Density study of (D (+) mannose + water), (D (+) mannose + water + sodium cyclamate), (D (+) maltose monohydrate + water) and (D (+) maltose monohydrate + water + sodium cyclamate) systems at $T = 298.15$ K

SANJEEVAN J. KHRAT1* and MANISHA D. PATIL1

1Department of Chemistry, HPT Arts and RYK Science College, Nashik-422005, (Maharashtra), India.
*Corresponding author E-mail: sanjeevan.kharat@gmail.com

http://dx.doi.org/10.13005/ojc/370607

(Received: October 01, 2021; Accepted: December 20, 2021)

ABSTRACT

Effect of different concentrations of aqueous solutions of sodium cyclamate on sugars (mono and disaccharides) are observed by measuring the densities of (sugar + water) and (sugar + water + sodium cyclamate) systems. Densities of aqueous solutions of D(+) mannose (monosaccharide) and D(+) maltose monohydrate (disaccharide) in (0.05, 0.15, 0.3) mol.kg$^{-1}$ of sodium cyclamate (Na-Cyclamate) at $T = 298.15$ K have been measured. From experimental values of densities, $V_{f0}$ (partial molar volumes) $\Delta V_{trs}$ (partial molar volumes of transfer) ASV (apparent specific volumes) interaction parameters ($V_{AB}$) and ($V_{ABB}$) have been determined. The calculated values of various parameters have been used to interpret the results in terms of (D (+) mannose–water), (D(+) mannose–water–Na-cyclamate), (D(+)+ maltose monohydrate–water) and (D(+)+ maltose monohydrate –water–Na-cyclamate) interactions in sugar–water–Na-cyclamate and quality of taste sense of solutions.

Keywords: Density, D(+) mannose, D(+) maltose monohydrate, Apparent specific volume.

INTRODUCTION

Carbohydrate gain importance and attention of researchers because of their multifunctional and significant roles in different areas like biological reaction, industrial field, pharmaceuticals, organic synthesis, structural determination and separation. The stabilities of such compounds and their position are verbalized by thermodynamic consideration$^1$. Sugars are the energetic biomolecule of living being. Sugar solutions are of considerable interest in various aspects of basic researches and application. Interactions of sugars with sweetener in aqueous media and its hydration properties are of significant biological and thermodynamic importance. Combinations of Non-caloric sweetener are mostly used to formulate pharmaceutical doses and food products.
Combination of two sweeteners results in synergistic effect which means sweetness of mixture or combination is high as compared with the sweetness of individual sugar. This was reported true in some blends of such sweetener\(^2\). Also by combining with other sugars reduces the bitterness of one of the sugar and enhances the taste quality. Application of non-nutritive sugars or artificial sugars are less caloric and thus provides choices for caloric sugars, reduces weight, assistance in the management of diabetes, provides cost effectiveness\(^3\), also have many applications in food and pharmaceutical industry.

For present work one monosaccharide (D(+) mannose) and one disaccharide (D(+) maltose monohydrate) taken. Mannose is a monosaccharide consists of one sugar unit and belongs to aldohexoses. It is nutritional and healthy food supplement. It is a natural bioactive. Maltose monohydrate also known as malt sugar, compose of two glucose unit join to each other by a 1-4-glycosidic bond. It plays important role in energy metabolism.

This paper reports densities of D(+) mannose–water, D(+) mannose–water–Na-cyclamate, D(+) maltose monohydrate–water, and D(+) maltose monohydrate–water–Na-cyclamate systems at 298.15 K. Furthermore, the parameter calculated from densities of aqueous solutions are reported to obtain the information regarding interactions present in D(+) mannose–water, D(+) mannose–water–Na-cyclamate, D(+) maltose monohydrate–water, and D(+) maltose monohydrate–water–Na-cyclamate systems.

