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Original Research Article

# Acclimatization through thermal diffusivity tuning of coconut oil — A mode mismatched dual-beam thermal lens study

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ABSTRACT

*Background:* *Ayurvedic* medicinal oils traditionally prepared by blending herbal extracts in different compositions are commonly used for treatment and improving health. The estimation of the thermal properties of medicinal oils is essential for practical applications.
*Objective:* The present work aims to expound the ability of medicinal oils for the acclimatization of body temperature by determining its thermal diffusivity and thereby providing a validation to the traditional knowledge.
*Materials and methods:* The medicinal oils are prepared by incorporating black pepper (*Piper nigrum*), aloe vera (*Aloe barbadensis*), hibiscus bud (*Hibiscus rosa-sinensis*) and *Ocimum sanctum* in coconut oil base. The samples are subjected to thermal diffusivity study using the mode-mismatched dual-beam thermal lens technique.
*Results:* The study reveals that the incorporation of black pepper (*Piper nigrum*), having hot potency (*Ushna veerya*), to the base fluid lowers the thermal diffusivity value, suggesting its potential in heat-trapping. The addition of aloe vera (*Aloe barbadensis*), hibiscus bud (*Hibiscus rosa-sinensis*), and *O. sanctum* dissipates heat energy quickly, thus increases the thermal diffusivity of coconut oil revealing a cold potency (*Sheeta veerya*). The study provides a validation for traditional knowledge and delineates the possiblity of thermal diffusivity tuning of the base fluids.
*Conclusion:* The thermal diffusivity tuning through incorporation of herbal extracts can effectively be used to acclimatize the human body temperature with the surroundings. A higher thermal diffusivity value induces a cooling effect and the lower value causes heating effect. This, opens up the possibility of using thermally tuned oils depending on climate and geographical location.


## 1. Introduction

*Ayurveda* is the traditional, popular, and holistic health care system that is considered to be originated about 5000 years back in India [1]. It gives importance to our mind, body and spirit equally, and hence it is considered as a complete health care system. *Ayurveda* not only emphasises on the treatment and prevention of an illness but also on the promotion of individual health [2,3]. The medicines used in *Ayurveda* are prepared by using a variety of practices and products like medicinal plants, organic matter, minerals and others. Many clinical investigations and scientific studies reported that these *Ayurvedic* medicine are effective in treating diseases including anxiety, depression, cancer, and Alzheimer's, to list a few [4–6]. Medicinal oils are a vital group of among various *Ayurvedic* medicines, which are the blends of extracts of medicinal herbs, seeds and flowers in base oils such as coconut oil, sesame oil, and ghee. The extracts of medicinal plants enhance the healing properties of the base oil. Medicinal oils are commonly used to treat health conditions including fever, digestion issues, suboptimal skin and hair health, and poor concentration [7].

Coconut oil enriched with saturated fatty acids extracted from the dried flesh of the coconut is commonly used as a base oil for making medicinal oils. The saturated fatty acids in the coconut oil like lauric acid, capric acid, caprylic acid and others are medium-chain fatty acids which increase the metabolic rate. Coconut oil is also well known for its antibacterial, antifungal, antimicrobial and antioxidant properties [8–10]. Coconut oil derived medicinal oils

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are frequently used as massage oils, that induce cooling or heating effect in the body or scalp, which helps in the acclimatization of body temperature. Acclimatization refers to the process of adaption of individual organisms to the changes in the environment such as temperature, altitude, photoperiod, pH or humidity [11]. The ability of a medicinal oil to induce acclimatization of body temperature can be studied by determining its thermal property, the thermal diffusivity ($\alpha$).

