ISSN 2583– 0260 (online) *ISSN 2394 -7837 (print)*

DETECTION AND ESTIMATION OF SUGAR CONTENT IN COCONUT WATER USING A NEW TEMPERATURE DEPENDENT ACOUSTIC RELATION

Bindu, R. G.

Received: 23/5/2021 **Revised: 25/11/2021** **Accepted:28/11/2021**

Abstract

A new temperature dependent relation of adiabatic compressibility has been deduced from its standard formula with the knowledge of temperature coefficient of sound velocity and density of the liquid at a lower temperature and at a particular concentration. The validity of the relation is examined by using it to detect the major sugar content in coconut water and also to estimate the sugar content in it. The results are then compared with those obtained experimentally.

Keywords: adiabatic compressibility, coconut water, sugar content

Introduction

From ancient times, people especially Keralites extensively used all parts of coconut tree. It is popularly known as "KalpaVriksha". Its product - coconut water (Cocos nucifera L.) is a nutritional hygienic drink from ancient days. Due to its medicinal and nutritional value, recently it has high value in international market (Alexia et al.,2012), (Chandrasekharan et al.,2004),(Steiner and Desser,2008), (Rethinam and Kumar,2001). In sports field, though energy drink has been considerably used, this natural functional drink due to its refreshing and rehydrating effect has been considered as a "sport beverage" and replaces the position of energy drink among players. (Saat et al.,2002). What makes coconut water a natural isotonic liquid is its mineral composition and sugar content in it (Nanda Kumar, 1990). It consists of 95% water, 4% carbohydrates and the rest minerals, fats and proteins. The sweetness in tender coconut water may be due to glucose, fructose or sucrose content in it. Though glucose and fructose are isomeric compounds having same chemical formula, but different structure, fructose is double sweeter than glucose. (Swaminathan, 1999). In our systematic study of liquids and liquid mixtures using Thermal Opto-Acoustic Analysis, a new temperature dependent relation of adiabatic compressibility has been deduced whose validity has been examined by applying it to detect and estimate the major sugar content in coconut water. From media reports it has been found that high quality liquor – 'Coconut Scotch'- which has a quality superior to Scotch Whisky can be made from coconut water (Mohanan et al., 2001), (Augustine, 2007). The subsequent industrial importance prompted to take up the present study.

Materials and Methods

The sound velocity and density of fructose solution, glucose solution and two samples of coconut water (TCW and DCW) have been determined for five different temperatures ranging from 298K to 313K at an interval of 5K.. TCW stands for water from tender coconut and DCW stands for water from matured coconut. The velocity measurements were performed using a single crystal ultrasonic interferometer (Mittal Enterprises – Model No: F81) at a frequency of 2MHz, having an accuracy of ±0.1m/s. Densities were measured using a 12cm^3 pyknometer and the masses were determined using an electronic balance having an accuracy of ± 0.1mg. During measurements, temperature was kept constant with the help of a thermostatically controlled water circulating arrangement having an

Department of Physics, NSS College, Nilamel, Kollam, Kerala, India - 691535
email of corresponding author : *drbindurg@gmail.com*

accuracy of ±0.1K.

Theory

Thermal analysis refers to studies of physico-chemical behaviour of substances as a function of temperature. Usually it covers properties like enthalpy, entropy, heat capacity, thermal expansion etc (West, 1998). Here we extended thermal analysis to study liquids using a reliable acoustic property namely adiabatic compressibility which is a function of ultrasonic velocity and density. Since liquids are volatile at high temperatures, we have chosen the temperature range from 298K to 313K for our study.

Temperature dependence of adiabatic compressibility

The adiabatic compressibility of a liquid is defined as

$$\beta_s = \frac{1}{U^2\rho} \tag{1}$$

where U is the sound velocity and ρ is the density of the liquid.

