Research Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2024.56.008794

From Cyclic Ribopyranose to Furfural-New Insight and New Concept

Iwan Iwanov[1]*, Nikolay Kaloyanov[1], Nikolay Lumov[2], Armen Sargsyan[3] and Mihail Neykov[1]

[1]*University of Chemical Technology and Metallurgy, Department of Organic Chemistry, Science and Research Unit, Bulgaria*

[2]*Institute of Organic Chemistry with Centre of Phytochemistry, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Building 9, 1113 Sofia, Bulgaria*

[3]*Scientific and Production Center "Armbiotechnology" NASRA, 14 Gyurjyan str., Yerevan 0056, Armenia*

***Corresponding author:** Iwan Iwanov, University of Chemical Technology and Metallurgy, Department of Organic Chemistry, Science and Research Unit, KL Ohridsky Boulevard 8, Sofia 1756, Bulgaria

ARTICLE INFO

Received: March 20, 2024

Published: April 12, 2024

Citation: Iwan Iwanov, Nikolay Kaloyanov, Nikolay Lumov, Armen Sargsyan and Mihail Neykov. From Cyclic Ribopyranose to Furfural-New Insight and New Concept. Biomed J Sci & Tech Res 56(1)-2024. BJSTR. MS.ID.008794.

ABSTRACT

Ribonucleic acid (RNA) is a molecule that is present in the majority of living organisms-plants and animals, and viruses. It is made up of nucleotides, which are ribose sugars attached to nitrogenous bases and phosphate groups. Three main types of RNA are involved in protein synthesis in plants and animals. They are messenger RNA (mRNA) in nucleus, transfer RNA (tRNA) in cytoplasm, and ribosomal RNA (rRNA) forming ribosomes, which are essential in protein synthesis. The free ribose is the main compound remaining after RNA biodegradation. What happens with ribose in plants as its amount is bigger than in animals due to more intensive gene expression corresponding to season change; we can investigate in laboratory conditions. The current Organic Chemistry lacks systematic ribopyranose-furfural transformation (10 steps), supported by any spectra analysis or computational calculation of charge distribution on the chain. Our idea is that first protonation and dehydratation will happen on the HO-group in cyclic ribopyranose, which forms the most stable carbocation after being deleted.

Keywords: Cyclic Ribopyranose; Full Mechanism; Induction Effect; IR Spectrum; Charge Calculation

Introduction

Ribose is a simple sugar with Chemical formula C5H10O5. The naturally occurring form, D- ribose, is a component of the ribonucleotides from which RNA is built, and so this compound is necessary for coding, decoding, regulation and expression of genes. L-ribose is an unnatural sugar that was first prepared by Emil Fischer and Oscar Piloty in 1891[1]. Like most sugars, ribose exists as a mixture from equal parts of cyclic forms and linear structure, especially in aqueous solution [2]. For D-ribose, we have five structures in water: open chain, α-D-ribopyranose, β-D-ribopyranose, α-D-ribofuranose, and β-D- ribofuranose. For L-ribose, we have open chain, α-L-ribopyranose, β-L-ribopyranose, α-L-ribofuranose, and β-L-ribofuranose in aqueous solution. Our team has decided to verify the ribopyranose-furfural transformation from 2016 [3] by investigation on ribopyranose carbocations, calculation of their positive charges, assessment of their stabilities and induction effect analysis on reaction steps.

