Supporting Information

Facile and Benign Conversion of Sucrose to Fructose
Using Zeolites With Balanced Brønsted and Lewis Acidity

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Catalyst characterization

X-Ray Powder Diffraction (XRPD)

H-USY (6) and (30), H-Beta (12.5) and Sn-DeAl-Beta zeolites were analyzed by powder X-ray diffraction using a Huber G670 imaging-plate Guinier powder diffraction camera using CuK$_\alpha$ radiation at a wavelength of 0.15406. The X-ray diffractograms of the samples were recorded in the 2$\theta$ range of 3 to 80$^\circ$ at a rate of 1.5 $^\circ$/min and the results are shown in Figures S1 and S2 below.

![Figure S1. The powder XRD patterns of H-Beta (12.5) and modified H-Beta zeolites.](image1)

![Figure S2. The powder XRD patterns of USY zeolites.](image2)
Ammonia-Temperature Programmed Desorption (NH$_3$-TPD)

The weak/medium/strong acid sites present in Beta, modified Beta and USY zeolites were measured by NH$_3$-TPD using an AutoChem II 2920 Chemisorption Analyzer from Micromeritics. About 100 mg sample was placed in U-tubes made up of quartz and treated at 500 °C for 1 h under helium (99.999%, AGA) with a flow rate of 50 mL/min, then cooled down to 100 °C. Ammonia (1% in He, AGA) with a flow rate of 50 mL/min was then passed through to the sample holder for 2 h. In order to remove any physisorbed ammonia, the samples were flushed with He (50 mL/min) prior to the measurement. Ammonia desorption was carried out and measured every second from 100 to 500 °C at a ramp of 10 °C/min, and the number of available acid sites was calculated based on the area under the desorption curve. The amounts of weak/medium (acid type 1) (desorption approx. between 100-270 °C) and strong acid sites (acid type 2) (desorption approx. between 270-500 °C) were calculated from the desorption area under the curve (Figure S3).

![NH$_3$-TPD profiles of Beta and USY zeolites](image)

Figure S3. NH$_3$-TPD profiles of Beta and USY zeolites

Nitrogen-sorption measurement

Brunauer-Emmet-Teller (BET) surface area and pore volume were analyzed by nitrogen adsorption and desorption measurements using a Micromeritics ASAP 2020 Surface Area and Porosity Analyzer system at liquid nitrogen temperature. The sample was degassed at 300 °C overnight prior to the measurement, except for the acid-dealuminated Beta zeolite (DeAl-Beta) that was degassed at 90 °C.
Physicochemical properties of the zeolites described herein are compiled in Table S1 below.

Table S1. Physicochemical properties and composition of USY and Beta zeolites

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Acid sites type 1 (100-270 °C) (µmol/g)</th>
<th>Acid sites type 2 (270-500 °C) (µmol/g)</th>
<th>Total acid sites (µmol/g)</th>
<th>BET area (m²/g)</th>
<th>Pore volume (cm³/g)</th>
<th>Si/Al²</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-USY (6)</td>
<td>488</td>
<td>539</td>
<td>1027</td>
<td>708</td>
<td>0.2436</td>
<td>6.5</td>
</tr>
<tr>
<td>H-USY(30)</td>
<td>140</td>
<td>226</td>
<td>366</td>
<td>792</td>
<td>0.2504</td>
<td>29.7</td>
</tr>
<tr>
<td>H-Beta(12.5)</td>
<td>693</td>
<td>395</td>
<td>1088</td>
<td>579</td>
<td>0.1631</td>
<td>12.5</td>
</tr>
<tr>
<td>DeAl-Beta²</td>
<td>28</td>
<td>91</td>
<td>119</td>
<td>526</td>
<td>0.1492</td>
<td>145</td>
</tr>
<tr>
<td>Sn-DeAl-Beta³</td>
<td>196</td>
<td>95</td>
<td>291</td>
<td>506</td>
<td>0.1767</td>
<td>144⁴</td>
</tr>
<tr>
<td>Amberlyst-36⁵</td>
<td>-</td>
<td>-</td>
<td>&gt;5400</td>
<td>33</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

¹Determined using Panalytical Epsilon-3 X-ray Fluorescence Spectrometer.
²Nitric acid dealuminated H-Beta(12.5).
³Nitric acid dealuminated H-Beta(12.5) and washed with distilled water.
⁴Si/Sn ratio of 15.6.
⁵from Sigma-Aldrich

Catalyst reuse sequence

Figure S4. Catalyst reusability for H-USY (6). Reusability was assessed at elevated temperature (120 °C) relative to optimized conditions.

SEM pictures of catalysts
Figure S5. Scanning Electron Microscope images recorded on a FEI Quanta 200 ESEM FEG instrument of a) H-USY (6), b) Sn-DeAl-Beta (12.5), c) H-Beta (12.5), d) DeAl-Beta (Nitric acid dealuminated) and e) DeAl-Beta (steamed).
Conversion to rare functional tautomers

Figure S6. ¹H-¹³C HSQC NMR spectra of a reaction mixture obtained by subjecting galactose to Sn-DeAl-Beta catalysed reaction at 100 °C (4 g methanol, 75 mg of catalyst and 125 mg galactose) for 2 hours. The reaction yields 61% methyl-tagatoside, 2% tagatose, 5% galactose and 23% methyl-galactoside. Reference spectra for methyl-tagatoside (middle and grey outline in the left panel), galactose and methyl-galactoside are shown.