Both U and ρ are temperature sensitive parameters. Hence as temperature of the liquid changes, adiabatic compressibility also changes. So differentiating eqn (1) with respect to temperature at constant pressure and dividing by β_s throughout, we get

$$\frac{1}{\beta_s}\left(\frac{\partial\beta_s}{\partial T}\right)_P = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_P - \frac{2}{U}\left(\frac{\partial U}{\partial T}\right)_P$$

$$= \alpha + 2\,\beta \tag{2}$$

where α and β are the temperature coefficients of density and sound velocity respectively at the lowest temperature and at a particular concentration.

Rearranging eqn (2) and integrating we get,

$$\ln\beta_s = (\alpha + 2\,\beta)\,T + C \tag{3}$$

where C is a constant of integration.

If β_s' is the adiabatic compressibility at a lower temperature T ′, then from eqn (3)

$$\ln\beta_s' = (\alpha + 2\,\beta)\,T' + C \tag{4}$$

From eqns (3) and (4), we get

$$\beta_s = \beta_s' \exp\,(\alpha + 2\,\beta)\,\Delta T \tag{5}$$

where $\Delta T = T - T'$ is the difference in temperature.

This is the temperature dependent relation of adiabatic compressibility of a liquid.

Table 1. Variation of U, ρ, β_s^{expt} and β_s^{cal} for fructose, glucose and coconut water at different temperatures and concentrations

	Conc: (g/L)	U (m s^{-1})					ρ (kg m^{-3})				
		298K	303K	308K	313K	318K	298K	303K	308K	313K	318K
uctose	40	1519	1528	1537	1544	1550	1015.27	1013.03	1011.94	1009.77	1008.46
	50	1521	1531	1540	1547	1554	1018.77	1016.36	1015.32	1013.04	1012.18
	60	1525	1534	1544	1550	1556	1022.61	1020.28	1019.68	1017.51	1015.96
	70	1529	1539	1547	1553	1560	1026.08	1023.64	1022.54	1020.43	1019.43
	80	1531	1540	1550	1556	1561	1028.71	1026.33	1025.09	1022.98	1021.85
ucose	40	1513.9	1522.1	1532.6	1541	1547.2	1014.43	1012.46	1011.09	1009.02	1008.01
	50	1519.5	1528	1539	1546	1553	1018.44	1016.07	1015.55	1012.84	1012.00
	60	1523.5	1531	1541.5	1548.9	1555.3	1021.42	1019.28	1017.93	1015.42	1014.61
	70	1526.3	1534.3	1544	1552	1558.5	1025.27	1023.02	1022.29	1019.93	1018.97
	80	1529.1	1537.6	1548	1555.5	1563	1028.86	1026.79	1025.70	1023.58	1022.63
conut ater	TCW	1529.1	1538.6	1546.9	1553.4	1560.5	1026.06	1024.37	1022.90	1020.57	1018.94
	DCW	1521.6	1530.8	1540.5	1548	1555.6	1017.47	1015.54	1013.95	1011.65	1010.07

	Conc: (g/L)	β_s^{expt} (m^2 N^{-1}) × 10^{10}					β_s^{cal} (m^2 N^{-1}) × 10^{10}			
		298K	303K	308K	313K	318K	303K	308K	313K	318K
Fructose	40	4.269	4.228	4.183	4.154	4.127	4.228	4.187	4.147	4.107
	50	4.243	4.198	4.153	4.125	4.091	4.202	4.162	4.122	4.082
	60	4.205	4.165	4.114	4.091	4.065	4.167	4.125	4.085	4.046
	70	4-169	4.125	4.086	4.063	4.031	4.129	4.089	4.050	4.011
	80	4.147	4.108	4.060	4.038	4.016	4.107	4.068	4.029	3.990
Glucose	40	4.301	4.263	4.211	4.173	4.144	4.263	4.225	4.188	4.151
	50	4.253	4.215	4.157	4.131	4.097	4.215	4.178	4.141	4.104
	60	4.218	4.186	4.134	4.105	4.074	4.181	4.144	4.107	4.071
	70	4.187	4.152	4.103	4.070	4.040	4.150	4.113	4.077	4.041
	80	4.157	4.119	4.069	4.038	4.003	4.120	4.084	4.048	4.012
Coconut water	TCW	4.168	4.124	4.085	4.061	4.030	4.123	4.079	4.035	3.992
	DCW	4.245	4.202	4.156	4.125	4.091	4.199	4.154	4.110	4.066

