

## Electronic supplementary information

### **Solid acid catalysed one-pot selective approach for 2,5-diformylfuran synthesis from fructose/carbohydrate feedstocks**

Arvind Singh Chauhan,<sup>a,b</sup> Ajay Kumar,<sup>a,b</sup> Rohit Bains<sup>a,b</sup> and Pralay Das<sup>\*a,b</sup>

<sup>a</sup>Chemical Technology Division, CSIR-Institute of Himalayan Bioresource Technology, Palampur-176061, H.P., India, Fax: +91-1894-230433, \*E-mail: pdas@ihbt.res.in, [pralaydas1976@gmail.com](mailto:pralaydas1976@gmail.com).

<sup>b</sup>Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002, India.

## Table of contents

1. List of abbreviations.....	S3
2. Procedures.....	S4-S7
2A) 100 mg scale reaction of fructose for DFF synthesis.	
2B) 1 gram scale of various feedstock for DFF synthesis.	
2B) 20.0 gram scale up synthesis of DFF from fructose.	
2C) Synthesis of MSMFC intermediate	
3. NMR, GC-MS and UPLC spectra of products.....	S8-S13
4. FTIR of Amberlite IR 120 H .....	S14
5. Reference.....	S14

**1. List of abbreviations:**

**5-HMF:** 5-hydroxymethylfurfural

**DFP:** Diformylfuran

**MSMFC:** 5-methylsulfanylmethyl-furan-2-carbaldehyde

**NMR:** Nuclear magnetic resonance

**GC-MS:** Gas chromatography-Mass spectrophotometry

**UPLC:** Ultra performance liquid chromatography

## 2. Procedures:

All chemicals and solvents used in the present process were of analytical grade and used without any further purification: Fructose (Sigma, Avra, 98% pure), 2,5-diformylfuran (DFF, 96.5% pure), CuBr (Sigma Aldrich, Avra, 98% pure), Amberlite IR 120 H<sup>+</sup> form resin (Sigma, Merck),<sup>1</sup> KBr (Lobachemie, 98.5% pure), NaBr (Rankem, 98% pure), LiBr (Avra, 99% pure), HBr (48% pure), PTSA.H<sub>2</sub>O (98% pure), DMSO (SD Fine chemical ltd. 99.5% pure) and Xylene (99.5% pure), Dimethylacetamide (99.5% pure), Dimethylformamide (99.5% pure) (CDH) were purchased and used without further purification. The sugarcane molasses was purchased from sugar mill. Table sugar and jaggery were purchased from local shop and used directly. NMR were acquired on Bruker Advance 300 & 600 MHz (<sup>1</sup>H) and 151 MHz (<sup>13</sup>C). Spectra were recorded at 25 °C in CDCl<sub>3</sub> [residual CHCl<sub>3</sub> (δH 7.28 ppm) or CDCl<sub>3</sub> δC 77.00 ppm]. Chemical shifts were recorded in δ (ppm) relative to the TMS and NMR solvent signal. Coupling constants (*J*) are given in Hz and multiplicities of signals are reported as follows: s, singlet; d, doublet; m, multiplet. GCMS analysis was carried out on a Shimadzu (QP 2010) series GC-MS (Tokyo, Japan), equipped with a FID, AOC 5000 autosampler, DB-5MS capillary column (30 m × 0.25 mm i.e. with film thickness 0.25 μm). UV-vis spectra were recorded by using Thermo Scientific Genesys 180 UV-vis spectrometer. The UPLC purity experiment was performed by using Water made Acquity UPLC<sup>®</sup> H Class with PDA detector. The FTIR spectra were recorded using F.T. Infra-Red Spectrometer model RZX (Perkin Elmer). The purification of the compounds was performed through Flash Chromatography made Biotage, Isolera one.

**2A) 100 mg reaction of fructose to synthesize DFF:** In a neat and clean reaction vial (5 mL), fructose (1.0 equiv., 100 mg), KBr (0.5 equiv., 33.0 mg) and Amberlite IR 120 H (25 wt%, 25.0 mg) were mixed in DMSO (1.5 mL). After addition, the reaction vial was closed by tightening with PTFE cap. The reaction vial was heated and stirred at 120 °C for 12 hr. After completion of the reaction, the mixture was quenched by adding chilled water. The extraction of the compound was done by simple solvent extraction technique through ethyl acetate:diethyl ether (2:8) for three times. The extracted organic layer was further passed through a bed of sodium sulphate to remove traces of water. Finally, the organic layer was dried carefully under reduced pressure in rotavapor and the reaction crude was purified through silica gel (60-120 mesh size) column/flash chromatography using ethyl acetate:hexane (10:90) as the eluent, followed by drying and lyophilization of the product.

A off white/light yellowish DFF was obtained in 80% yield (55 mg). The final product was further analysed by NMR and GC-MS.  $^1\text{H NMR}$  (600 MHz,  $\text{CDCl}_3$ ):  $\delta$  9.87 (s, 2H), 7.36 (s, 2H);  $^{13}\text{C NMR}$  (151 MHz,  $\text{CDCl}_3$ ):  $\delta$  179.25, 154.20, 119.33; GC-MS  $[\text{M}]^+$  124.

