Introduction

Carbohydrates represent a very important class of compounds in biological systems and play a key role in many processes important to life[1-3]. Hydration of carbohydrates is an important point of research[4-5]. Spectroscopic parameters can be well determined using molecular modelling calculations. Molecular Mechanics (MM) can model very large compounds quickly[6]. Both Quantum Mechanics (QM) and (MM) are mixed to calculate several parameters for biological and many other systems[7-11]. The crystalline structures of α-D-Glucose, α-D-Glucose monohydrate and β-D-Glucose were studied by means of ab initio calculations[12]. The interaction between water and α/β-D-Glucose was studied by Density Functional Theory (DFT) B3LYP level[13]. Both α and β-D-Glucose anomers were studied in gas phase and solution form using both DFT and ab initio calculations [14]. In the same way, molecular dynamics (MD) study of 1,5 anhydro-D-Fructose in aqueous solution have been carried out[15]. High-level DFT methods were used to study the conformational preferences of the 4C1 and 1C4 chair conformations as well as boat and skew–boat conformations of α- and β-D-Mannopyranose[16]. Generally vibrational spectroscopic method of analyses were found useful to characterize carbohydrates. The Raman optical activity of D-fructose in aqueous solution were reported[17]. Both physicochemical properties and vibrational spectra of small carbohydrates was studied to asses the role of water in sweet-taste of carbohydrate. So that, D-Fructose in water and alkali solutions were studied using Raman spectroscopy in the OH
stretching region[18]. Sequential injection Fourier Transform Infrared (FTIR) spectroscopy is presented as a fully automated method for the rapid determination of Glucose, Fructose, and Sucrose in soft drinks[19]. FTIR was also used to study the adsorption of Glucose monomer on hematite and quartz. The common adsorption mechanism indicated is a surface reaction involving the iron ion[20]. Glucose among other carbohydrate molecules were linked to maleic anhydride functionalized polystyrene by polymer analogous reactions to produce biodegradable polymers. FTIR spectra confirmed the degradation of the polymer[21].

On the basis of the above considerations, the present study aims to use molecular modelling together with the experimental measurements to study the structure and vibrational spectra of two important biological molecules, Glucose and Fructose in their open chain, α-anomer and β-anomer monohydrate structures. Molecular modeling calculations were conducted using Semiempirical methods, AM1[22], PM3[22], PM5[23] and MINDO[24] as well as DFT method, Beck-Lee-Yang-Parr correlation functional, BLYP with the double zeta, DZVP basis set. For the DFT method, the vibrational spectra were performed after the harmonic approximation.

Results and Discussion

Optimized geometry: The calculations of geometry optimization locate the lowest energy molecular structure in close proximity to the specified starting structure[25-27]. The symmetry of the molecular structures as shown in Figure 1 corresponds to the C1 point group. The two studied molecules reveal that they both have the same chemical formula, which is C6H12O6. The open chain D-Glucose molecule in Figure 1-a starts with a CHO group bonded to four subsequent carbon atoms and each carbon atom carries a hydroxyl group and a hydrogen atom and the last carbon atom is bonded to methyl group CH2OH. Similarly the open chain D-Fructose can be described as in Figure 1-d. In contrast to D-Glucose the structure of the optimized D-Fructose contains 4 carbon atoms between two methyl groups CH2OH. The second carbon atom is bonded to an oxygen atom to form C=O while the rest of carbon atoms is carrying hydrogen atoms and hydroxyl groups. The flexibility of these open chain molecules together with the high reactivity of the CH2OH and CHO groups lead to an internal cyclizations, as the carbonyl groups reacts with one of the hydroxyl groups from the other end of the molecule. As shown in Figure 1-b, the resulting ring contains 5 carbon atoms and one oxygen atom. The closure of the linear molecules to make a ring creates a new chiral center at C1, called the anomeric carbon. When the hydroxyl group is attached to C1, the carbon atom next to the ring oxygen and which does not carry the methyl group is in an axial or equatorial position with respect to the ring, these anomers are called α and β.

Experimental

α-D-Glucose and β-D-Fructose were purchased from Aldrich (molecular weight for each is 180.16) and were used without further purification. The FTIR spectra were collected for these samples using Fourier Transform IR spectrometer Nexus 670, Nicolet, USA. The number of scans was 32 and the resolution was 4 cm⁻¹. All spectra were collected in the range (4000-400 cm⁻¹). The KBr technique was used to prepare the samples for IR measurements.

Calculation details

Calculations were carried out on a personal computer using quantum mechanical methods as implemented with the MOPAC 2002 Version 1.33
The bond distances C-C, C-H, O-H, C-O and C=O were calculated and presented in Tables 1 to 3. Regarding AM1, PM3, PM5 and MINDO results, there is a small variation in the calculated bond lengths as compared to BLYP/DZVP.