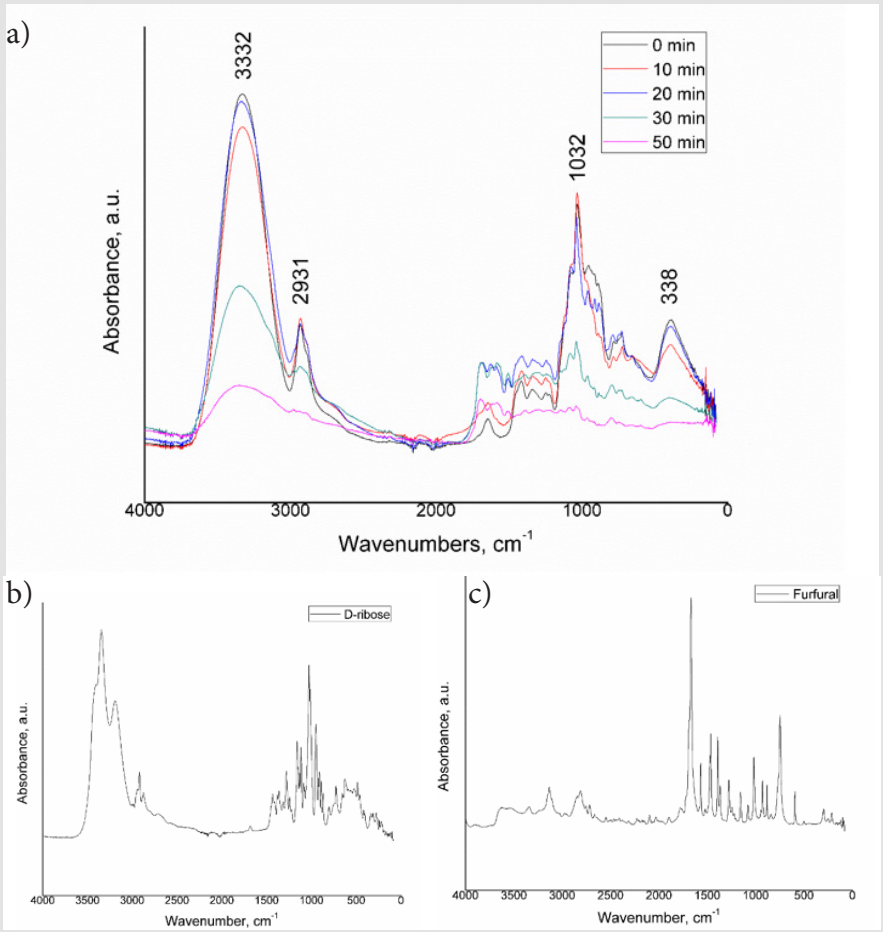
Materials and Methods

Infrared measurements. Attenuated Total Reflectance Fourier-Transform Infrared (ATR-FTIR) spectra of the D-ribose, furfural and the reaction products were measured on a Bruker Invenio R spectrometer, equipped with a diamond crystal ATR accessory at resolution 2 cm-1 accumulating 100 scans. Spectrum of air was used as a background. In order to measure the spectrum, the solid D-ribose was placed directly on the ATR crystal and pressed by a metal tip. The furfural was studied as a film on the surface of the ATR crystal, while the reaction products were deposited on glass plates, dried in desiccator and pressed to the surface of the ATR crystal in order to obtain the IR spectra. Computational details. The Gaussian 09 software [4]

was used to carry out density functional theory (DFT) calculations for molecular structure optimization and vibrational frequency analysis. The geometry of ribose and its carbocations, included several possible isomers, was optimized by applying the Becke's three-parameter hybrid functional (B3LYP) [5] in conjunction with 6-311++G(d,p) valence double-zeta polarized basis set [6,7]. The solvent (water) was acconted in the computations based on the IEF-PCM (Integral Equation Formalism Polarizable Continuum Model) solvation model implemented in the Gaussian 09 software package [8,9].

The optimized structures were confirmed as minima on the potential energy hypersurface by analytic vibrational frequency computations at the same level of theory. For all compounds and radicals, energy was minimized and the lowest energy structure was used in all calculations without any geometry or symmetry constraints. All calculations were performed using Gaussian 09 program package at the level of DFT/B3LYP with a basis set 6-31-G (d,p) [10] (Table 1). Cambridge Soft Chem 3D package of Chem Office 12 was used for calculation of charge distribution by Hűckel as well as for visualization of models. Infrared spectroscopy of the reaction products during the conversion of D-ribopyranose into furfural. The conversion of D-ribose into furfural was monitored by IR spectral study of the reaction products obtained at different stages of the reaction. The conversion was performed in solution by the procedure: 1g of D- ribose was dissolved in 15 ml mixture of conc HCl and water in portion 7/18. The reaction goes in four hours-1 hour at room temperature and 3 hours at 60 degrees Celsius at stirring. Small portions of the reaction mixture were taken at 10, 20, 30 and 50 min and deposited dropwise on glass plates. The films were dried in desiccator and then ATR-FTIR spectra were measured on a diamond ATR accessory. ATR- FTIR spectrum of the initial solution (0 min), containing only D-ribose, was measured as starting point and shown in Figure 1a, as it could be seen, corresponds over 80% to the pure D-ribose spectrum shown in Figure 1b.