Table 2. Values of slope $\frac{d\beta_s}{dT}$ of curves of TCW, DCW, fructose and glucose at concentrations 50g/L and 70g/L

Conc: g/L	Slope $\frac{d\beta_s}{dT}$ $(m^2\ N^{-1}\ K^{-1}) \times 10^3$			
	TCW	DCW	Fructose	Glucose
50		9.1	8.4	7.6
70	8.9		8.0	7.6

Table 3. Estimated fructose content in TCW and DCW using experimental and calculated values of adiabatic compressibility at 303K

Sample	$\beta_s^{expt} \times 10^{10}$ $(m^2\ N^{-1})$	$\beta_s^{cal} \times 10^{10}$ $(m^2\ N^{-1})$	Estimated fructose content in g/L using	
			β_s^{expt}	β_s^{cal}
TCW	4.124	4.123	70	71
DCW	4.202	4.199	50	51

Results and Discussion

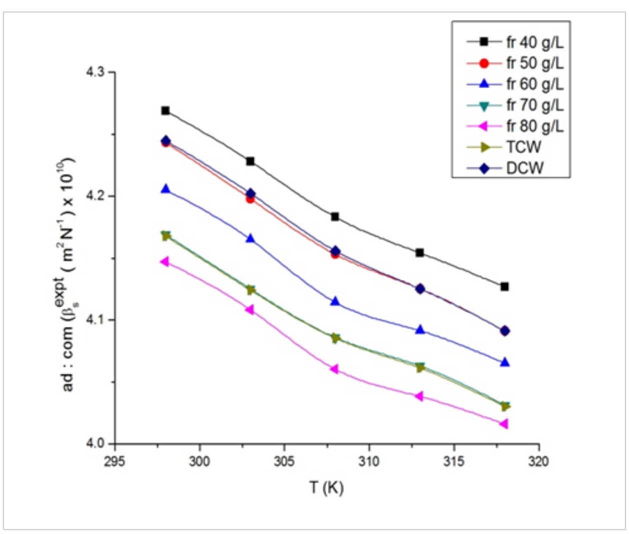
The experimental as well as calculated values of adiabatic compressibility of fructose solution, glucose solution, TCW and DCW are evaluated using eqns (1) and (5) and are plotted in Table.1. The variations of β_s^{expt} with temperature for fructose and glucose at different concentrations (40g/L to 80g/L at an interval of 10g/L) and coconut water were plotted in graphs 1(a) and 1(b).

From the graphs, it can be seen that the experimental values of β_s for fructose, glucose and coconut water are not linear and the shape is characteristic of a particular liquid (Mohanan et al., 2001). This clearly indicates that the thermal response of a physical property is unique for a given liquid. Figure 1(a) shows that the shape of the curves for tender coconut water and dry coconut water is exactly similar to those of fructose solutions of 70g/L and 50g/L respectively. Moreover they coincide with the graphs of fructose. But in figure 1(b), the curves of both tender and dry coconut water deviate widely from those of glucose solution curves. There is no similarity between the curves of coconut water and that of glucose and the shapes are also entirely different

