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Ultrasonic Studies on Molecular Interactions in Soybean and Safflower Oils

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Abstract

Ultrasonic velocity measurements are widely used to probe molecular interactions and thermodynamic behaviour of liquids. In the present study, ultrasonic velocity (U), adiabatic compressibility (β_a), Wada constant (W), and acoustic impedance (Z) of soybean oil and safflower oil were evaluated in the temperature range 30–80 °C at a fixed frequency of 2 MHz. The results show that ultrasonic velocity, density, Wada constant, and acoustic impedance decrease with increase in temperature, whereas adiabatic compressibility increases. These variations are attributed to reduced molecular packing and weakening of intermolecular forces at elevated temperatures. Similar trends observed for both oils are explained on the basis of their comparable fatty-acid composition dominated by oleic and linoleic acids.

Keywords

Ultrasonic velocity; Adiabatic compressibility; Acoustic impedance; Wada constant; Edible oils; Molecular interaction

1. Introduction

Ultrasonic investigation has emerged as a reliable and non-destructive approach for probing molecular interactions and thermodynamic behaviour of liquids. The velocity of ultrasonic waves travelling through a liquid is governed by its elastic properties and density, which in turn depend on the nature and strength of intermolecular forces [1–3]. Consequently, ultrasonic velocity measurements, along with derived parameters such as adiabatic compressibility and acoustic impedance, provide valuable insight into molecular arrangement in liquid systems.

Because of these advantages, ultrasonic techniques have been widely applied in several scientific and technological domains. Their applications range from medical diagnostics and imaging [4], non-destructive evaluation of engineering materials [5,6], and characterization of wood and composites [7], to quality assessment in the food industry [8], studies on biological materials [9–11], and geophysical investigations [12]. These diverse applications underline the versatility of ultrasonic methods in characterizing condensed matter.

Edible oils form an important class of liquids whose physical properties are closely linked with molecular interactions among constituent fatty acids. Properties such as compressibility and acoustic response influence stability, processing behaviour, and shelf life of oils [13]. However, systematic ultrasonic studies on edible oils over a wide temperature range remain limited. In this context, the present work aims to examine the temperature-dependent ultrasonic behaviour of soybean oil and safflower oil and to interpret the observed trends in terms of molecular interactions.

2. Theoretical Background

2.1 Ultrasonic Velocity and Adiabatic Compressibility

Ultrasonic waves are mechanical waves with frequencies greater than 20 kHz. In liquids, the ultrasonic velocity is a fundamental property associated with molecular structure and intermolecular forces [18]. According to molecular kinetic theory, the ultrasonic velocity (U) in a liquid is related to density (ρ) and adiabatic compressibility (β_a) by [1,14,15]:

$$[\, U = \frac{1}{\rho\beta_a}]^{1/2}$$

or equivalently,

$$[\, \beta_a = \frac{1}{\rho U^2}]$$

Thus, adiabatic compressibility can be evaluated from experimentally measured ultrasonic velocity and density values.

2.2 Wada Constant

Wada proposed an empirical relation connecting density and adiabatic compressibility of liquids [1,21]:

$$[\, W = \rho\beta_a]$$

where W is known as the Wada constant. This parameter is useful for understanding molecular packing and the strength of intermolecular interactions.

2.3 Acoustic Impedance

The specific acoustic impedance (Z) of a liquid is defined as the product of its density and ultrasonic velocity [16]:

$$[\, Z = \rho U]$$

Acoustic impedance determines the extent of reflection and transmission of ultrasonic waves in a medium and is analogous to electrical impedance. Variations in Z reflect changes in molecular structure and interaction within the liquid.

3. Experimental Methodology

3.1 Materials

Soybean oil and safflower oil samples were obtained from a local oil expeller and filtered once before use to remove suspended impurities.

3.2 Ultrasonic Velocity Measurements

Ultrasonic velocity measurements were carried out using a variable-path ultrasonic interferometer (Model F-81) operating at a constant frequency of 2 MHz. The interferometric technique is based on the formation of standing waves between a quartz crystal source and a movable reflector in the liquid column [10].

The ultrasonic velocity was calculated using the relation:

[U = λf]

where λ is the wavelength determined from micrometer displacement corresponding to successive maxima and f is the ultrasonic frequency.

3.3 Temperature Control and Density Measurement

Measurements were conducted in the temperature range 30–80 °C at intervals of 10 °C. The temperature of the liquid was maintained constant within ±0.5 °C using a circulating water bath. Density measurements were carried out using a standard density bottle immersed in the same water bath, and mass was measured using an electronic weighing balance.

