characteristic	Reference range
Freezing temperature	16.5-23.5 °C
Specific weight at 30 °C	0.850
Acid value	0.92 – 3.75
Etheric value	7.2 – 17.2
Saponification value	8 – 21
Refractive index at 25 °C	1.46
Polarisation with 100 mm tube	1.2 – 4.8
Acetyl number	197 – 233
Free alcohol Geraniol	63 – 75%
Related alcohols Geraniol	2 – 5 %
Stearoptene	15 – 23 %

Subsequently, the average distribution of wetting angles f(θ) and the normalized distribution of hydrogen bonds energy f(E) were calculated as follows (21, 22):

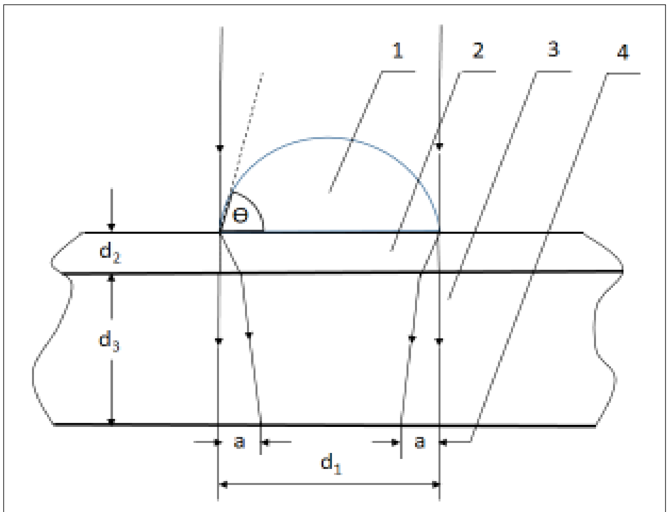

Fig. 1. Measurement of wetting angle ***1****-droplet,* ***2*** *– thin BoPET film,* ***3*** *–glass plate,* ***4*** *– refraction ring width (****a****). The wetting angle θ is a function of* ***a*** *and* ***d₃****.*

$$f(E) = \frac{14{,}33 f(\theta)}{[1-(1+bE)^2]^2} \quad (1)$$

where **E** is the energy corresponding to a particular value of the wetting angle **θ,** and **b** depends on the number of water molecules per unit area at the surface layer, as well as on the water surface tension and the initial wetting angle of the corresponding droplet.

The transformational information entropy analysis of the obtained spectrum was performed according to the approach described in (26). It is based on the Shannon entropy (H) of a probability distribution (P) defined as:

$$H(P) = -\sum_{i=1}^{n} p_i \log\ (p_i) \quad (2)$$

Where n is the number of possible outcomes and p_i is the probability of the i-th outcome. If base 2 logarithm is used, the Shannon entropy is expressed in bits. As the non-equilibrium energy spectra are probability distributions of hydrogen bond energies, this formalism is adequate for their analysis.

In order to analyze how different dissolved substances influence hydrogen bonds and their energy in the solvent (in this case, deionized water), a novel metric called transformational information (TI) entropy had been proposed. It can be interpreted as the amount of information necessary to transform the NES of the solvent into the NES of the solution. If p and q are their probability distributions, then TI can be defined as:

$$TI(p,q) = \sum_{i \in X} |p_i \log\ (p_i) - q_i \log\ (q_i)| \quad (3)$$

Whenever p and/or q are zero, the contribution of the corresponding term is by definition zero because:

$$\lim_{y \to 0+} y \log(y) = 0$$

Results and Discussion

The Non-equilibrium energy spectrum (NES) of the investigated solution is presented in Table 2 and Fig. 2 in comparison to that of deionized water.

The following local maxima were observed in the hydrogen bonds energy distribution:

E= -0.1112 eV (corresponding to λ=11.15 μm and ṽ=897 cm^{-1});

E = -0.1212 eV (corresponding to λ=10.23 μm and ṽ=978 cm^{-1});

E = -0.1262 eV (corresponding to λ=9.82 μm and ṽ= 1018 cm^{-1});

E= -0.1387 eV (corresponding to λ=8.95 μm and ṽ=1117 cm-1).

Their comparison with identical maxima found in other biologically active solutions points to a fundamental connection between the distributions of hydrogen bonds energy and caused/accompanying biological effects.

The hydrogen bond energy maximum at E= -0.1387 eV (corresponding to λ=8.95 μm and ṽ=1117 cm-1) has been previously found in plant extracts and other substances with antibacterial (27) and anti-tumor (28-31) effects. Reports are on the blood serum of cancer patients and healthy subjects in order to identify key factors contributing to human health and longevity (32-34). In addition, Russian authors have reported its association with anti-inflammatory and antitumor effects (35). Such a

Table 2. The Non-equilibrium energy spectrum (NES) of the investigated solution is presented in comparison to that of deionized water.