**MATERIAL AND METHODS**

D(+) Mannose, D(+) Maltose monohydrate and Sodium cyclamate were bought from suppliers Sigma Aldrich used for this study. Table 1. includes the details of chemicals.

| Chemical name          | CAS Number | Molar mass | %Purity |
|------------------------|------------|------------|---------|
| D(+) Mannose           | M8574      | 180.36     | 99.0%   |
| D(+) Maltose monohydrate| M5885      | 360.31     | 99.0%   |
| Sodium Cyclamate       | 71440      | 201.22     | 99.0%   |

Aqueous solutions of D(+) mannose and D(+) maltose monohydrate were freshly prepared using triply distilled water. In dry airtight stoppered glass bottle solutions were prepared using weight/weight method. Dhona balance accurate to 0.0001 g was used to undertake weight of solute and solvent. Densities were measured in glass-walled thermostat at 298.15 K using Bi-capillary pycnometer\(^4\)\(^-\)\(^7\) with bulb size of 15 cm\(^3\) volume. Triply distilled water and pure organic solvents were used to calibrate pycnometer. Observed uncertainties in temperature and measured density were 0.005 K and 5.4 \(\times\) 10\(^{-2}\) kg m\(^{-3}\), respectively.

**RESULT AND DISCUSSION**

In this present work, aqueous solutions of sugars (D(+) mannose and D(+) maltose monohydrate) in (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate have been studied at \(T = 298.15\) K. Density data of sugars (mono and disaccharides) of concentration ranges from (0.04 to 0.2) mol.kg\(^{-1}\) in water and in (0.05, 0.15, 0.3) mol.kg\(^{-1}\) Na-Cyclamate at \(T = 298.15\) K have been generated. From the experimentally measured density values, apparent molar volume \(\left(V'_a\right)\) values are calculated using equation no.1\(^8\)\(^-\)\(^9\).

\[
V'_a = \frac{M}{\rho} - \frac{\rho - \rho_0}{m \rho_0}
\]

Where, \(M\) is molar mass of the solute, and \(m\) molality of the solution, \(\rho_0\) density of solvent, and \(\rho\) density of the aqueous solution. Literature\(^10\) value for density of water \(\left(\rho_0 = 997.07\right.\) kg.m\(^{-3}\)\) at \(T = 298.15\) K has been considered for the calculation of \(V'_a\). Calculated values of \((\rho)\) and \((V'_a)\) for aqueous solutions of (D(+) mannose and D(+) maltose monohydrate) in (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate are given in Table 2 and 3.

From the measured density data, it is understood that density of solutions of (D(+) mannose and D(+) maltose monohydrate) in water and in Na-Cyclamate varies linearly with molalities.

Fig. 1 and Fig. 2 show 3-D plots of \((V'_a)\) vs \((m)\) of (D(+) mannose and D(+) maltose monohydrate) in (water) and in (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate, respectively at \(T = 298.15\) K.
Table 2: Density (\(\rho\)) and apparent molar volume (\(V_f\)) values of D(+) mannose in water and (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate at \(T = 298.15\) K

| \(m\) (mol.kg\(^{-1}\)) | \(\rho\) (kg.m\(^{-3}\)) | \(10^6 V_f\) (m\(^3\).mol\(^{-1}\)) | \(m\) (mol.kg\(^{-1}\)) | \(\rho\) (kg.m\(^{-3}\)) | \(10^6 V_f\) (m\(^3\).mol\(^{-1}\)) |
|------------------------|-----------------|-----------------|------------------------|-----------------|-----------------|
| \(\text{D(+) mannose + Water}\) | | | \(\text{D(+) mannose + (0.05) m Na-cyclamate}\) | | |
| 0.0402 | 999.81 | 111.99 | 0.0403 | 1003.82 | 112.31 |
| 0.0803 | 1002.48 | 112.31 | 0.0806 | 1006.50 | 112.51 |
| 0.1203 | 1005.11 | 112.56 | 0.1196 | 1009.05 | 112.74 |
| 0.1604 | 1007.70 | 112.82 | 0.1602 | 1011.66 | 113.00 |
| 0.2005 | 1010.24 | 113.12 | 0.1990 | 1014.11 | 113.26 |
| \(\text{D(+) mannose + (0.05) m Na-cyclamate}\) | | | \(\text{D(+) mannose + (0.3) m Na-cyclamate}\) | | |
| 0.0402 | 1011.11 | 112.55 | 0.0401 | 1022.74 | 112.81 |
| 0.0803 | 1013.75 | 112.79 | 0.0800 | 1025.33 | 113.16 |
| 0.1197 | 1016.30 | 113.04 | 0.1200 | 1027.89 | 113.44 |
| 0.1604 | 1018.89 | 113.29 | 0.1603 | 1030.40 | 113.69 |
| 0.1998 | 1021.35 | 113.56 | 0.2000 | 1032.84 | 113.95 |