Study of thermal properties of materials has been the focus of human interest from stone-age. Understanding of the thermal behaviour of various substances led to the present civilised society with a variety of items that we use in our day to day life. 'Heat' is the oldest branch of physics, where several techniques have been developed for thermal characterisation of materials. The advent of lasers and ultrafast data acquisition systems have revolutionised the field of material characterisation with high sensitivity and accuracy [12]. Among various laser-based characterisation techniques, the photothermal spectroscopy stands unique because of its non-destructive nature and high signal to noise ratio with respect to conventional transmission spectroscopy [13]. The photothermal spectroscopy comprises of a group of highly sensitive spectroscopic techniques such as the thermal lens (TL), photoacoustics, and photothermal beam deflection, which exploit the photothermal effects in the sample due to the heat generated by the photon absorption followed by non-radiative deexcitation [14,15]. Among these photothermal techniques, the TL spectroscopy detects the changes in refractive index temparature and density in the sample, to determine the thermo-optic properties including quantum yield [16], thermal diffusivity [17], and absorption coefficient [18]. There are various thermal lens experimental schemes for the determination of thermal diffusivity of transparent samples, among these the mode-mismatched dual-beam TL technique offers high accuracy, repeatability and sensitivity [19,20]. The present work aims to expound the ability of Ayurvedic medicinal oils, prepared by incorporating herbal extracts in different composition in the coconut oil base for the acclimatization of body temperature, by determining its thermal diffusivity using the mode-mismatched dual-beam TL technique. The study also aims to provide a scientific validation of the traditional hypothesis in the preparation of medicinal oils in Ayurveda.

## 2. Theory

The thermal lens technique, first reported by Gordon et al. employs the refractive index gradient formed inside the sample due to the heat generated by laser irradiation to determine its thermo-optic parameters [21]. The refractive index gradient acts as a lens like element called thermal lens and diverges the transmitted laser beam in liquids having a negative temperature coefficient of refractive index ($dn/dT$). In dual beam TL technique, pump laser, a high power laser (power − $P_e$, wavelength - $\lambda_e$, beam waist radius - $\omega_e$) is used to generate the thermal lens and probe laser, a low power laser (power − $P_p$, wavelength − $\lambda_p$, beam waist radius − $\omega_{0p}$) to analyse it. Shen et al. in 1992, presented a high sensitive mode-mismatched dual-beam thermal lens configuration in which the sample is placed at a small distance ($Z_1$) from the probe beam waist and at the pump beam waist [19]. The spot size of the probe ($\omega_{1p}$) and pump ($\omega_e$) beam at the sample is mismatched in this configuration for getting enhanced TL signal. Shen et al. also derived the equation for change in intensity of the probe beam centre with time ($I(t)$) at the detector placed at $Z_d$ distance from the sample, which is given in Eq. (1) [19,20]. The probe beam centre intensity mainly depends on (i) the beam centre intensity at time $t = 0$ ($I(0)$), (ii) the parameter m that depends on the mismatching between the probe and pump beam spot size, (iii) the parameter $V$ that depends on experimental configuration, (iv) the characteristic time constant $t_c$ and (v) the parameter $\theta$.

$$I(t)=I(0)\left[1-\frac{\theta}{2}\tan^{-1}\left(\frac{2mV}{\left[(1+2m)^2+V^2\right](t/t_c)+1+2m+V^2}\right)\right]^2 \tag{1}$$

The parameters $m$, $V$, $t_c$, and $\theta$ in Eq. (1) are given in Eq. (2) − Eq. (5).

$$m=\left(\frac{\omega_{1p}}{\omega_e}\right)^2 \tag{2}$$

$$V=\frac{Z_1}{Z_c}+\frac{Z_c}{Z_d}\left[1+\left(\frac{Z_1}{Z_c}\right)^2\right] \tag{3}$$

where $Z_c=\frac{\pi\omega_{0p}^2}{\lambda_p}$ is the Rayleigh parameter of the probe beam.

$$t_c=\frac{(\omega_e)^2}{4\alpha} \tag{4}$$

$$\theta=\frac{P_eAl\frac{dn}{dT}}{k\lambda_p} \tag{5}$$

where $A$ is the sample's absorption coefficient, and $l$ is the path length of the cuvette. The experimental data $I(t)$ is least square curve fitted using Eq. (1) to get the parameters $t_c$ and $\theta$, from which the thermal diffusivity ($\alpha$) of the sample can be calculated using Eq. (4) [12]. The amount of heat absorbed and the extent of the heated region can be understood from the profile of the refractive index gradient inside the sample. The profile of the refractive index gradient at a point $r$ and at a time $t$ ($\Delta n(r,t)$) inside the sample can be simulated using the thermal lens parameters $t_c$ and $\theta$ using Eq. (6) in Matlab software [22,23].

$$\Delta n(r,t)=\frac{\theta\lambda_p}{t_c*2\pi l}\int_0^t\frac{1}{1+\frac{2t'}{t_c}}e^{\left(-\frac{2r^2/\omega^2}{1+\frac{2t'}{t_c}}\right)}dt' \tag{6}$$

## 3. Materials and methods

In the present study, the property of heat transfer in medicinal oils with coconut oil as base was investigated using mode-mismatched dual-beam thermal lens technique. The commonly used medicinal oils are prepared with the ingredients listed in Table 1 using coconut oil as the base fluid. The ingredients were added to lukewarm oil in powder form and kept at room temprature for 3 hours. The samples were then gradually heated to a temperature below the fuming point and allowed to cool. The cooled medicinal oils are then subjected to thermal lens study. The oils were labelled as A,B,C and D based on the ingredients used in the preparation. The details are summarized in Table 1.