## **2B) 1 gram scale of various feedstock for DFF synthesis:**

**a) 1 gram scale up of DFF synthesis from table sugar:** In a 100 mL round bottom flask, table sugar (1.0 equiv., 1.0 gram), KBr (0.5 equiv., 0.33 gram) and Amberlite IR 120 H (25 wt%, 0.25 gram) were mixed in DMSO (8 mL). The flask was heated and stirred at 120 °C under reflux for 12 hr. Further the progress of the reaction was monitored by TLC. After completion of reaction, the mixture was quenched by adding chilled water. The extraction of the compound was done by simple solvent extraction technique through ethyl acetate:diethyl ether (2:8) for three times. The extracted organic layer was further passed through a bed of sodium sulphate to remove traces of water. Finally, the organic layer was dried carefully under reduced pressure in rotavapor and the reaction crude was purified through silica gel (60-120 mesh size) column/flash chromatography using ethyl acetate:hexane (10:90) as the eluent, followed by drying and lyophilization of the product. A off white/light yellowish DFF was obtained in 73% molar yield (25 wt% yield) (251 mg) (the molar yield was calculated on the basis of fructose content present in table sugar). The final product was further analysed by NMR and GC-MS.  $^1\text{H NMR}$  (600 MHz,  $\text{CDCl}_3$ ):  $\delta$  9.87 (s, 2H), 7.36 (s, 2H);  $^{13}\text{C NMR}$  (151 MHz,  $\text{CDCl}_3$ ):  $\delta$  179.25, 154.20, 119.33; GC-MS  $[\text{M}]^+$  124.

**b) 1 gram scale up of DFF synthesis from sugarcane molasses:** In a 100 mL round bottom flask, sugarcane molasses (1.0 equiv., 1.0 gram), KBr (0.5 equiv., 0.33 gram) and Amberlite IR 120 H (25 wt%, 0.25 gram) were mixed in DMSO (8 mL). The flask was heated and stirred at 120 °C under reflux for 12 hr. Further the progress of the reaction was monitored by TLC. After completion of reaction, the mixture was quenched by adding chilled water. The extraction of the compound was done by simple solvent extraction technique through ethyl acetate: diethyl ether (2:8) for three times. The extracted organic layer was further passed through a bed of sodium sulphate to remove traces of water. Finally, the organic layer was dried carefully under reduced pressure in rotavapor and the reaction crude was purified through silica gel (60-120

mesh size) column/flash chromatography using ethyl acetate:hexane (10:90) as the eluent, followed by drying and lyophilization of the product. A off white/light yellowish DFF was obtained in 20 wt% yield (200 mg). The final product was further analysed by NMR and GC-MS. **<sup>1</sup>H NMR** (600 MHz, CDCl<sub>3</sub>): δ 9.87 (s, 2H), 7.36 (s, 2H); **<sup>13</sup>C NMR** (151 MHz, CDCl<sub>3</sub>): δ 179.25, 154.20, 119.33; GC-MS [M]<sup>+</sup> 124.

**c) 1 gram scale up of DFF synthesis from jaggery:** In a 100 mL round bottom flask, jaggery (1.0 equiv., 1.0 gram), KBr (0.5 equiv., 0.33 gram) and Amberlite IR 120 H (25 wt%, 0.25 gram) were mixed in DMSO (8 mL). The flask was heated and stirred at 120 °C under reflux for 12 hr. Further the progress of the reaction was monitored by TLC. After completion of reaction, the mixture was quenched by adding chilled water. The extraction of the compound was done by simple solvent extraction technique through ethyl acetate:diethyl ether (2:8) for three times. The extracted organic layer was further passed through a bed of sodium sulphate to remove traces of water. Finally, the organic layer was dried carefully under reduced pressure in rotavapor and the reaction crude was purified through silica gel (60-120 mesh size) column/flash chromatography using ethyl acetate:hexane (10:90) as the eluent, followed by drying and lyophilization of the product. A off white/light yellowish DFF was obtained in 25 wt% yield (250 mg). The final product was further analysed by NMR and GC-MS. **<sup>1</sup>H NMR** (600 MHz, CDCl<sub>3</sub>): δ 9.87 (s, 2H), 7.36 (s, 2H); **<sup>13</sup>C NMR** (151 MHz, CDCl<sub>3</sub>): δ 179.25, 154.20, 119.33; GC-MS [M]<sup>+</sup> 124.

### **2C) 20.0 gram scale up synthesis of DFF from fructose:**

In a 500 mL round bottom flask, fructose (1.0 equiv., 20.0 gram), KBr (0.5 equiv., 6.6 gram) and Amberlite IR 120 H (25 wt%, 5.0 gram) were mixed in DMSO (160 mL). The flask was subjected for heating and stirring at 120 °C under reflux for 12 hr. After specified time, the reaction was monitored by TLC. After completion of reaction, the mixture was quenched by adding chilled water in the reaction flask. To extract the product from the aqueous DMSO, we used ethyl acetate:diethyl ether (2:10) solvent system. After extraction, the organic layer was passed through a bed of sodium sulphate to remove any trace amount of water followed by drying the organic layer under rotavapor to get pure DFF (73%, 10.0 gram) without any further

purification by column chromatography.  $^1\text{H NMR}$  (600 MHz,  $\text{CDCl}_3$ ):  $\delta$  9.87 (s, 2H), 7.36 (s, 2H);  $^{13}\text{C NMR}$  (151 MHz,  $\text{CDCl}_3$ ):  $\delta$  179.25, 154.20, 119.33; GC-MS  $[\text{M}]^+$  124.