Table 3: Density (\(\rho\)) and apparent molar volume (\(V_f\)) values of D(+) maltose monohydrate in water and (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate at \(T = 298.15\) K

| \(m\) (mol.kg\(^{-1}\)) | \(\rho\) (kg.m\(^{-3}\)) | \(10^6 V_f\) (m\(^3\).mol\(^{-1}\)) | \(m\) (mol.kg\(^{-1}\)) | \(\rho\) (kg.m\(^{-3}\)) | \(10^6 V_f\) (m\(^3\).mol\(^{-1}\)) |
|------------------------|-----------------|-----------------|------------------------|-----------------|-----------------|
| \(\text{D(+)}\) maltose monohydrate + Water | | | \(\text{D(+)}\) maltose monohydrate + (0.05) m Na-cyclamate | | |
| 0.0400 | 1002.31 | 228.34 | 0.0401 | 1006.32 | 228.83 |
| 0.0801 | 1007.44 | 228.76 | 0.0801 | 1011.41 | 229.12 |
| 0.1199 | 1012.42 | 229.07 | 0.1202 | 1016.39 | 229.48 |
| 0.1599 | 1017.31 | 229.39 | 0.1600 | 1021.22 | 229.82 |
| 0.1999 | 1022.10 | 229.65 | 0.1999 | 1025.96 | 230.06 |
| \(\text{D(+)}\) maltose monohydrate + (0.05) m Na-cyclamate | | | \(\text{D(+)}\) maltose monohydrate + (0.05) m Na-cyclamate | | |
| 0.0399 | 1013.57 | 229.21 | 0.0400 | 1024.59 | 229.43 |
| 0.0800 | 1018.63 | 229.48 | 0.0801 | 1029.59 | 229.74 |
| 0.1199 | 1023.55 | 229.76 | 0.1201 | 1034.46 | 229.96 |
| 0.1601 | 1028.39 | 230.09 | 0.1601 | 1039.22 | 230.27 |
| 0.2002 | 1033.11 | 230.39 | 0.2000 | 1043.88 | 230.48 |

Figure 1 and Figure 2 show the effect of concentration of Na-cyclamate on the \(V_f\) values for D(+) mannose and D(+) maltose monohydrate. \(V_f\) varies linearly with the concentration of (D(+)) mannose and D(+) maltose monohydrate in water and in (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate at \(T = 298.15\) K. \(V_f\) of (D(+)) mannose and D(+) maltose monohydrate increases with increase in molality of Na-cyclamate.