The schematic diagram of the mode-mismatched dual-beam thermal lens experimental setup is shown in Fig. 1. He−Cd laser (442 nm, 60 mW) was used as the pump laser and He−Ne laser (632 nm, 1 mW) was used as the probe. The pump laser power at the sample was controlled with a neutral density (ND) filter placed in front of it. A convex lens (L1) with focal length 40 cm was used to

**Table 1**
Sample code of medicinal oils with their ingredients.

| Sample Code | Ingredients |
|---|---|
| A | Cumin (2 g) and Black Pepper (5 g) |
| B | Base coconut oil |
| C | Hibiscus bud (2 nos), Aloe Vera (10 g) and Onion (2 g) |
| D | Onion (10 g), Plectranthus amboinicus (2 g) and *Ocimum sanctum* (1 g) |

focus the pump laser on the sample, taken in a quartz cuvette of path length,($l$), = 1 cm, placed at its beam focus. The pump laser beam is intensity-modulated at a frequency 4 Hz before falling into the sample. The probe is focused by a convex lens (L2) of focal length 10 cm and made to fall on the sample placed at a distance $Z_1 = 20$ cm from its beam waist, making an angle less than 1.5° with the pump beam. Mirrors M1 and M2 are used to guide the probe beam through the sample to the aperture. Multimode optical fibre is carefully placed at the aperture to collect the intensity changes at the beam centre. The output of the optical fibre is fed to the detector placed at a distance $Z_d = 63$ cm from the sample, and the waveform is viewed through a digital storage oscilloscope (DSO). The experimental data of the beam centre intensity is collected from the DSO and is used for the analysis [19].

## 4. Results and discussion

Medicinal oils applied on the body and scalp facilitates the energy transfer between our body and surroundings based on its thermal properties. The value of the beam waist radius of the pump and probe beam needs to be highly accurate for obtaining error-free thermal diffusivity values [20]. The beam waist radius of the pump and probe laser beam is determined by using a commercial scanning slit beam profiler (NanoScan 2s Pyro/9/5 head with Nanoscan V2 software). The beam waist radius is selected as the half beam width at $\frac{1}{e^2}$ value of the maximum intensity. The beam waist radius obtained for the lasers is $\omega_{0p} = 40$ μm and $\omega_e = 236$ μm. The two dimensional (2D) and three-dimensional (3D) profile of the He–Cd laser and He–Ne laser beam at the waist are given in Fig. 2. The figure confirms the perfect Gaussian nature of the pump and the probe laser beams. The probe beam radius at the sample, $\omega_{1p}$, is calculated using Eq. (7) employing the value of $\omega_{0p}$ and is obtained as $\omega_{1p} = 1$ mm. These values are used for fitting the experimental data to get the thermal diffusivities of the medicinal oils.

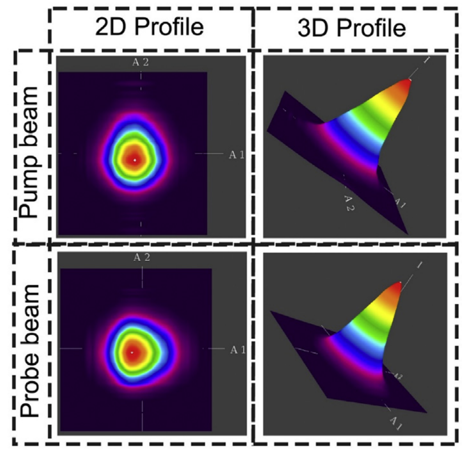


**Fig. 2.** 2D and 3D profile of the pump and probe beam.

$$\omega_{1p} = \left[\omega_{0p}^2\left[1 + \left(\frac{Z_1}{Z_c}\right)^2\right]\right]^{1/2} \tag{7}$$