### 2C) Synthesis of MSMFC intermediate:

In a 100 mL round bottom flask, fructose (1.0 gram), KBr (0.33 gram) and Amberlite IR 120 H (0.25 gram) were mixed in DMSO (8 mL). The flask was heated and stirred at 120 °C under reflux for 4 hr. Further the progress of the reaction was monitored by TLC. After completion of reaction, the mixture was quenched by adding chilled water. The extraction of the compound was done by simple solvent extraction technique through ethyl acetate:diethyl ether (2:8) for three times. The extracted organic layer was further passed through a bed of sodium sulphate to remove traces of water. Finally, the organic layer was dried carefully under reduced pressure in rotavapor subsequently the reaction crude was purified by silica gel (mesh size 60-120) chromatography using ethyl acetate:hexane (05:95) as the eluent, to afford the desired MSMFC. Yellow liquid (45%, 388 mg). The final product was further analysed by NMR and GC-MS.  $^1\text{H NMR}$  (600 MHz,  $\text{CDCl}_3$ ):  $\delta$  9.49 (s, 1H), 7.16 (d,  $J = 3.5$ , 1H), 6.39 (d,  $J = 3.5$ , 1H), 3.66 (s, 2H), 2.05 (s, 3H);  $^{13}\text{C NMR}$  (151 MHz,  $\text{CDCl}_3$ ):  $\delta$  177.20, 159.20, 152.28, 122.90, 110.28, 30.24, 15.68; GC-MS  $[\text{M}]^+$  156.



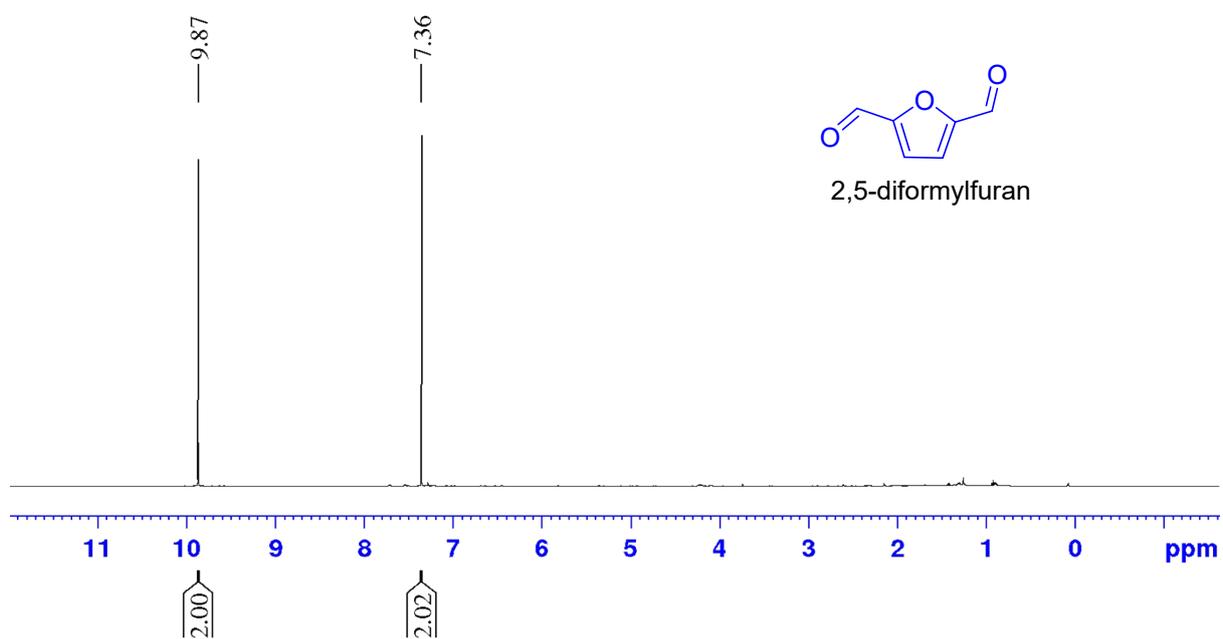
a)