Results



Note: In the course of the reaction, the intensity of the bands at 1646 cm-1 and 1032 cm^{-1} gradually decrease and some new bands appear: at 1694, 1625, 1583, and 1505 cm^{-1}.

Figure 1:

a) ATR-FTIR spectra of the reaction products obtained during the conversion of D-ribose into furfural in minutes 0-50.

b) ATR-FTIR spectra of D-ribose.

c) ATR-FTIR spectra of furfural.

 DOI: 10.26717/BJSTR.2024.56.008794

Table 1: Huckel charges of cyclic ribopyranose cations.

N	Atom	Atom Type	Charge (Huckel)
	Carbocation 1		
1	C(1)	C Alkane	0.214321
2	C(2)	C Alkane	0.199537
3	O(3)	O Ether	-0.39271
4	C(4)	C Alkane	0.490194
5	C(5)	C Alkane	0.229556
6	C(6)	C Carbocation	0.471362
7	O(7)	O Alcohol	-0.32844
8	O(8)	O Alcohol	-0.29453
9	O(9)	O Alcohol	-0.31777
10	H(10)	H	0.017107
11	H(11)	H	0.02987
12	H(12)	H	0.026331
13	H(13)	H	0.006068
14	H(14)	H	0.063773
15	H(15)	H	0.029561
16	H(16)	H Alcohol	0.184841
17	H(17)	H Alcohol	0.18676
18	H(18)	H Alcohol	0.184167
	Carbocation 2		
19	C(1)	C Alkane	0.193329
20	C(2)	C Alkane	0.108014
21	O(3)	O Ether	-0.35257
22	C(4)	C Alkane	0.384965
23	C(5)	C Carbocation	0.677648
24	C(6)	C Alkane	0.192102
25	O(7)	O Alcohol	-0.29211
26	O(8)	O Alcohol	-0.34058
27	O(9)	O Alcohol	-0.26266
28	H(10)	H	0.013275
29	H(11)	H	0.023509
30	H(12)	H	0.023185
31	H(13)	H	0.032645
32	H(14)	H	0.030813
33	H(15)	H	0.012981
34	H(16)	H Alcohol	0.186829
35	H(17)	H Alcohol	0.184784
36	H(18)	H Alcohol	0.183838
	Carbocation 3		
37	C(1)	C Carbocation	0.580152
38	C(2)	C Alkane	0.162539
39	O(3)	O Ether	-0.33759
40	C(4)	C Alkane	0.361003
41	C(5)	C Alkane	0.187533

42	C(6)	C Alkane	0.229413
43	O(7)	O Alcohol	-0.33495
44	O(8)	O Alcohol	-0.34749
45	O(9)	O Alcohol	-0.32136
46	H(10)	H	0.032333
47	H(11)	H	0.060708
48	H(12)	H	0.079217
49	H(13)	H	-0.00211
50	H(14)	H	0.010774
51	H(15)	H	0.078497
52	H(16)	H Alcohol	0.187755
53	H(17)	H Alcohol	0.188454
54	H(18)	H Alcohol	0.185114
	Carbocation 4		
55	C(1)	C Alkane	0.162708
56	C(2)	C Alkane	0.147044
57	O(3)	O Ether	-0.12745
58	C(4)	C Carbocation	0.634201
59	C(5)	C Alkane	0.207333
60	C(6)	C Alkane	0.257579
61	O(7)	O Alcohol	-0.32392
62	O(8)	O Alcohol	-0.34572
63	O(9)	O Alcohol	-0.33476
64	H(10)	H	0.016791
65	H(11)	H	0.026551
66	H(12)	H	0.026417
67	H(13)	H	0.025989
68	H(14)	H	0.064977
69	H(15)	H	0.009363
70	H(16)	H Alcohol	0.183392
71	H(17)	H Alcohol	0.184005
72	H(18)	H Alcohol	0.185494

Discussion

Only in carbocation 1 we have two carbon atoms on both sides of the positive charge (denoted as 1-2 and 1'-2'), which implies the highest stability, confirmed by the lowest positive charge on deleted HO-group of carbocation 1. Cyclic ribopyranose transformation to furfural is going in 10 steps as presented in Figure 2.