-E[eV]	0.0937	0.0962	0.0987	0.1012	0.1037	0.1062	0.1087	**0.1112**	0.1137	0.1162
f(E)[%]	7.4	5.6	0.0	0.0	7.4	7.4	7.4	**11.1**	0.0	0.0

-E[eV]	0.1187	**0.1212**	0.1237	**0.1262**	0.1287	0.1312	0.1337	0.1362	**0.1387**
f(E)[%]	0.0	**11.1**	0.0	**18.5**	0.0	5.6	0.0	0.0	**18.5**

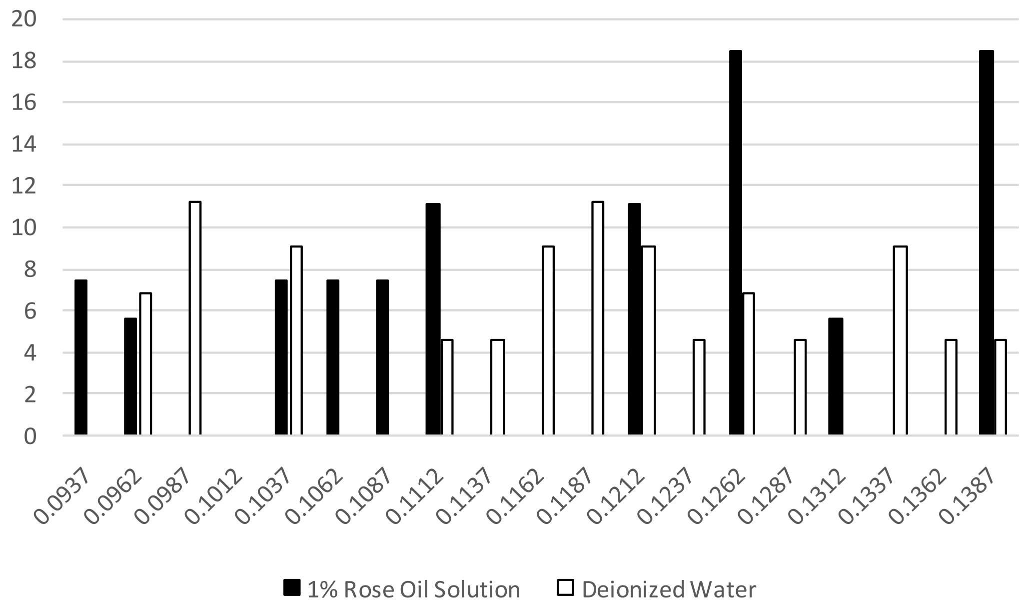

Fig. 2. Non-equilibrium Energy Spectrum of 1% Rosa damascena Mill oil solution compared to that of deionized water.

local maximum has been registered in the –COO– (carboxylate) group (27, 28) and in the aliphatic amines of R. damascene (29, 36, 37).

The local maximum at E = -0.1262 eV (corresponding to λ=9.82 μm and ṽ= 1018 cm-1) is typical for antibiotics with anti-inflammatory effects (38).

According to one report, the local maximum at E= -

Table 3. Antioxidant activity and polyphenols concentration of 40% water-ethanol extracts from *V. myrtillus* L., *Rosa dmascena* and *Salvia.*

Species	Antioxidant activity [mmol/L] UAE	Polyphenols concentration [mmol/L] QE
V. myrtillus L.	9.18±0.48	1.42±0.01
Rosa dmascena	8.37±0.14	1.28±0.02
Salvia	5.75±0.04	1.31±0.02