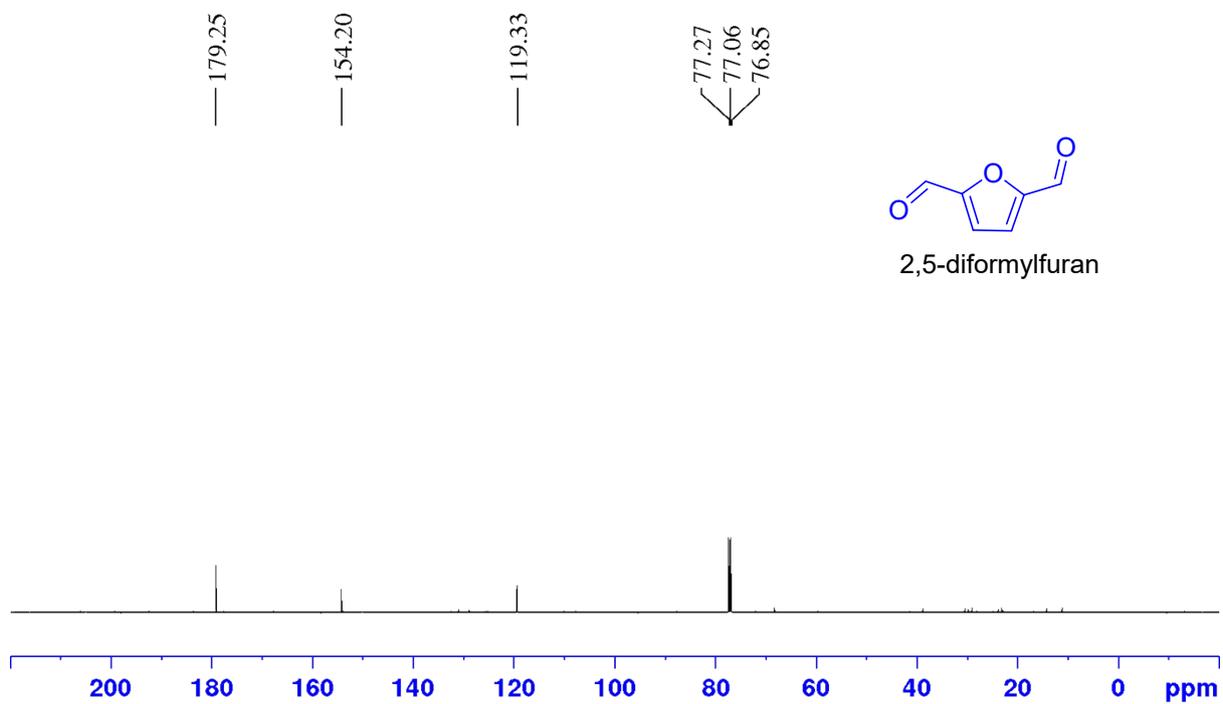
b)

**Figure S1. Synthesis of DFF from fructose:** Photos of reaction vial after completion of reaction; a) standard reaction with Amberlite IR 120 H, *no humin formation* b) standard reaction with PTSA.H<sub>2</sub>O, *humin formation*.

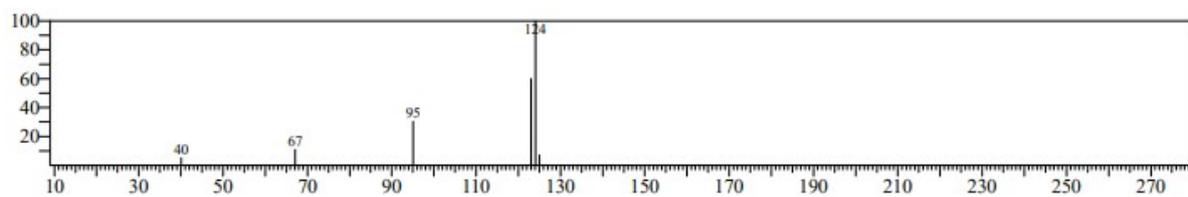
### 3. NMR and GC-MS spectra of products:



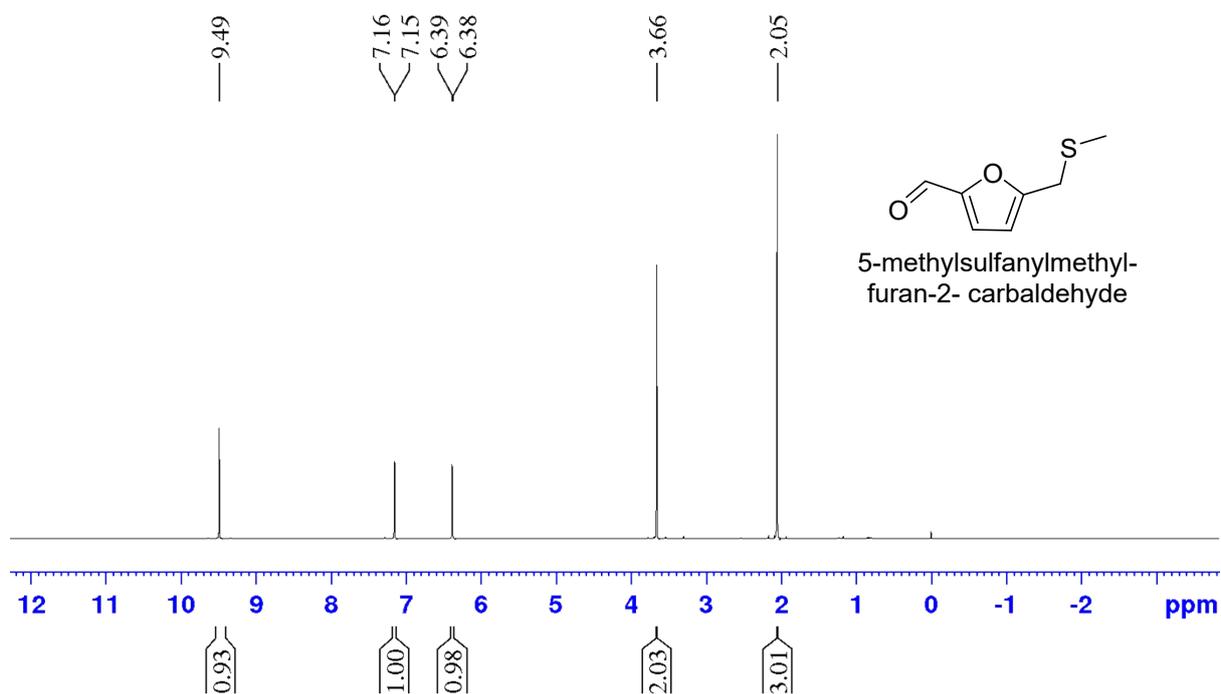
Spectrum S1.  $^1\text{H}$  NMR of DFF.