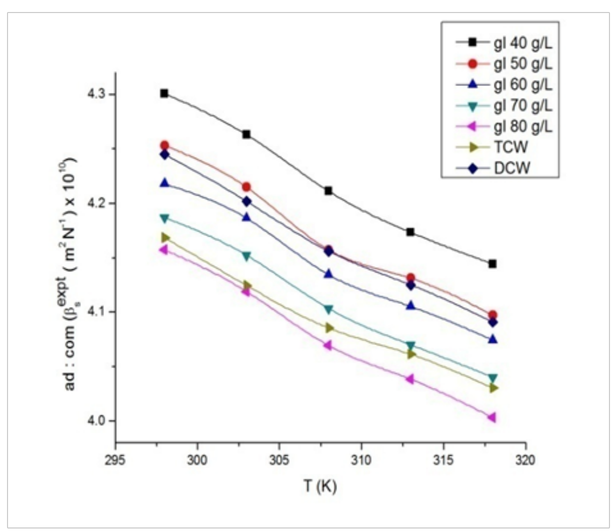
Inorder to show this fact clearly we have drawn graphs of variation of β_s^{expt} versus temperature for (a) 50g/L fructose solution and tender coconut water (b) 50g/L glucose solution and tender coconut water and (c) 50g/L sucrose solution and tender coconut water. These are shown in figures 2(a, b and c).

We have chosen this concentration range for convenience and to compare the shapes of the graphs of glucose, fructose and sucrose with that of coconut water. Sucrose was chosen in this concentration range for better authenticity of the work. On analysing these graphs also, it can be seen that the shape of the curve for coconut water is similar to the curve of fructose solution and is different from those of glucose and sucrose.

Because of the concentration difference between the fructose content in fructose solution and in coconut water, a shift is observed in figure 2 (a). But in this case, the shift is uniform throughout the temperature range. However, the shift is irregular in the case of glucose and coconut water (figure 2b) and sucrose and coconut water (figure 2c).For glucose solution, a dip is observed at 308K and its slope is different from that of coconut water in the temperature -

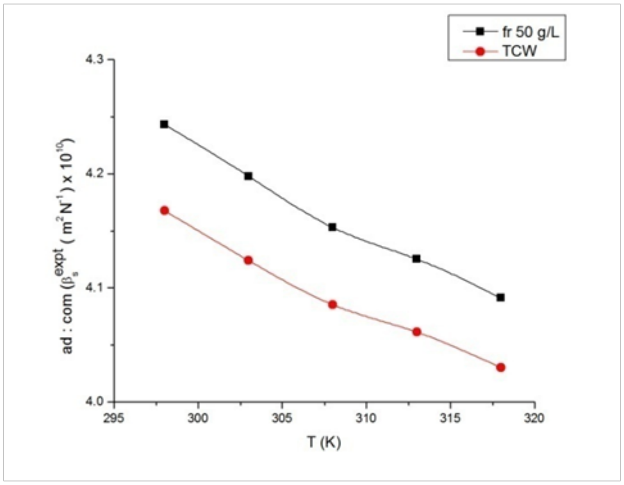


a



b

Figure 1. Variation of β_s^{expt} with temperature for (a) fructose and coconut water (b) glucose and coconut water



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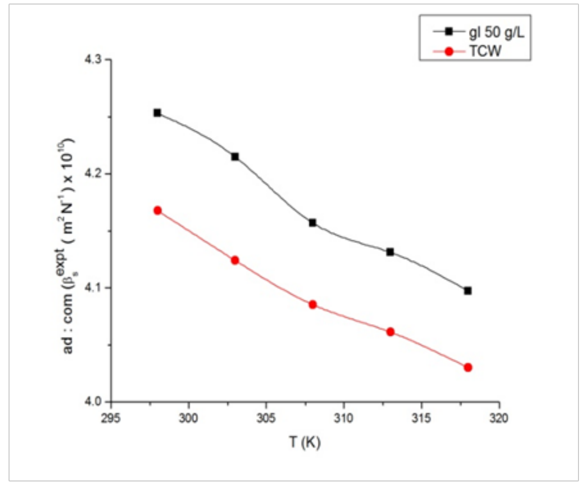