Equation 2 shows the correlation between calculated \(V_f\) and \(m\)\(^{11}\).

\[
V_f = V_f^0 + S_m m \tag{2}
\]
The reported values of 

$$V_f^0$$

and 

$$S_f$$

are very close. Experimentally observed interactions are small than 

maltose monohydrate in water are 

$$228.12 \pm 0.05$$

and 

$$227.78 \pm 0.15$$

× 10^{-6} m^3.mol^{-1} at 

T = 298.15 K. The reported values of 

$$V_f^0$$

for D(+) mannose and D(+) maltose monohydrate in water and in presence of 

Na-cyclamate increase with increase in concentration of Na-cyclamate. Dey P. C et al., show the same trend in results. Banipal et al., reported 

$$\Delta_{tr}V_f^0$$

values for all D(+) mannose and D(+) maltose monohydrate) studied as positive and increase with increase in concentration of guanidine hydrochloride. Authors also reported same trend in results for 

$$\Delta_{tr}V_f^0$$

values of sugars in presence of cosolute. The concentration effect of co-solute (Na-cyclamate) on 

$$\Delta_{tr}V_f^0$$

values of (D(+)

maltose monohydrate) shown in Figure 3.

It is observed that with increasing concentration of solute and cosolute, 

$$V_f^0$$

values go on increasing. This observed behaviour of 

$$V_f^0$$

is due to the strong [(D(+) mannose and D(+)

maltose monohydrate)–cosolute (Na-cyclamate)] interactions. Reported and experimental 

$$V_f^0$$

values for D(+) mannose and D(+) maltose monohydrate in water at 

T = 298.15 K were compared. The reported 

$$V_f^0$$

values for D(+) mannose in water are 

$$(111.72 \pm 0.05, 111.70 \pm 0.05, 111.70 \pm 0.05) \times 10^{-6} m^3.mol^{-1}$$

at 

T = 298.15 K while experimental 

$$V_f^0$$

value is 

$$111.73 \times 10^{-6} m^3.mol^{-1}$$

at 

T = 298.15 K. The reported values of 

$$V_f^0$$

D(+) maltose monohydrate in water are 

$$(228.12 \pm 0.15, 228.14 \pm 0.15, 227.78 \pm 0.15) \times 10^{-6} m^3.mol^{-1}$$

at 

T = 298.15 K and experimental 

$$V_f^0$$

value is 

$$228.07 \times 10^{-6} m^3.mol^{-1}$$

at 

T = 298.15 K. The reported values of 

$$V_f^0$$

for studied mono and disaccharides are very close. Experimentally observed 

$$S_f$$

values are positive and smaller than 

$$V_f^0$$

values interprets strong solute–solvent interaction than solute–solute interaction.

The values of standard transfer partial volume 

$$\Delta_{tr}V_f^0$$

are estimated to focus on the nature and extent of solute–cosolute interactions. 

$$\Delta_{tr}V_f^0$$

at infinite dilution of sugar solutions from water to Na-

cyclamate have been calculated using Equation (3).

$$\Delta_{tr}V_f^0 = V_f^0 (\text{in aqueous sodium cyclamate}) - V_f^0 (\text{in water})$$

10

Table 4: 

$$V_f^0$$, 

$$S_f$$, 

ASV, 

$$\Delta_{tr}V_f^0$$ of D(+) mannose in water and 

(0.05, 0.15, 0.3) mol.kg^{-1} Na-cyclamate at 

T = 298.15 K

| Substance | Water | 0.05 m | 0.15 m | 0.3 m |
|-----------|-------|--------|--------|-------|
| $$V_f^0$$ | 111.73 | 112.05 | 112.29 | 112.57 |
| $$S_f$$ | 6.916 | 5.365 | 6.289 | 7.013 |
| ASV | 0.62 | 0.622 | 0.623 | 0.625 |
| $$\Delta_{tr}V_f^0$$ | -0.32 | 0.56 | 0.84 |

Table 5: 

$$V_f^0$$, 

$$S_f$$, 

ASV, 

$$\Delta_{tr}V_f^0$$ of D(+) maltose monohydrate in water and 

(0.05, 0.15, 0.3) mol.kg^{-1} Na-cyclamate at 

T = 298.15 K

| Substance | Water | 0.05 m | 0.15 m | 0.3 m |
|-----------|-------|--------|--------|-------|
| $$V_f^0$$ | 228.07 | 228.51 | 228.89 | 229.19 |
| $$S_f$$ | 8.133 | 7.91 | 7.423 | 6.572 |
| ASV | 0.633 | 0.634 | 0.635 | 0.636 |
| $$\Delta_{tr}V_f^0$$ | -0.44 | 0.44 | 0.82 | 1.12 |
–OH and –O– group of D(+) mannose and D(+) maltose monohydrate) and ions (Na+)/(cyclamate–) of Na-cyclamate. Prevalence of interaction between hydrophilic groups of sugars and ions of cosolute leads to dehydration of sugars.