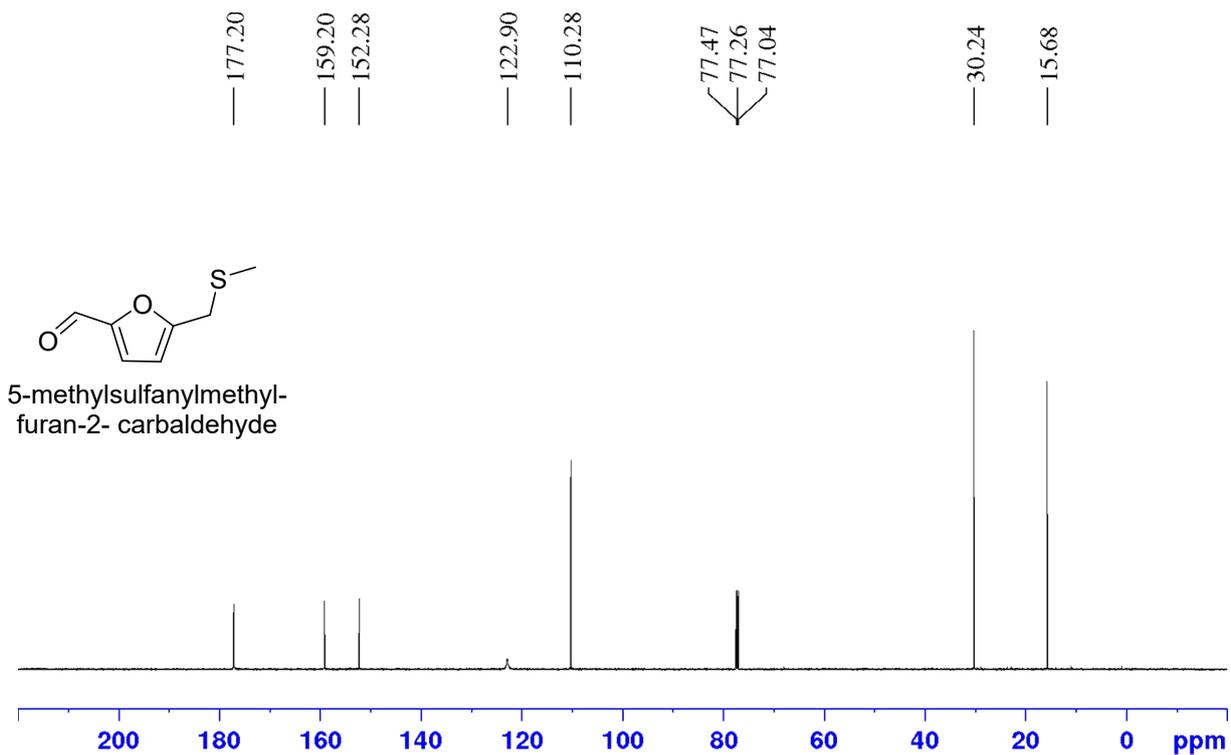
Spectrum S2.  $^{13}\text{C}$  NMR of DFF.



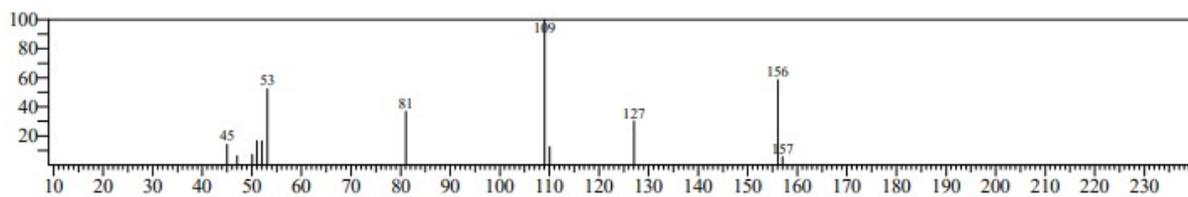
**Spectrum S3.** GC-MS of DFF.