As can be seen in Table 3 the two molecules show comparable bond distances at the BLYP level of theory. The calculated bond lengths for D-Glucose are 1.537 Å, 1.120 Å, 0.984 Å, 1.455 Å and 1.235 Å for the bonds C-C of CH₂O, C-H, O-H, C-O and C=O respectively.

![Structure of a- D-Glucose, b- α-D-Glucose, c- β-D-Glucose, d- D- Fructose, e- α-D-Fructose and f- β-D-Fructose.](image)

**Figure 1.** Structure of a- D-Glucose, b- α-D-Glucose, c- β-D-Glucose, d- D- Fructose, e- α-D-Fructose and f- β-D- Fructose.

**Table 1.** Calculated bond lengths in angstroms for D-Glucose and α-D-Glucose, which were optimized at the semiempirical AM1, PM3, PM5, MINDO as well as Density Functional method BLYP/DZVP levels of theory.

<table>
<thead>
<tr>
<th>Bond</th>
<th>AM1</th>
<th>PM3</th>
<th>PM5</th>
<th>MINDO</th>
<th>BLYP</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-C (CH₂O)</td>
<td>1.513</td>
<td>1.532</td>
<td>1.531</td>
<td>1.539</td>
<td>1.554</td>
</tr>
<tr>
<td>C-C (Ring)</td>
<td>1.534</td>
<td>1.548</td>
<td>1.544</td>
<td>1.547</td>
<td>1.559</td>
</tr>
<tr>
<td>C-H</td>
<td>1.132</td>
<td>1.123</td>
<td>1.117</td>
<td>1.104</td>
<td>1.129</td>
</tr>
<tr>
<td>O-H</td>
<td>0.968</td>
<td>0.964</td>
<td>0.959</td>
<td>0.949</td>
<td>0.955</td>
</tr>
<tr>
<td>C-O</td>
<td>1.415</td>
<td>1.419</td>
<td>1.405</td>
<td>1.400</td>
<td>1.389</td>
</tr>
<tr>
<td>C=O</td>
<td>1.231</td>
<td>1.213</td>
<td>1.209</td>
<td>1.221</td>
<td>1.235</td>
</tr>
</tbody>
</table>

D: Open chain D-Glucose, α-D: α-anomer Glucose
Similarly the calculated distances for the same bonds for D-Fructose are 1.529 Å, 1.110 Å, 0.987 Å, 1.428 Å and 1.243 Å, respectively. Comparing between D-Glucose and D-Fructose structures one can observe a similarity in the calculated bond distances. As shown in Table 3 a slight change in the structure is noticed as a result of changing open chain into anomeric. Momany[13] studied the effect of hydration on the α-D Glucopyranose. It is stated that, although monohydrated β-D Glucopyranose has only one-water molecule good geometries are obtained for this structure. It is proposed that, both of α and β anomers can be studied in its monohydrate form. At this level of theory α-anomer monohydrate is unstable and no optimal structure is found. On the other hand, the optimum structure of β-anomer monohydrate has been found. As seen in Table 3, it is clear that solution phase is slightly lower than gas phase. It seems to be that the molecules in gas phase are rearranged so that their bonds are enlarged slightly as compared with monohydrate structure.

**Infrared spectra:** Assignments of infrared frequencies are achieved by comparing of the band positions and intensities observed in IR spectra with wavenumbers and intensities from molecular modeling calculations. As seen in Table 4 there are similarities in vibrational spectra of both D-glucose and D-Fructose. The spectra can be assigned generally as in the following: The OH vibrational stretching is calculated to be in the region 3876 to 3005 cm⁻¹, then the CH vibrations up to 2061 cm⁻¹. The
C=O stretching is calculated from 1849 to 1634 cm\(^{-1}\). A combination band of OCH and COH deformation is calculated from 1526 to 1347 cm\(^{-1}\). Then the in plane CH and OH deformation from 1362 to 1191 cm\(^{-1}\) can be observed. A band of CO and CC stretching is regarded from 1191 to 995 cm\(^{-1}\). The following spectra are assigned as CH deformation followed by CH2 vibration. As a general trend, Semiempirical methods AM1, PM3, PM5 and MINDO gave higher calculated frequencies as compared to scaled DFT method. This can be attributed to the effect of electron correlation, which is not included in semiempirical calculations.