At an infinite dilution when the \( V_f \) of sugar is equal to \( V_f^0 \) can be expressed using Shahidi’s equation as given below

\[
V_f^0 = V_{VW} + V_{void} - V_{shrinkage}
\]  

Where \( V_{VW} \) denotes the van der Waals volume, \( V_{void} \) represents empty volume and \( V_{shrinkage} \) is the shrinkage volume due to solute-water interactions. \( V_{shrinkage} \) arise due to hydrogen bonding between water molecule and hydroxyl group of sugars. The magnitude of \( V_{VW} \) and \( V_{void} \) are same in presence of water and aqueous electrolyte solutions. Thus the positive \( \Delta V_f \) is because of decrease in shrinkage volume which is further due to the reduced electrostriction of water in aqueous solutions of Na-cyclamate. Thus the positive \( \Delta V_f \) values depict the sugar dehydration in aqueous solutions of Na-cyclamate.

Equation (5) has been used for calculation of interaction parameters (\( V_{AB} \) (doublet) and \( V_{ABB} \) (triplet)) using \( \Delta V_f \) based on McMillan-Mayer theory of solutions,

\[
\Delta V_f = 2 V_{AB} M_b + 3 V_{ABB} M_b^2 +
\]

Where A symbolizes sugars (D(+) mannose and D(+) maltose monohydrate) and B symbolizes Na-cyclamate. By using least square method values of \( V_{AB} \) and \( V_{ABB} \) were calculated. The observed values of \( V_{AB} \) and \( V_{ABB} \) interaction parameters are reported in Table 6.

Table 6 : \( V_{AB} \) and \( V_{ABB} \) for D(+) mannose and D(+) maltose monohydrate at \( T = 298.15 K \)

|                      | D(+) mannose | D(+) maltose monohydrate |
|----------------------|--------------|--------------------------|
| \( V_{AB} \) \( \times 10^6 \) m\(^3\)mol\(^{-2}\)kg\(^{-1}\) | 2.634        | 3.921                    |
| \( V_{ABB} \) \( \times 10^6 \) m\(^3\)mol\(^{-2}\)kg\(^{-2}\) | -2.775       | -4.598                   |

The sign of magnitude of \( V_{AB} \) and \( V_{ABB} \) values predicts which kind of interactions occurring between sugars (D(+) mannose and D(+) maltose monohydrate) and Na-cyclamate. For all studied solutions positive \( V_{AB} \) values and negative \( V_{ABB} \) values suggest pairwise interactions. The positive values of \( V_{AB} \) have been interpreted by group additivity model. This model suggest four types of interaction occurs between the polar groups of sugars and ions of electrolyte as (Hydrophilic–ionic, hydrophobic–ionic, hydrophilic-hydrophilic interaction between polar group, and hydrophobic-hydrophobic interaction between non-polar groups).

According to structural interaction and hydration models, the positive contribution to \( V_{AB} \) is due to sugar-cation interaction. Thus positive values of \( V_{AB} \) for studied systems are contributed by interaction between polar (hydrophilic) groups of D(+) mannose and D(+) maltose monohydrate) and ions of Na-cyclamate.