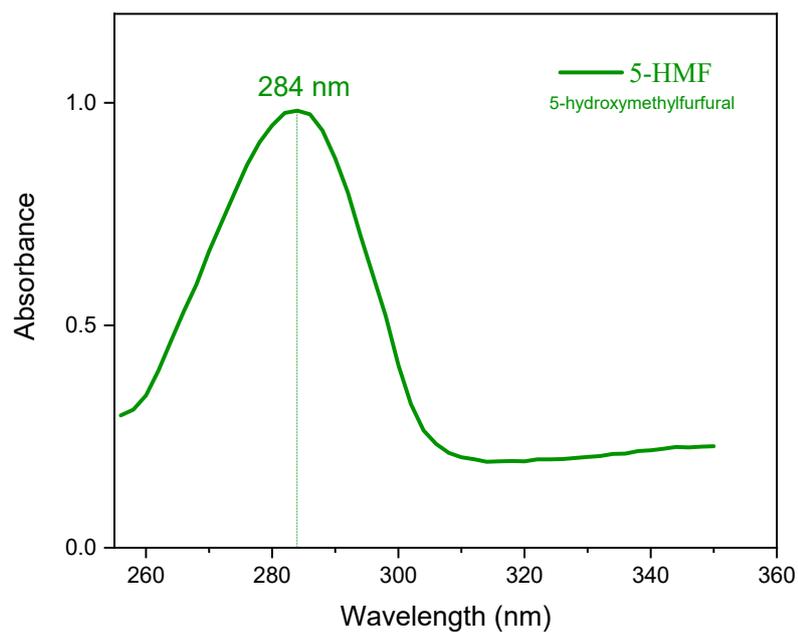
**Spectrum S4.** <sup>1</sup>H NMR of MSMFC.



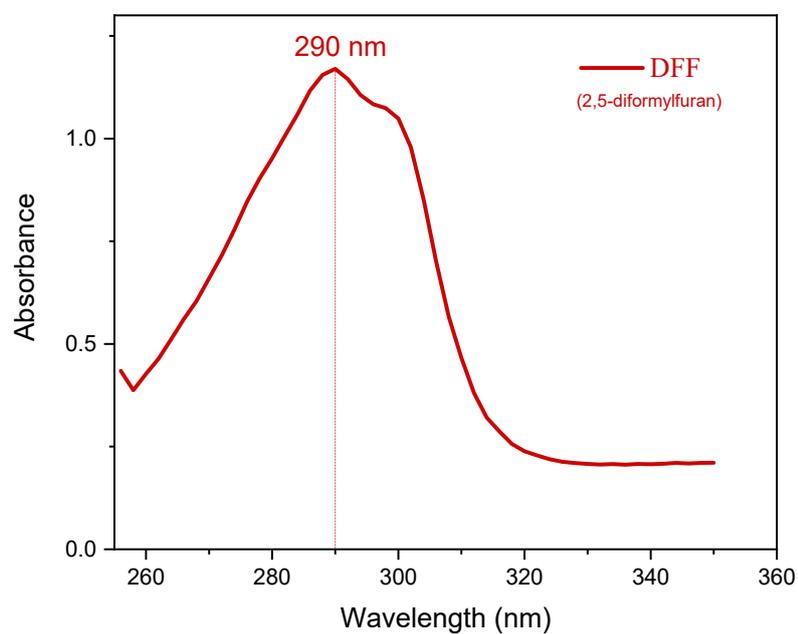
**Spectrum S5.**  $^{13}\text{C}$  NMR of MSMFC.



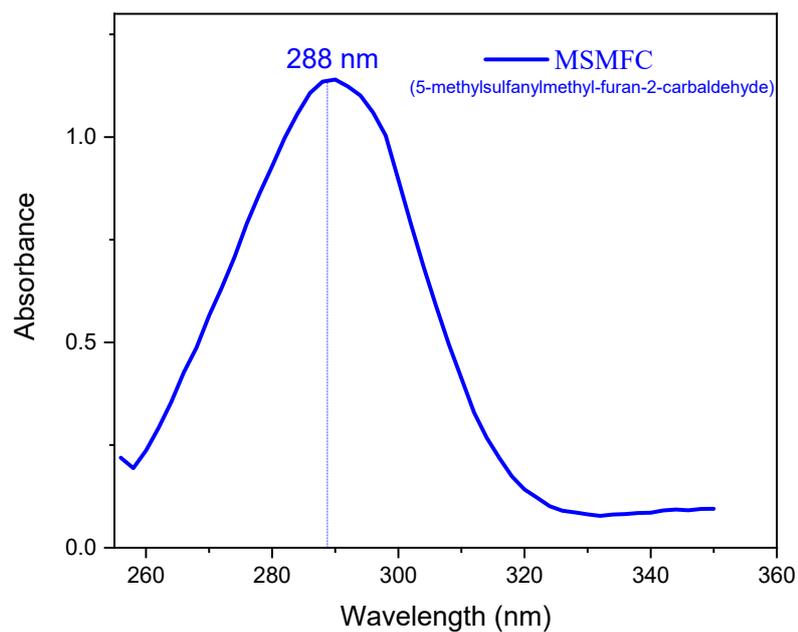
**Spectrum S6.** GC-MS of MSMFC.