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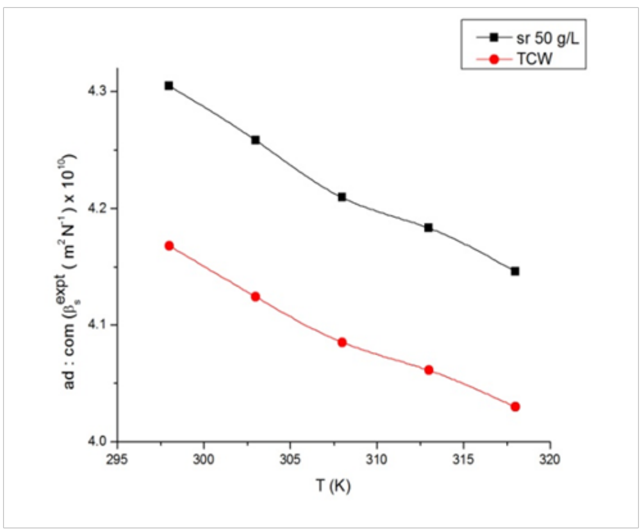
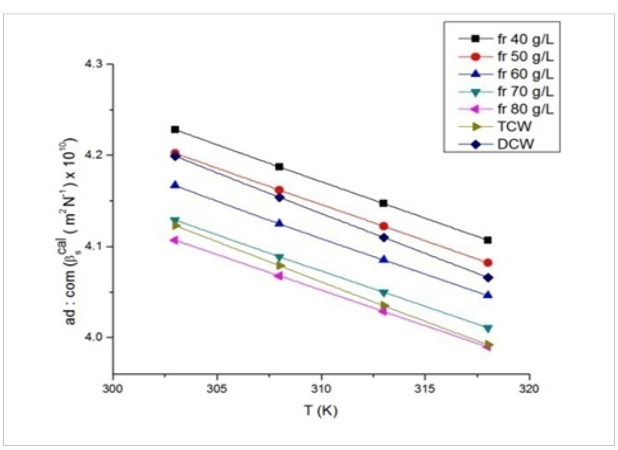
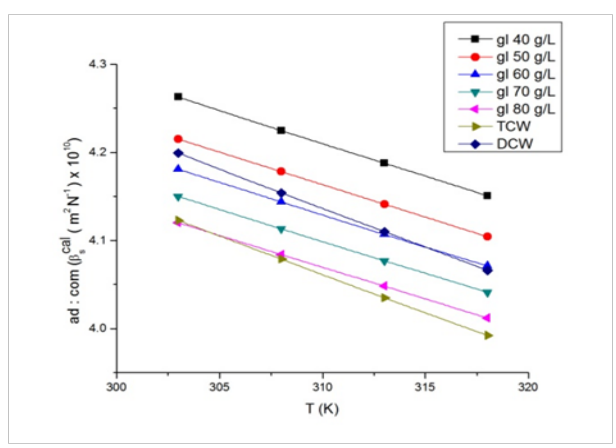


c

Figure 2. Variation of β_s^{expt} with temperature for (a) fructose & TCW (b) glucose & TCW (c) sucrose & TCW



a



b

Figure 3. Variation of β_s^{cal} with temperature for (a) fructose and coconut water (b) glucose and coconut water