The valuable information about quality of taste for studied solutions of D(+) mannose and D(+) maltose monohydrate in absence/presence of Na-cyclamate can be obtained from apparent specific volume (ASV). Values of ASV were calculated using equation

\[
ASV = \frac{V_f^0}{M}
\]

Apparent specific volume values estimate about the taste quality of sweeteners and distinguish them as sweet, salty, sour and bitter. The complete variety of human taste responsiveness is more or less narrowed to ASV between \( 0.1-0.9 \) m\(^3\) kg\(^{-1}\). ASV value range from \((0.51-0.71) \times 10^{-6} \) m\(^3\) kg\(^{-1}\) fit nicely for sweet taste molecules reported by Shamil et al., ASV value\(^{22} \) for perfect sweet taste obtained at middle of the range \( 0.618 \times 10^{-6} \) m\(^3\) kg\(^{-1}\).

Table 4 and Table 5 report observed values of ASV for (D+) mannose and D(+) maltose monohydrate) in water (0.05, 0.15, 0.3) mol.kg\(^{-1}\) of Na-Cyclamate at \( T = 298.15 K \), respectively. Experimentally observed ASV values for studied systems lies in the range from \((0.620-0.636) \times 10^{-6} \) m\(^3\) kg\(^{-1}\). Thus, studied all solutions show sweet taste. ASV values for D(+) mannose and D(+) maltose monohydrate increases with increase in concentration of Na-cyclamate. Fig. 4 shows the variations of ASV values for D(+) mannose and D(+) maltose monohydrate with molality of Na-cyclamate.
CONCLUSION

From measured density values volumetric parameters $V_0^0$, $S_n$, ASV, $\Delta_{tr}V_0$ and interaction parameters ($V_{AB}$ and $V_{ABB}$) have been calculated. The observed values reveal the following conclusions.

1. Observed positive values of $V_0^0$ specify strong sugar-water interactions in absence and presence of Na-cyclamate.
2. Prevalence of interactions between polar groups of D(+) mannose and D(+) maltose monohydrate and ions of Na-cyclamate suggested by positive values of $\Delta_{tr}V_0^0$ and $V_{AB}$.
3. ASV values for (D(+) mannose and D(+) maltose monohydrate) in water and in (0.05, 0.15, 0.3) mol.kg$^{-1}$ of Na-Cyclamate lies in range from $(0.620-0.636) \times 10^{-6}$ m$^3$.kg$^{-1}$. Hence studied combinations of aqueous solutions of (D(+) mannose and D(+) maltose monohydrate and Na-cyclamate under investigation show sweet taste.

ACKNOWLEDGEMENT

MDP sincerely thanks principal (HPT/RYK College, Nashik) for providing facilities to perform this research.