The power of the pump beam plays a crucial role in getting accurate results in TL spectroscopy. When the power increases beyond a threshold value, the refractive index gradient inside the sample becomes very large and then distorts the probe laser wavefront. This distortion at high power known as thermal blooming adds error into the experimental thermal lens signal and makes the thermal diffusivity values erroneous. To avoid introducing this error, initially we adjusted the pump beam power to 20 mW, which is below the threshold. A neutral density filter was used to avoid the effects due to thermal blooming. The TL signals of the medicinal oils taken after adjusting the power below the threshold value are shown in Fig. 3. Though all the samples are studied at the same laser power, the refractive index gradient formed in different media is different, as shown in Fig. 4. The change in the refractive index *Δn(r,t)* gives information about thermal energy flow in the medium. More than ten TL signals of each sample are curve fitted in Matlab software to obtain the thermal diffusivity value. The experimental setup is standardised by determining the thermal diffusivity of water. The calculated value of $\alpha$ for water which is obtained as $1.40 \times 10^{-7}$ $m^2$/s matches well with the reported value of $1.43 \times 10^{-7}$ $m^2$/s [22,24].

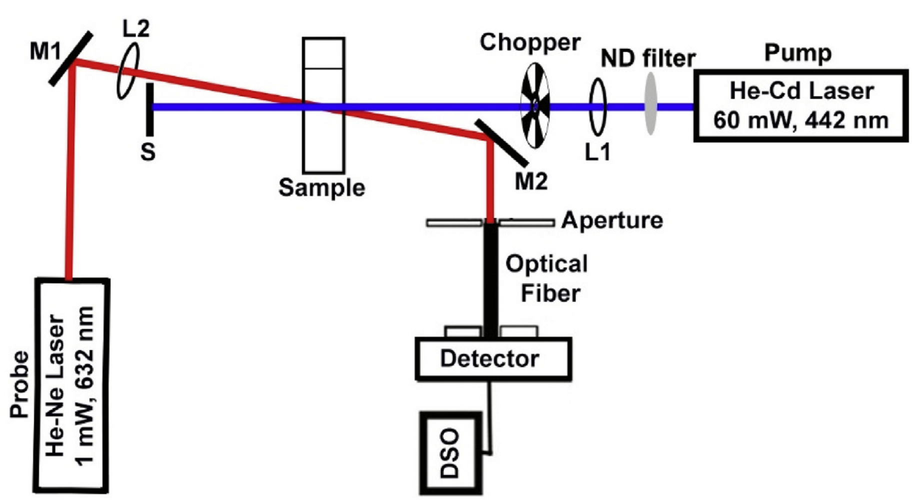


**Fig. 1.** Schematic diagram of mode-mismatched dual-beam thermal lens technique.

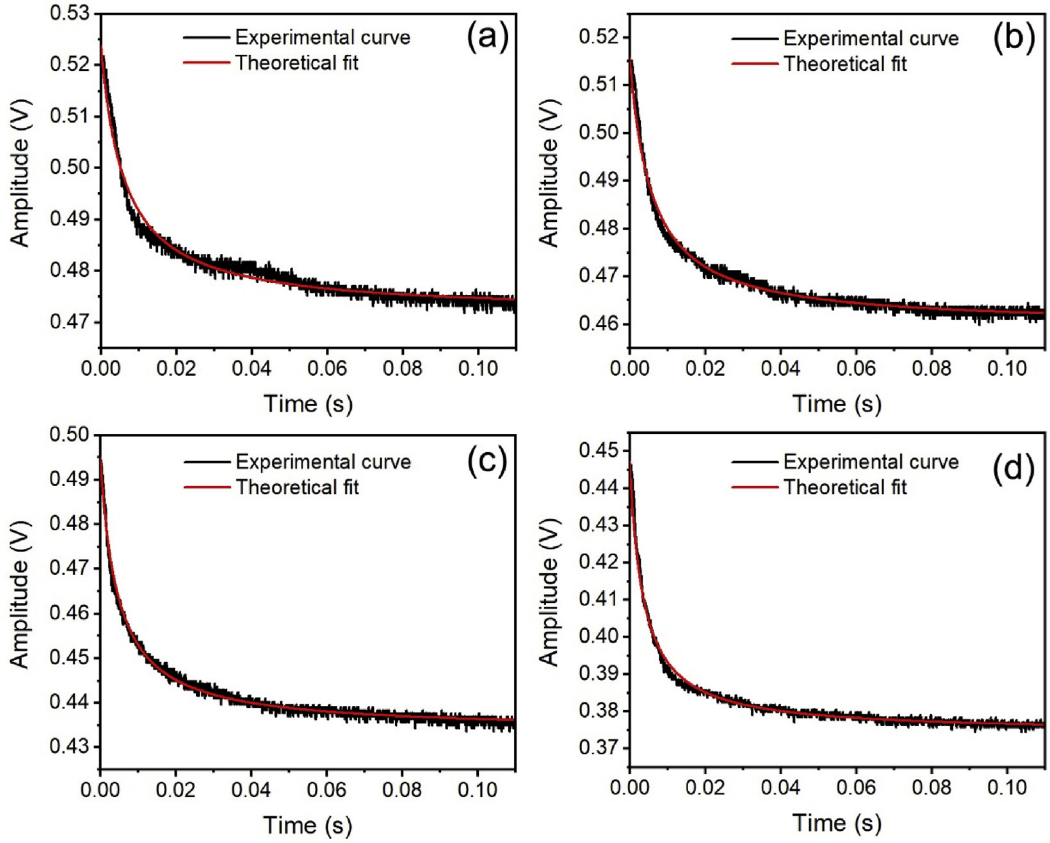


**Fig. 3.** Thermal lens signals obtained for the medicinal oils (a) sample A, (b) sample B, (c) sample C and (d) Sample D.

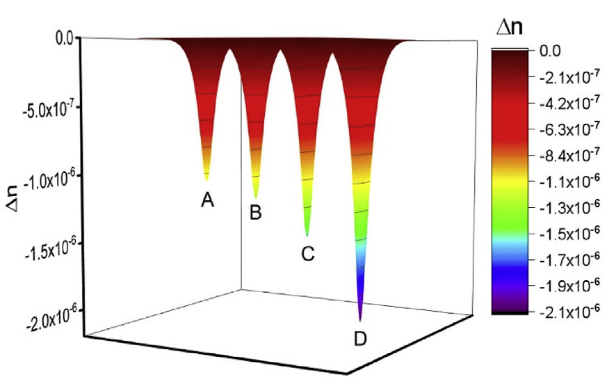


**Fig. 4.** Change in refractive index of the medium, the medicinal oils, for sample A, sample B, sample C and sample D.

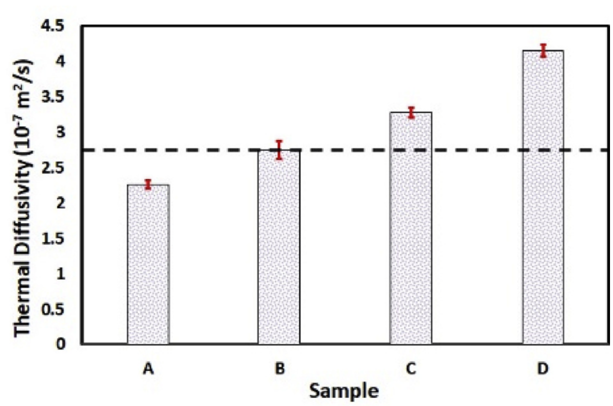