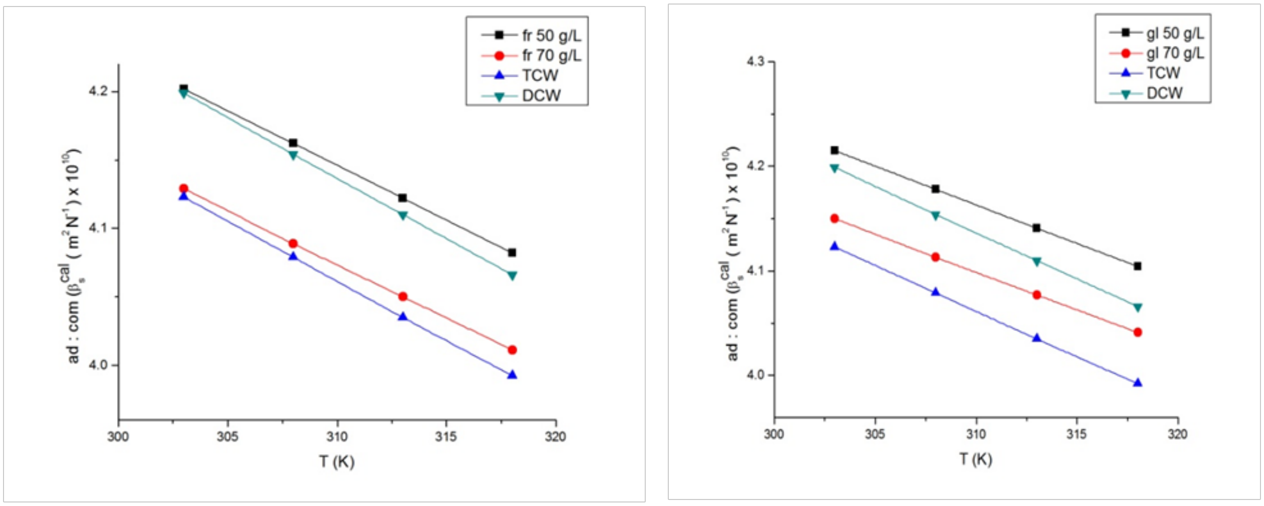
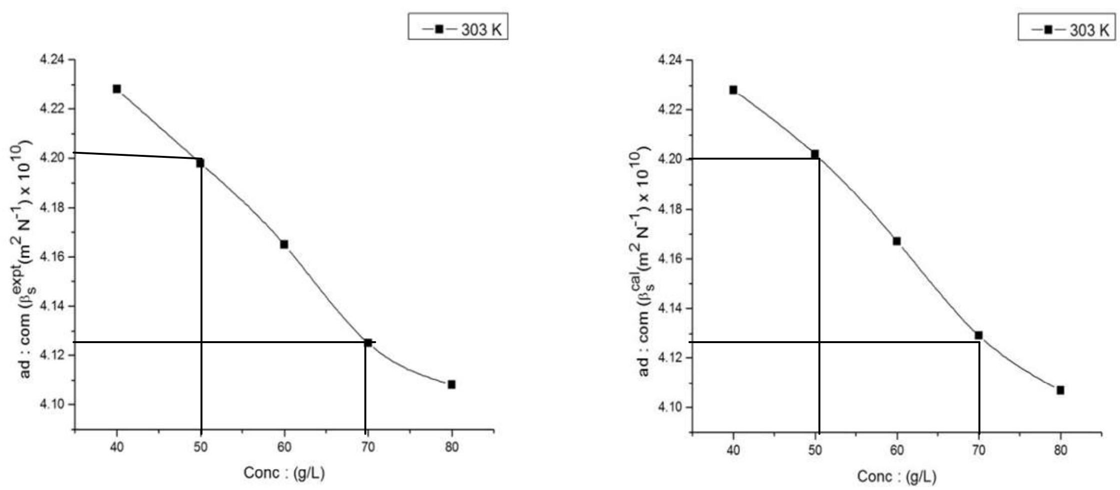


Figure 4. Variation of β_s^{cal} with temperature for (a) 50g/L, 70g/L fructose and coconut water (b) 50g/L, 70g/L glucose and coconut water



(a) **(b)**

Figure 5 Estimation of fructose content from (a) β_s^{expt} vs concentration graph (b) β_s^{cal} vs concentration graph range 303K to 308K. In the case of sucrose also, the shape of the curve is entirely different from that of coconut water. The shift between the curves for sucrose and coconut water is not uniform throughout the temperature range. The shift increases in the range 308 to 318K. Moreover, on comparing the graphs 2(a), 2(b) and 2(c), it is clear that the shift between the curves of sucrose and coconut water is large when compared to those of fructose and glucose with coconut water. This clearly shows that the major sugar content in coconut water is fructose and not glucose or sucrose.