Conflict of interest

No conflict of interest

REFERENCES

1. Robert N. Goldberg and Yadu B. Tewari, J. Phys. Chem. Ref. Data., 1989, 18.
2. Schiffman, S. S.; Booth B. J., Brain Research Bulletin., 1995, 38(2),105. https://doi.org/10.1016/0361-9230(95)00062-J.
3. Alternative Sweeteners 3rd edition edited by Lyn O'Brien Nabors.
4. Kharat, S. J., J. Mol. Liqs., 2008, 140, 10-14. https://doi.org/10.1016/j.molliq.2007.12.006.
5. Kharat, S. J., Int. J. Thermophys., 2010, 31, 585-594. https://doi.org/10.1007/s10765-010-0736-6.
6. Kharat, S. J. Thermochimica Acta, 2013, 566, 124-129. https://doi.org/10.1016/j.tca.2013.05.030.
7. Kharat, S. J. Phys. Chem. Liqs., 2014, 52(1), 7-16.
8. Harned H.S., Owen B.B., The physical Chemistry of electrolytic solutions, ACS monograph No. 137 third ed., Reinhold publishing Corp., New York., 1958.
9. Kupke D.W., Physical principles and techniques of physical chemistry, Part C, Academic press, New York., 1973.
10. Herington E.G., Pure Appl. Chem.,1976, 45, 1-9.
11. Masson D O. Solute molecular volumes in relation to solvation and ionization. Philos Mag., 1929, 8, 218-235. https://doi.org/10.1080/14786440808564880.
12. Hedwig G. R., J. Solution Chem., 1988, 17, 383-397. https://doi.org/10.1007/s10765-010-0736-6.
13. Zielenkiewicz W.; Perlovich, G. L.; Nikitina G. E., and Semeykin A. S., J. Solution Chem., 1996, 25, 135-153. https://doi.org/10.1007/100972685.
14. A. F. Fucaloro.; Y. Pu.; K. Cha.; A. Williams.; K. Conrad, J Solution Chem., 2007, 36, 61-80. Doi: 10.1007/s10953-006-9100-7.
15. P. K. Banipal.; T. S. Banipal.; B. S. Lark.; J. C. Ahiuwalla., J. Chem. Soc., Faraday Trans., 1997, 93, 81-87.https://doi.org/10.1039/a 604656h.
16. P. K. Banipal.; A. K. Chahal.; T. S. Banipal, J. Chem. Thermodyn., 2009, 41, 452-483. https://doi.org/10.1016/j.jct.2008.11.009
17. R. V. Jasra.; J. C. Ahiuwalla.; J. Chem. Thermodyn., 1984, 16, 583–590. https://doi.org/10.1016/0021-9614(84)90010-7.
18. Dey P. C.; Motin M.A.; Biswas T K and Huque E. M., Monatshefte fur Chemie., 2003, 134, 797-809. https://doi.org/10.1007/s00706-002-0530-7.
19. T. S. Banipal.; Damanjit Kaur.; Gagandeep Singh.; B. S. Lark.; P. K. Banipal Indian Journal of Chemistry., 2002, 41A, 1131-1138.

20. Teychene J.; Balmann H.; Roux-De.; Galier S., Carbohydrate research., 2017, 448, 117-127. https://doi.org/10.1016/j.carres.2017.06.006.

21. F. Shahidi.; P. G. Ferrell.; J. T. Edwards, J. Solut. Chem., 1976, 5, 807-816. https://doi.org/10.1007/BF01167236

22. Kozak J. J.; Knight W.; Kauzman W.; Solute-solute interactions in aqueous solutions, J. Chem. Phys., 1968, 48, 675-690. https://doi.org/10.1063/1.1668700.

23. McMillan W.G., Mayer J.E, J.E. Mayer, J. Chem. Phys., 1945, 13, 276-305. https://doi.org/10.1063/1.1724036.

24. Franks F.; Pedley M.; Michael, D.S. Reid, J. Chem. Soc. Faraday Trans. I., 1976, 72, 359-367.https://doi.org/10.1039/f19767200359.

25. Friedman H.L.; Krishnan C.V.; Franks F,(Ed), Water: A Comprehensive Treatise, Plenum, New York., 1993, 3, Chapter 1.

26. Savage. J. J.; Wood, R., J. Sol. Chem., 1976, 5, 733-750.https://doi.org/10.1007/BF00643457.

27. Desnoyers J. E.; Joly M.; Perron G., and Jolicoeur C, J. Phys. Chem., 1969, 73, 3346. https://doi.org/10.1021/j100844a032.

28. Conway B. E., Ionic hydration in Chemistry and Physics, Elsevier, Amsterdam, The Netherlands., 1980.

29. Parke S.A.; Birch G.G.; Portman M. O.; David K., Food Chemistry., 1999, 67, 247-259.https://doi.org/10.1016/S0308-8146(99) 00125-9.

30. Birch G.; Parke S.; Siertsema R.; Westwell J.M., Pure Appl. Chem., 1997, 69, 685-692. https://doi.org/10.1351/pac199769040685

31. Shamil, S.; Birch, G. G.; Mathlouthi, M. and Clifford, M. N., Chem senses., 1987, 12, 397-409.

32. Birch G.G., Journal of pure and applied Chemistry, 2002, 74, 1103-1108. https://doi.org/10.1351/pac200274071103.