- Steps 1,2: Protonation of the hydroxyl group corresponding to carbocation 1 and release of a water molecule. Step 3: Catalyst deprotonation and recovery. Here a hydrogen proton can be released from both sides of the positive charge: from C2 or from C4. Because of the strong positive induction effect of the methylene group, it serves as a conductor for withdrawing electron density from neighboring atoms or groups of atoms. Therefore, the O-atom of the pyran ring withdraws more electron density from C4 compared to C2, and accordingly, the H-atom at C4 is more mobile and more easily cleaved.
- Steps 4,5: Protonation of the hydroxyl group at C2 as it is closer to the double bond, which is highly electrophilic and release of a water molecule.
- Step 6. Catalyst deprotonation and recovery. Here there are three possibilities for releasing a hydrogen proton: from C1, from C3 or form C5. Because of its sp2-hybrid state, C-H bond at C3=C4 double bond is the strongest of all C-H bonds in the pyran ring and the H atom at C3 is strongly bonded and cannot be easily cleaved. The other two possibilities are C1 or C5, which are adjacent to the pyran O-atom, but C5 is closer to the most electronegative element in the pyran ring, which

is the double bond at C3=C4. Therefore the two H-atoms at C4 are more mobile than the H-atom at C3 and one of them is released as a proton. At the same time, the ring opens forming a di-hydroxy aldehyde.

- Step 7: Protonation of the HO-group at C4.
- Step 8: Dehydration.
- Step 9: Intramolecular nucleophilic attack of HO-group (the only one after dehydration three times) to positive charge and formation of furfural ring.
- Step 10: Deprotonation and turning back the final catalyst.

Conclusion

The lowest charge on C-6 of Carbocation-1 indicates the highest charge distribution along the chain and the highest stability of Carbocation-1 Figure 2. After first deprotonation on C-6 and Carbocation-1 appearance, we have a completely new chemical structure and we can suppose what happens next as presented in Figure 3.

Acknowledgements

No.

Conflict of Interest

No.

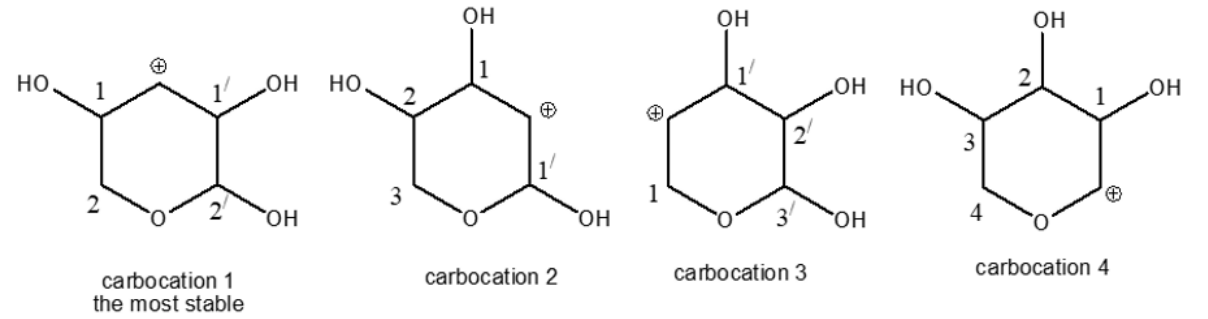


Figure 2: Carbocations of cyclic ribopyranose.