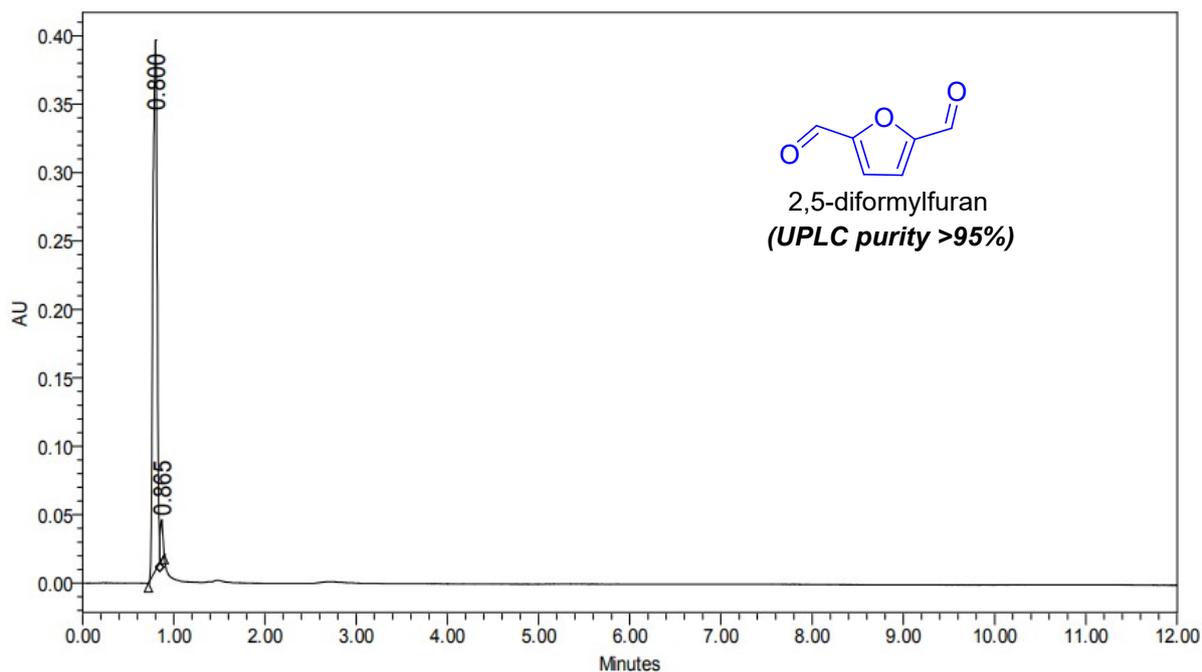
**Figure S2.** UV chromatogram of 5-HMF (5-hydroxymethylfurfural).



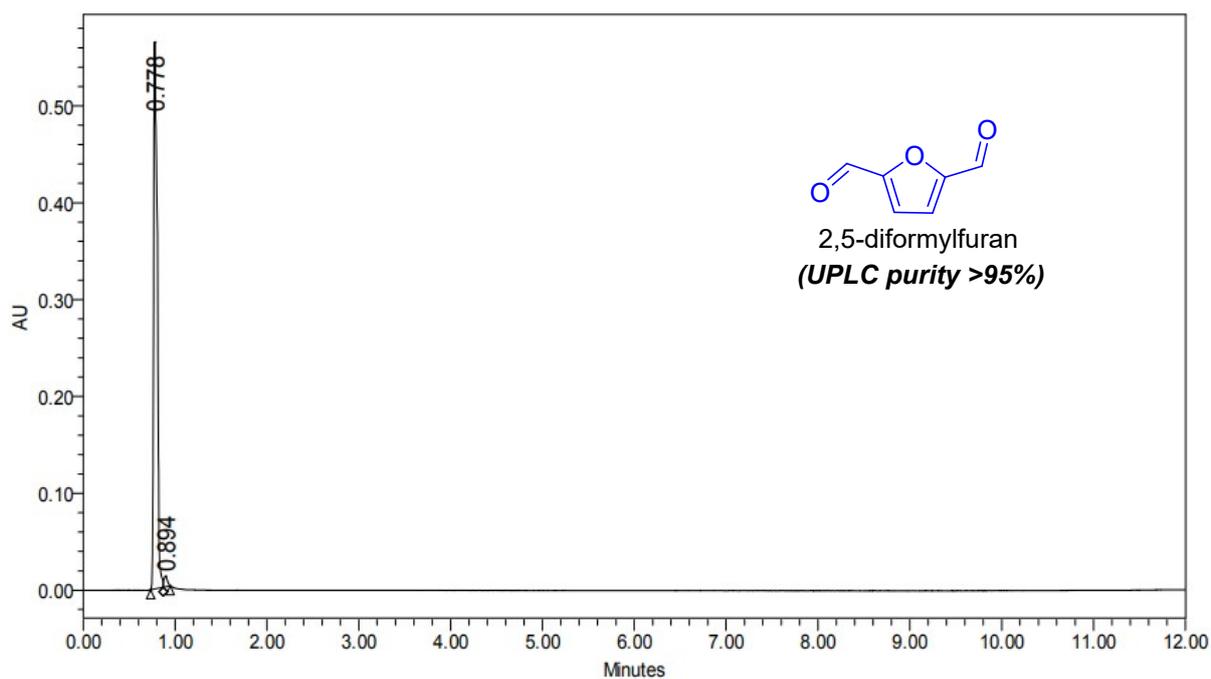
**Figure S3.** UV chromatogram of DFF (2,5-diformylfuran).