3.4 Evaluation of Acoustical Parameters

Using experimentally measured ultrasonic velocity and density values, adiabatic compressibility, Wada constant, and acoustic impedance were calculated using standard relations reported in the literature [14–16].

4. Results

4.1 Soybean Oil

The ultrasonic velocity, adiabatic compressibility, Wada constant, and acoustic impedance of soybean oil at different temperatures are presented in Table 1. Ultrasonic velocity and density were found to decrease with increasing temperature, whereas adiabatic compressibility increased.

4.2 Safflower Oil

Table 2 summarizes the acoustical parameters of safflower oil at various temperatures. Trends similar to those observed for soybean oil were obtained, indicating comparable temperature dependence of acoustical properties.

5. Discussion

The experimental results reveal a systematic decrease in ultrasonic velocity with increasing temperature for both soybean and safflower oils. Such behaviour has been reported earlier for vegetable oils and organic liquid systems [13,17]. An increase in temperature enhances thermal motion of molecules, leading to expansion of the liquid structure and reduction in density. As a consequence, the elastic restoring forces responsible for sound propagation weaken, resulting in lower ultrasonic velocity [18].

The observed increase in adiabatic compressibility with temperature further supports this interpretation. Higher compressibility indicates that the liquid structure becomes more responsive to pressure changes, reflecting weakened intermolecular attractions and increased free volume. Similar temperature-dependent increases in adiabatic compressibility have been reported for vegetable oils [13], bromobutyl rubber [19], and polymer solutions [20].

Acoustic impedance and Wada constant exhibit a gradual, non-linear decline with temperature. Since both parameters depend on density and ultrasonic velocity, their decrease signifies loosening of molecular packing and diminished intermolecular interactions at elevated temperatures [21,22].

A close resemblance in the acoustical behavior of soybean and safflower oils is evident throughout the investigated temperature range. This similarity can be attributed to their fatty-acid composition, as both oils predominantly contain oleic acid and linoleic acid, which possess comparable molecular structures and melting points [23]. Therefore, the ultrasonic response of these oils is governed by similar intermolecular interaction mechanisms.

6. Conclusions

1. Ultrasonic velocity, acoustic impedance, and Wada constant of soybean and safflower oils decrease with increase in temperature.
2. Adiabatic compressibility increases with temperature, indicating weakening of intermolecular forces.
3. Both oils exhibit similar acoustical behaviour due to comparable fatty-acid composition.
4. Ultrasonic techniques are effective tools for studying molecular interactions and thermal behaviour of edible oils.

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- Table 1: Soybean oil acoustical parameters

sr.no.	Temp.in ℃	Ultrasonic Velocity m/s	Adiabatic compressibility dynes/cm2	wada constant W	Acoustical Impedence gm/cm2sec
1	30	1421.8	5.400*10^-11	4.989	1.302*10^5
2	40	1368	5.878*10^-11	4.923	1.243*10^5
3	50	1300	6.003*10^-11	4.818	1.164*10^5
4	60	1268	6.842*10^-11	4.731	1.134*10^5
5	70	1264	7.244*10^-11	4.627	1.092*10^5
6	80	1240	7.687*10^-11	4.518	1.049*10^5

- Table 2: Safflower oil acoustical parameters

sr.no.	Temp.in ℃	Ultrasonic Velocity m/s	Adiabatic compressibility dynes/cm2	wada constant W	Acoustical Impedence gm/cm2sec
1	30	1420	5.402*10^-11	4.999	1.303*10^5
2	40	1394	5.921*10^-11	4.719	1.211*10^5
3	50	1337	6.604*10^-11	4.572	1.132*10^5
4	60	1320	6.840*10^-11	4.521	1.107*10^5
5	70	1300	7.278*10^-11	4.371	1.056*10^5
6	80	1265	7.860*10^-11	4.258	1.005*10^5

Figure 1. Variation of ultrasonic velocity with temperature for soybean oil and safflower oil at 2 MHz.