To compare the calculated spectra with the experimental ones, FTIR Spectroscopy can be used to study the two molecules. Figure 2 shows the FTIR spectra of \(\alpha\)-D-Glucose and \(\beta\)-D-Fructose respectively. Table 5 shows the assignment of the main characteristic absorption bands for each of two molecules. The vibrational spectra that indicated in both Figure 2 and Table 5 can be classified into two main groups of spectra. The region from 600 to 1500 cm\(^{-1}\) in which C-O and C-C groups vibration modes are present and the carbohydrates generally shows their characteristic bands. On the other hand the bands from 2900 to 3450 cm\(^{-1}\) assigned to CH and OH vibrations groups. \(\alpha\)-D-anomer is tested with one water molecule (monohydrate form) and compared with both \(\beta\)-anomer as well as AM1                   PM3                  PM5                MINDO           BLYP/DZVP

<table>
<thead>
<tr>
<th></th>
<th>AM1</th>
<th>PM3</th>
<th>PM5</th>
<th>MINDO</th>
<th>BLYP/DZVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-G</td>
<td>3482</td>
<td>3500</td>
<td>3869</td>
<td>3876</td>
<td>-</td>
</tr>
<tr>
<td>D-F</td>
<td>3460</td>
<td>3458</td>
<td>3768</td>
<td>3830</td>
<td>-</td>
</tr>
<tr>
<td>D-G</td>
<td>3443</td>
<td>3020</td>
<td>3022</td>
<td>3020</td>
<td>3132</td>
</tr>
<tr>
<td>D-F</td>
<td>2061</td>
<td>2059</td>
<td>1965</td>
<td>1973</td>
<td>1849</td>
</tr>
<tr>
<td>D-G</td>
<td>1571</td>
<td>1577</td>
<td>1525</td>
<td>1460</td>
<td>-</td>
</tr>
<tr>
<td>D-F</td>
<td>1430</td>
<td>1513</td>
<td>1408</td>
<td>1428</td>
<td>-</td>
</tr>
<tr>
<td>D-G</td>
<td>1404</td>
<td>1444</td>
<td>1398</td>
<td>1406</td>
<td>1366</td>
</tr>
<tr>
<td>D-F</td>
<td>1372</td>
<td>1322</td>
<td>1362</td>
<td>1307</td>
<td>1319</td>
</tr>
<tr>
<td>D-G</td>
<td>1257</td>
<td>1300</td>
<td>1262</td>
<td>1268</td>
<td>1256</td>
</tr>
<tr>
<td>D-F</td>
<td>1207</td>
<td>1279</td>
<td>1225</td>
<td>1244</td>
<td>1217</td>
</tr>
<tr>
<td>D-G</td>
<td>1191</td>
<td>1161</td>
<td>1172</td>
<td>1227</td>
<td>1160</td>
</tr>
<tr>
<td>D-F</td>
<td>1123</td>
<td>1066</td>
<td>1111</td>
<td>1159</td>
<td>1095</td>
</tr>
<tr>
<td>D-G</td>
<td>1060</td>
<td>1015</td>
<td>1016</td>
<td>1085</td>
<td>1000</td>
</tr>
<tr>
<td>D-F</td>
<td>963</td>
<td>974</td>
<td>947</td>
<td>911</td>
<td>946</td>
</tr>
<tr>
<td>D-G</td>
<td>926</td>
<td>957</td>
<td>897</td>
<td>884</td>
<td>887</td>
</tr>
<tr>
<td>D-F</td>
<td>797</td>
<td>793</td>
<td>740</td>
<td>753</td>
<td>751</td>
</tr>
</tbody>
</table>

D-G: Open chain D-Glucose and D-F: Open chain D-Fructose.
experimental FTIR frequencies for α-D-anomer. It is worth to mention that, the β-D-anomer assignment is in a good agreement with that presented by Guo and Zhang[28]. Regarding the results of α-D-anomer, it is clear that the computed frequencies are in a good agreement with experimental ones except for CH and OH region. But there is agreement in the characteristic region of carbohydrate. In this region, there is a good correlation between both α and β anomer in one hand and the experimental frequencies on the other. The computed frequencies of α-anomer for both Glucose and Fructose are in a good agreement with experimental frequencies for both carbohydrate region as well as OH and CH region. Comparing computed and the experimental frequencies one can conclude that, accurate results could be achieved with scaled DFT method BLYP/DZVP with higher computation time as compared to semiempirical methods.

Conclusions

In the present study molecular models for two biological molecules, Glucose and Fructose are presented on the basis of Semiempirical and DFT calculations. The models present the structure and vibrational spectra for D-Glucose and D-
Fructose in their open chain, α-anomer and β-anomer monohydrate forms. The obtained result indicates that there are similarities in the structural and vibrational characteristic of both molecules. Although monohydrate α-anomer is not a complete hydration structure, its computed IR spectra is in a good agreement with experimental spectra for β-D-Fructose. In addition, the computed spectra for α-D-Glucose monohydrate are in a good agreement with experimental one in the characteristic region (600 – 1500 cm⁻¹) and far from it in the OH region. It can be concluded that with a comparable results and lower computation time, semiempirical method could be used to study carbohydrates such as Glucose and Fructose. On the other hand for accurate and precise structural and vibrational data DFT method could be used with a good agreement with experimental results.

Received 27 July 2006
Accepted 17 August 2006

References