**Fig. 5.** Thermal Diffusivity of the medicinal oils, for sample A, sample B, sample C and sample D.

The thermal diffusivity values of the samples determined using the mode mismatched dual-beam thermal lens setup are given in Fig. 5. The study reveals that the medicinal ingredients have a profound effect on the thermal behaviour of the base oil. When the oil is applied to the body and scalp, it acts as a medium for energy exchange as oils have low specific heat capacity. The oil takes heat energy from the body and dissipates to the surroundings and thereby giving a cooling effect. The medicinal ingredients contain a variety of minerals such as calcium, iron, magnesium, manganese, phosphorous, and potassium along with proteins and carbohydrates [25]. The variations in composition are responsible for the thermal diffusivity changes. In Ayurveda literature one can see the mentioning of hot potency (*Ushna veerya*) and cold potency (*Sheeta veerya*) to indicate the efficacy of the material used in the preparation of medicine [26]. From the Physics point of view of explaining thermal energy transport capability of a material in nanofluids, the materials can be either increasing or decreasing the thermal diffusivity of the base fluid. In the present study, the material ingredients used for the preparation of medicinal oils also exhibited a thermal diffusivity lowering or enhancing effect. Hence, as the application of oils with lower thermal diffusivity helps in trapping the heat energy within the body, the one enhancing the thermal diffusivity helps to dissipate heat from the body. This is equivalent or analogue to the two types of *veerya* — *Ushna* (hot) and *Sheeta* (cold).