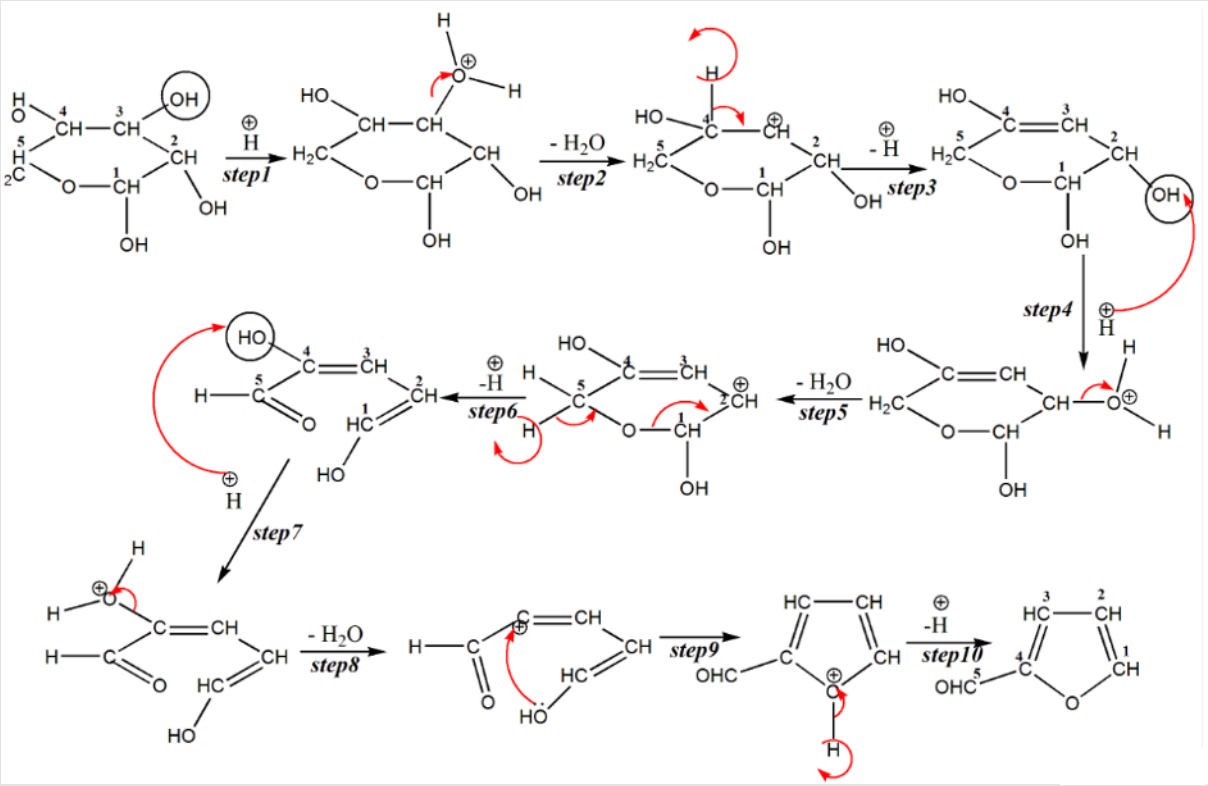


Figure 3: Ribopyranose reaction.

References

1. Fischer, Emil Piloty, Oscar (1891) "Ueber eine neue Pentonsäure und die zweite inactive Trioxyglutarsäure" (About a new pentonic acid and the second inactive trioxyglutaric acid]). Berichte der deutschen chemischen Gesellschaft (in German) 24(2): 4214-4225.
2. Bhutani S P (2019) "Aldopentoses—The Sugars of Nucleic Acids". Chemistry of Biomolecules (2nd Edn.)., CRC Press, p. 63-65.
3. Prasenjit Bhaumik, Paresh Laxmikant Dhepe (2016) Solid acid catalyzed synthesis of furans from carbohydrates. Catalysis Reviews 58(1): 36-112.
4. M Frisch, G Trucks, H Schlegel, G Scuseria, M Robb, et al. (2009) Gaussian 09, Revision A.1, Gaussian Inc., Wallingford CT.
5. Becke A D (1993) Density-functional thermochemistry. III. The role of exact exchange. The Journal of Chemical Physics 98: 5648-5652.
6. Hehre W J, Ditchfield R, Pople J A (1972) Self-Consistent Molecular Orbital Methods. XII. Further Extensions of Gaussian—Type Basis Sets for Use in Molecular Orbital Studies of Organic Molecules. The Journal of Chemical Physics 56: 2257-2261.
7. Clark T, Chandrasekhar J, Spitznagel G W, Schleyer P V R (1983) Efficient diffuse function-augmented basis sets for anion calculations. III.† The 3-21+G basis set for first-row elements, Li–F. Journal of Computational Chemistry 4: 294-301.
8. T Brinck, M Haeberlein, M Jonsson (1997) A Computational Analysis of Substituent Effects on the O−H Bond Dissociation Energy in Phenols: Polar Versus Radical Effects. J Am Chem Soc 19: 4239-4244.
9. J Tomasi, B Mennucci, E Cances (1999) The IEF version of the PCM solvation method: an overview of a new method addressed to study molecular solutes at the QM ab initio level. J Mol Struct (Theochem) 464: 211-226.
10. Ali H M, Ali I H (2017) A DFT and QSAR study of the role of hydroxyl group, charge and unpaired-electron distribution in anthocyanidin radical stabilization and antioxidant activity. Med Chem Res 26: 2666-2674.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2024.56.008794

Iwan Iwanov. Biomed J Sci & Tech Res

Submission Link: https://biomedres.us/submit-manuscript.php