**Figure S4.** UV chromatogram of MSMFC (5-methylsulfanylmethyl-furan-2-carbaldehyde).



**Figure S5.** UPLC chromatogram of product before column chromatography.



**Figure S6.** UPLC chromatogram of product after column chromatography.

#### **Regeneration of Amberlite IR 120 H:**

After seven cycles, the regeneration of Amberlite IR 120 H was simply performed by stirring it in 5% (aq.) HCl solution for 30 minutes at room temperature. The Amberlite IR 120 H was then washed with distilled water and acetone followed by drying in oven for its further application.

#### 4. FTIR of Amberlite IR 120 H:

To confirmed the sulfonic acid group functionality in Amberlite IR 120 H, the resin was subjected for FTIR analysis. From the spectra the C-H group associated with polymeric styrene was found at 2920 and 2827  $\text{cm}^{-1}$ . The specific peak at 1639  $\text{cm}^{-1}$  assigned the benzene ring vibration. Similarly, the  $-\text{SO}_2$  group stretching vibration of both symmetric as well as asymmetric form in Amberlite IR 120 H were assigned by 1215 and 1411  $\text{cm}^{-1}$ . Moreover, the presence of sulfonic acid group was also confirmed by the peaks at 1000 and 1122  $\text{cm}^{-1}$ .<sup>2</sup> The activation/regeneration of Amberlite IR 120 H<sup>+</sup> form resin was performed by 5% (aq.) HCl solution.

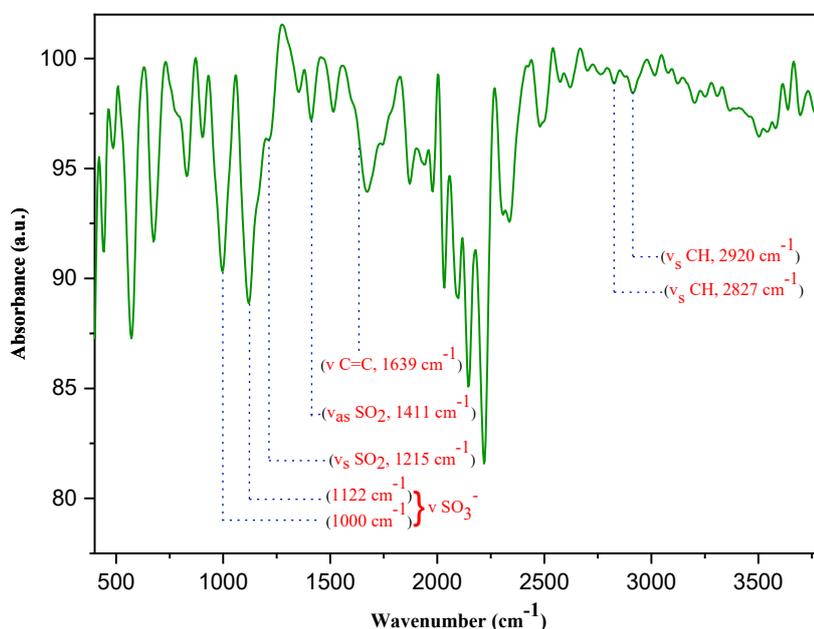


Figure S7. FTIR spectra of Amberlite IR 120 H.

#### 5. References:

1. a) [https://www.sigmaaldrich.com/IN/en/product/sial/06428?gclid=Cj0KCQjwzLCVBhD3ARIsAPKYTcQYKR1a\\_eaSMHYpdPuPbeeTroVADvzroKbZ48V57\\_cbVclBqnkhmR4aAkAxEALw\\_wcB](https://www.sigmaaldrich.com/IN/en/product/sial/06428?gclid=Cj0KCQjwzLCVBhD3ARIsAPKYTcQYKR1a_eaSMHYpdPuPbeeTroVADvzroKbZ48V57_cbVclBqnkhmR4aAkAxEALw_wcB) b) [https://www.merckmillipore.com/IN/en/product/Ion-exchanger-Amberlite-IR-120,MDA\\_CHEM-115131#overview](https://www.merckmillipore.com/IN/en/product/Ion-exchanger-Amberlite-IR-120,MDA_CHEM-115131#overview)

2. A. Perkob, V. Hajdu and G. Muranszky, *Reac Kinet Mech Cat* 2020, **129**, 85–94.