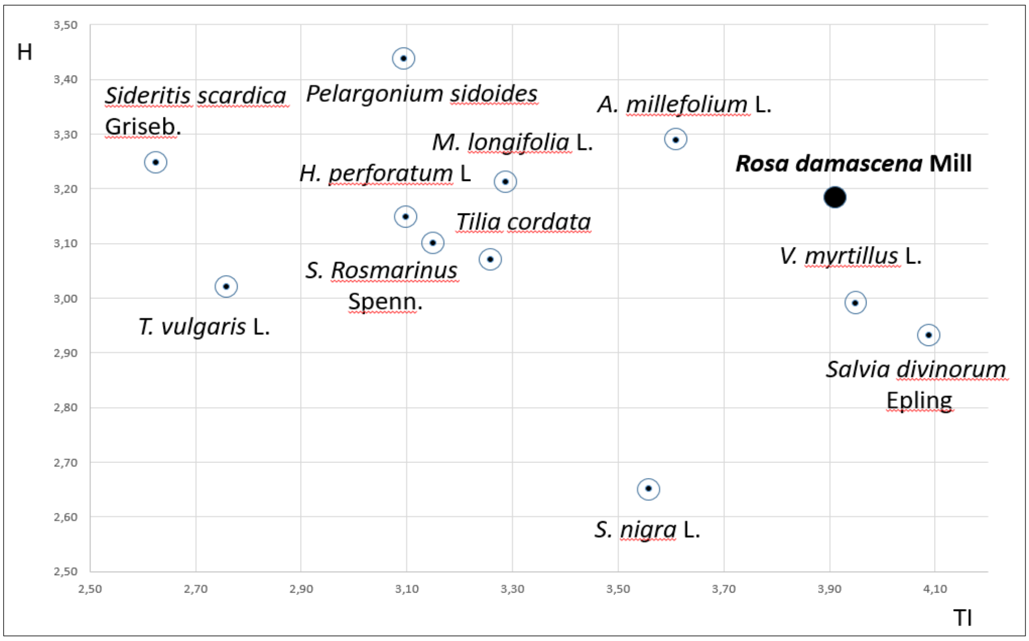

Fig. 3. Shannon entropy and Transformational Information of the investigated 1% *Rosa damascena* Mill oil solution compared to those of other 1% medicinal plant extracts

0.1112 eV (corresponding to λ=11.15 μm and ṽ=897 cm-1) is related to calcium conductivity in the nervous system and nerve conductivity (21)**.** This is completely in line with previous reports about *R. damascena* sedative, relaxing and hypnotic effects (39). Geraniol and citronellol are considered as the most important for the pharmacological activity of this plant (1, 2). The above considerations shed more light on the soothing, anti-inflammatory, regenerating and rejuvenating effects of rose oil on the skin as well as on its successful application in cases of inflammation, itching, dryness and aging.

The values of Shannon entropy and Transformational Information for the investigated 1% *Rosa damascena* Mill oil solution were calculated as follows: H = 3.18 bit and TI = 3.91 bit.

They were compared with those of other 1% solutions of medicinal plant extracts reported in (25, 26), i.e.

M. longifolia L.	*H. perforatum* L.
T. vulgaris L.	*V. myrtillus* L.
S. rosmarinus Spenn.	*S. nigra* L.;
A. millefolium L.	*Sideritis scardica* Griseb.
Tilia cordata Mill	*Pelargonium sidoides*
Salvia divinorum Epling	

The corresponding diagram is presented in Fig. 3

According to previous analysis based on H and TI coordinates, *Pelargonium sidoides*, *Hypericum perforatum* L., *Tilia cordata*, *S. rosmarinus* Spenn. and *M. longifolia* L. form a distinct cluster of medicinal plants with common anti-inflammatory effects, mostly expressed in the respiratory system (21). In addition, *Hypericum perforatum* L. and *Tilia cordata*, being in close proximity within the same cluster, have a common feature of fluoride content. Such considerations pointed to the possibilities of finding similarities between biological effects of extracts from different medicinal plants based on the NES of the corresponding solutions.

Added to this graph, the H and TI coordinates of the 1% *Rosa damascena* Mill oil solution form a distinct cluster with those of *V. myrtillus* L. and *Salvia divinorum* Epling 1% solutions. The common characteristics of this cluster can be found in an earlier work (40-42). The author has measured the antioxidant activity and polyphenols concentration of 40% water-ethanol extracts from a variety of medicinal plants. The results for *V. myrtillus* L., *Rosa damascena* and *Salvia* are presented in Table 3.

While all plants in the cluster have similar values of polyphenol concentration, *Rosa damascena* is closer to *V. myrtillus* L. in terms of antioxidant activity. It should be pointed out that *Rosa dmascena* and *V. myrtillus* L. are closest to one another also in terms of TI and H values.

Thus, the similarities of informational characteristics of non-equilibrium energy spectra presented in this work provided additional evidence about a possible fundamental connection between the distributions of hydrogen bonds energy and the (bio)chemical properties of the investigated extracts.

Conclusion

Investigation of *Rosa damascena* oil as 1% solution in deionized water with the method of non-equilibrium energy spectrum revealed the presence of local maxima of the hydrogen bonds energy distribution that are typical for other biologically active solutions with antibacterial, antitumor, anti-inflammatory and nervous system stimulating effects. In addition, the similarities on the one hand in terms of informational characteristics between the NES of *Rosa dmascena* oil and those of *V. myrtillus* L. and *Salvia* and on the other hand, in terms of antioxidant activity and polyphenols concentration, provided additional evidence about a possible fundamental connection between the distributions of hydrogen bonds energy and the (bio) chemical properties of the investigated extracts. The same interdisciplinary approach can be further applied in prediction and subsequent verification of possible new health effects of rose oil and other medicinal plant extracts as well as in development of new commercial products.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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