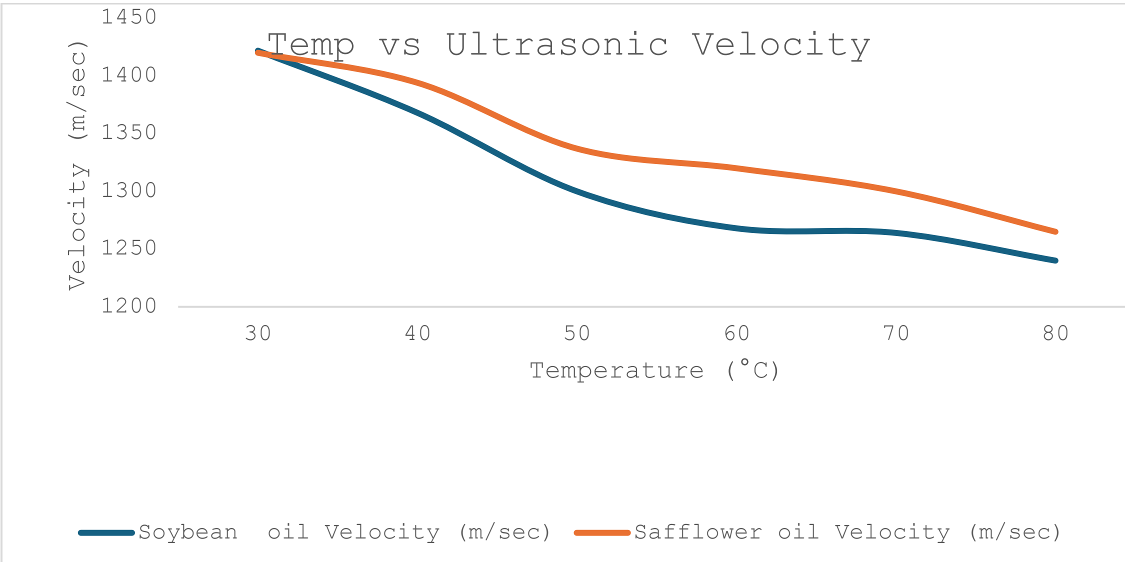


Figure 2. Temperature dependence of adiabatic compressibility for soybean and safflower oils.

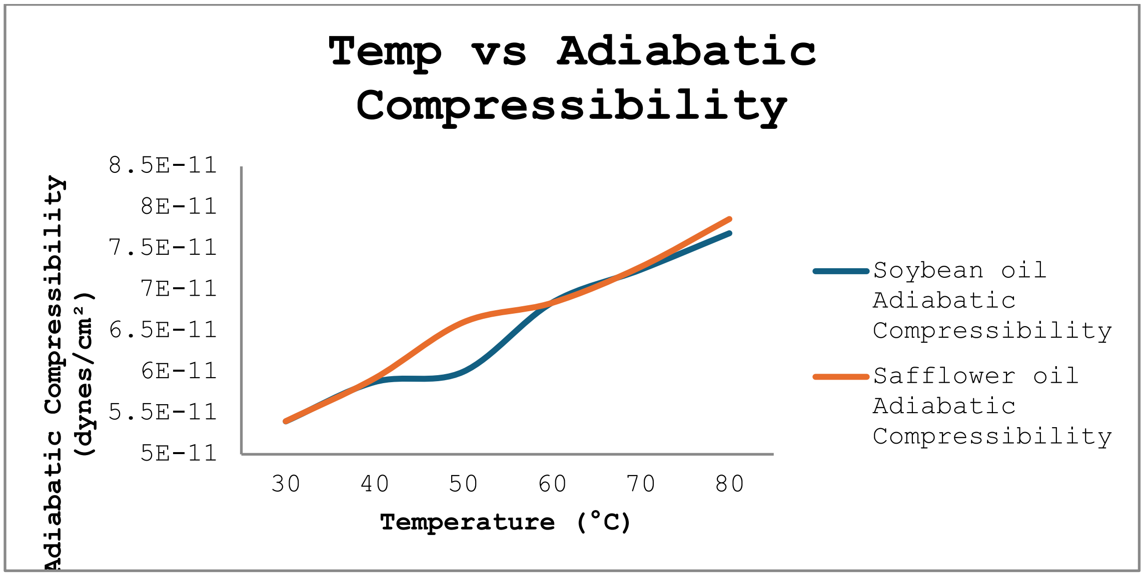


Figure 3. Variation of Wada constant with temperature for soybean and safflower oils.