In the present work, it is observed that the ingredients of sample A have the effect of lowering the thermal diffusivity of the base oil (sample B). In *Ayurveda* literature the black pepper present in sample A is categorised as a spice with 'hot potency' (*Ushna Veerya*) [27]. This property can effectively be used for keeping the body temperature at a higher level. The reduction in the thermal diffusivity values indicates the reduction in the heat dissipation, leading to a heat trap [28]. Hence the application of such oils lower the thermal energy exchange between body and surroundings and thereby giving the feeling of warmness. This observation agrees well with the traditional knowledge reported in Ayurveda literature [26].

When aloe vera [29], hibiscus bud [30] and *Ocimum sanctum* [31] (sample C and D) are used as ingredients for the preparation of medicinal oils in the coconut oil, an increase in thermal diffusivity value is observed. The increase in the value of $\alpha$ increases the heat energy flow from the body to the surroundings. Though the ingredients Plectranthus amboinicus, onion and *O. sanctum* are categoried as hot potency in Ayurvedic literature [29,31,32], in the present study, these ingredients are found to enhance the thermal diffusivity by which a cooling effect can be induced in the body. The juxtaposing behavior of the ingredients may be due to the well reported behavior of nanofluids with the concentration of the ingredients. There are reports of transforming a base fluid to exhibit heat trap to heat dissipating nature or thermal diffusivity reduction to thermal diffusivity enhancement simply by changing the concentration of the nanoparticle ingredient [33,34]. This behavior of nanofluids might have been the reason for the coconut oil with *Plectranthus amboinicus*, onion and *O. sanctum* as ingredients to exhibit enhanced heat dissipation and hence can be regarded as *sheeta veerya*. A detailed investigation of the concentration of these ingredients at which the oil becomes *ushna veerya* is to be carried out. Thus the study reveals that the samples C and D facilitates better energy exchange to the surroundings, as their $\alpha$ values are higher than the base fluid. Hence it is advisable to use samples like C and D for the people in the tropical region (Latitude $\pm$ 23°) or during the summer season as it can aid the heat removal mechanism from the human body to maintain the equilibrium temperature. Sample A is good for people from the subtropical region as it retards heat loss from the body and in the tropical region during autumn and winter season. Thus by tuning the thermal diffusivity of a base oil by adding medicinal ingredients can facilitate maintaining the body temperature providing acclimatization effect.

## 5. Conclusion

The scientific validation of the traditional knowledge is essential to allow assess and acceptance of this knowledge by the scientific community. The adaptation to the changing climate is essential for maintaining good health. The traditional preparation of medicinal oils detailed in Ayurveda literature involves the incorporation of various parts of plants and seeds to the base fluid. These oils are widely used by people of different ages as part of treatment or improving health. The Ayurveda literature categorises some leaves or seeds as *ushna veerya* (hot potency) and some others as *sheeta veerya* (cold potency). In the present study, medicinal oils are prepared with black pepper, aloe vera, hibiscus bud, *O. sanctum* and others in the base fluid coconut oil. The thermal diffusivity of these oils is studied using mode mismatched dual-beam thermal lens technique. The study reveals that the incorporation of black pepper to the base fluid lowers the thermal diffusivity value indicating its potential for heat-trapping. This may be the reason for categorising black pepper as of hot potency in Ayurveda. The incorporation of aloe vera, hibiscus bud, and *O. sanctum* is found to enhance the thermal diffusivity of coconut oil, revealing its potential in the fast dissipation of heat energy or providing a cooling effect upon its application to the human body. Though the ingredients *Plectranthus amboinicus*, onion and *O. sanctum* are categoried as hot potency in *Ayurvedic* literature, the concentration dependent behavior of nanofluids gives a cold potency to the coconut oil with these ingredients. Thus the study established the relevance of concentration of the ingredients in the preparation of medicinal oils. As the same ingredient can induce thermal duality in the base oil by varying the concentration. The thermal diffusivity tuning through the incorporation of herbs and seeds can effectively be used in the acclimatization of the human body with surroundings. The study also throws light on the selection of oils, that can give a soothing effect, in the tropical/subtropical regions and during different seasons. Thus the study unveils the underlying principle of *Ayurvedic* medicinal oils.

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None.

## Author contributions

All authors contributed equally to work.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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