Inorder to demonstrate the application of newly derived temperature dependent relation of adiabatic compressibility (β_s^{cal}), its value for fructose solution, glucose solution and samples of coconut water were determined using equation (5). Analysing Table.1, it can be seen that the calculated values of β_s (β_s^{cal}) agree well with the experimental values (β_s^{expt}) for all the systems. Variation of β_s^{cal} with temperature for different concentrations of fructose and glucose with coconut water is shown in figures 3(a) and 3(b). The graphs are found to be linear for fructose, glucose and coconut water.

To make a comparison between the graphs of coconut water, fructose and glucose solution using the β_s^{cal} values, graphs were plotted with samples of coconut water, 50g/L and 70g/L fructose and glucose solution. These are shown in figures 4(a) and 4(b). From these figures it can be seen that the graph of tender coconut water having slope 8.9×10^{-3} $m^2N^{-1}K^{-1}$ is close to the graph of fructose having concentration 70g/L (slope 8.0×10^{-3} $m^2N^{-1}K^{-1}$) and different from the graph of glucose having slope 7.6×10^{-3} $m^2N^{-1}K^{-1}$. The slope of the graph of dry coconut water (9.1×10^{-3} $m^2N^{-1}K^{-1}$) is also closer to that of fructose of concentration 50g/L (8.4×10^{-3} $m^2N^{-1}K^{-1}$) whereas different from that of glucose of concentration 50g/L (7.6×10^{-3} $m^2N^{-1}K^{-1}$). The values of the slope of curves of glucose, fructose, TCW and DCW are shown in Table 2.

Again, the shift between the graphs of fructose and coconut water samples is small when compared with that of glucose and coconut water. The graphs of TCW and DCW are close to 70g/L and 50g/L fructose solution graphs whereas they deviate more from the respective concentrations of glucose solution. Thus these results again confirms to the same conclusion as obtained in experimental case that fructose is the major sugar content in coconut water.

With the help of figure 1 (a), an approximate estimation of fructose content in coconut water can be determined using β_s^{expt} values. It can be seen from the figure that the curve for tender coconut water merges with the curve for fructose solution having concentration 70g/L, while that for dry coconut water , the curve is close to the one having concentration 50g/L. This again confirms that the tender as well as dry coconut water contains fructose as the major sugar content and the range of concentration of fructose in them are 70g/L and 50g/L respectively.

Even though the curve for tender coconut water merges exactly with the curve for fructose solution, the one for dry coconut water deviates a little from fructose solution in lower concentration range. This further confirms that the tender coconut water has fructose only as the major sugar content while in dry coconut water, conversion of fructose to sucrose takes place with ageing of coconut. This result is in perfect agreement with the studies of Morris Jacobs (1951) and Jayalekshmy *et al.* (1986). On -

analysing the graph, it is exciting to observe that the curve for dry coconut water approaches that of sucrose solution. This further confirms the above information.

To estimate accurately the fructose content in TCW and DCW, graphs of β_s^{expt} versus concentration and β_s^{cal} versus concentration of fructose solutions and the coconut samples were plotted at a particular temperature, say 303K. These are shown in figures 5 (a) and 5 (b). The estimated fructose content of these samples was tabulated in Table 3. It can be seen that the fructose content in TCW using experimental and calculated values of β_s is around the concentration range of 70g/L while that for DCW is around 50g/L respectively. The estimation can be extended for different temperatures as well as for different samples of coconut water.

Conclusion

The identification of fructose as the major sugar content in coconut water has been done using experimental and empirically calculated values of adiabatic compressibility and we arrive at the same result in both cases. Thus this temperature dependent acoustic relation helps us to detect as well as estimate the sugar content in any samples of coconut water just as experimental values which is helpful in analysing the age and breed of coconuts having greater fructose content. Moreover, the new temperature dependent relation is useful in predicting the values of β_s of any samples of liquid at any higher temperature, provided its value at a low temperature is known.

Acknowledgement

The author is grateful to the Principal, Mahatma Gandhi College, Thiruvananthapuram, for providing the facilities for conducting the above work.

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