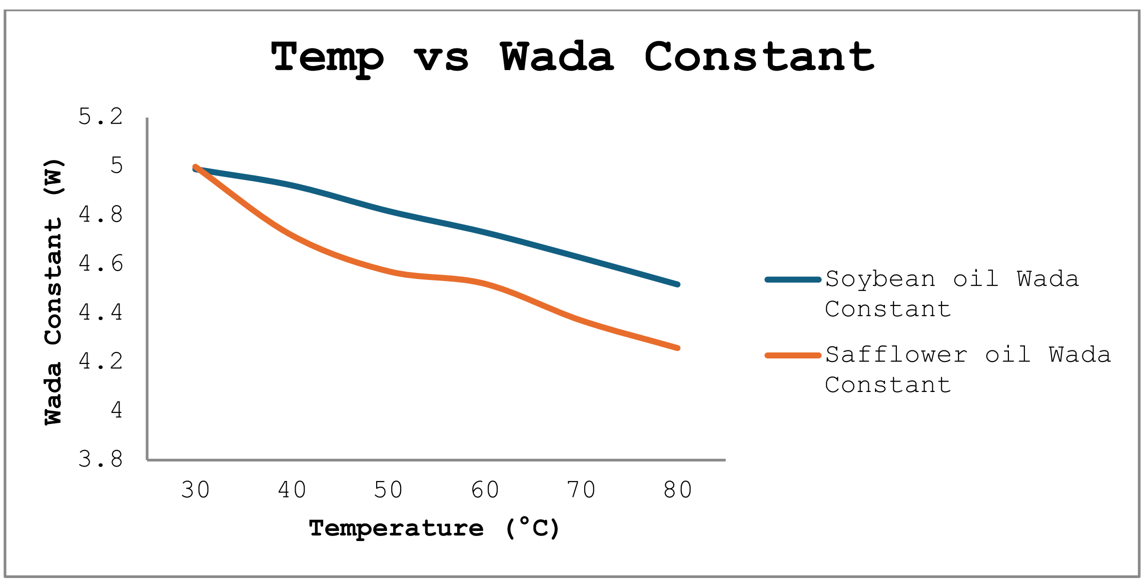
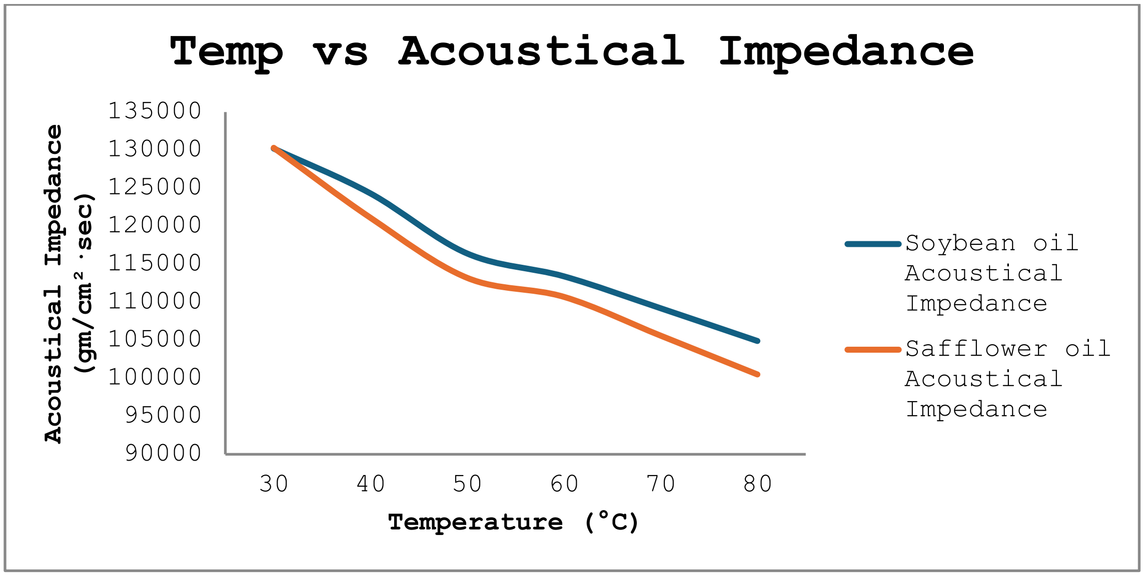


Figure 4. Acoustic impedance as a function of temperature for soybean and safflower oils.


Temp vs Acoustical Impedance
Acoustical Impedance (gm/cm²·sec)
135000
130000
125000
120000
115000
110000
105000
100000
95000
90000
30
40
50
60
70
80
Temperature (°C)
Soybean oil Acoustical Impedance
Safflower oil Acoustical Impedance