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Research article

Chromium-based metal-organic framework, MIL-101 (Cr), assisted hydrothermal pretreatment of teff (*Eragrostis tef*) straw biomass

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ABSTRACT

Teff (*Eragrostis tef*) is a staple crop and holds the biggest share of grains cultivated area in Ethiopia, consequently, a large quantity of Teff straw is produced. The Teff straw was pretreated for the first time with Chromium-based Metal-Organic Framework, MIL-101(Cr), assisted hydrothermal method at temperatures ranging from 160 to 240 °C for 1/2, 1, or 2 h time independently. With an increase of pretreatment severity, the yield of total reducing sugar (TRS) was increased until reaching maximum (185 mg g^{-1}). The identified optimum hydrothermal pretreatment condition, (180 °C and 1 h), had a feature of higher TRS yield and lower furfural concentration. The morphological analysis showed that treated Teff straw had degraded structure, higher surface area, and distorted bundles than native Teff straws. This study insight into MOFs' application in lignocellulose biomass processing, and optimizing the pretreatment condition of Teff straw biomass.

1. Introduction

Energy consumption has increased progressively since the beginning of the 20th century as the rise of world population and nations industrialization [1]. Fossil fuel is presently the main energy basis in the world; however, the reserves are limited and will be depleted shortly at its current consumption rate [2]. The consequences of insufficient fossil fuel availability could harm the economy and burning fossil fuels causes environmental concerns such as greenhouse emissions [3]. Hence there is a great necessity of searching alternative energy sources. The negative environmental effect of fossil fuels could be addressed by sustainable and environmentally friendly the alternative energy source [4].

Lignocellulosic biomass is the leading potential feedstock for reducing sugar production [5,6]. The main sources of lignocellulosic feedstocks are from the agriculture, forest, and industry. Using lignocellulose biomass for biofuel and value-added chemicals has several advantages, such as cost-effective, ecofriendly, resolving food vs. fuel controversy [7]. The pretreatment of lignocellulose biomass is a prime method to enhance the surface area and porosity of lignocellulosic material [8]. Different scholars worked on lignocellulosic biomass pretreatment such as dilute acid [9], ionic liquid [10], alkaline solution [11], steam explosion [12], organic

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solvent [13] and hydrothermal [14].

Hydrothermal pretreatment method employs hot compressed water as a reaction medium; and the method is reported as eco-friendly and safe [15]. The hydrothermal technique has been used for the pretreatment of various biomasses before and many research were executed on altered hydrothermal reaction medium [16,17]. In the same manner solid acid assisted hydrothermal pretreatment techniques have gained greater interest in the advantages to promote the pretreatment system and increase efficiency [18].

Metal-organic frameworks (MOFs) are crystalline materials built from fascinating networked structures of the organic linkers and metal centers [13]. MOFs are characterized by high surface area and porous structure that lets in fast mass transfer [19]. MIL-101(Cr), which is a category of Chromium-based MOF, consists of Cr $(NO_3)_3.9H_2O$ nodes and 1,4-Benzenedicarboxylic acid linker; the connections of MIL-101 (Cr) attain octahedral geometry [20]. MIL-101(Cr) MOF-owned capabilities of ultrahigh balance toward chemical substances, and brilliant tolerance for thermal, pH, and pressure [21]. MIL-101 (Cr) had been reported for various applications such as adsorption of gas, dye and drug; and as catalyst in hydrogen generation, oxidation, condensation, coupling, hydrogenation, acid-base synergy and ring opening reactions [20–22]. Consequently it's beneficial to investigate the ability of MIL-101(Cr) MOF in real scenario for lignocellulose biomass processing.

Teff (*Eragrostis tef)* is self-pollinated annual cereal crop, staple food in Ethiopia and for that it accounts the highest portion of cereal crops farming in the nation [23]. Teff is gluten free whole grain and major source of various nutrients including carbohydrates, proteins, minerals, vitamins, fibers, and polyphenols [24–27]; it is rich in unsaturated fatty acids such as linoleic acid, oleic acid and palmitic acid [28]. Teff also contains aldehydes, ketones and alcohols [29] Teff flour has been used in Ethiopia to make injera, which is a fermented pan cakelike traditional and staple food [30].

About 3.7 million tons teff cereal has been harvested per year in Ethiopia; consequently, beyond 2 million tons of straw is produced each year and it has been discarded mainly through burning [31]. This disposal could cause environmental contamination; however, this biomass could be a potential resource of fermentable sugar. Hence this work intended to investigating the potential of MIL-101(Cr) MOF assistance in hydrothermal pretreatment of teff straw. The optimum pretreatment condition was identified by comparing the impact of experimental parameters on total reducing sugar recovered and minimal inhibitor accumulated. Besides that morphological deformation, enhanced porosity and surface area of the pretreated biomass indicated the favored pretreatment condition.

2. Material and methods

2.1. Materials

The teff straw was gathered from Minjar Shenkora Arerti, North Shewa zone, Ethiopia. The straw was powdered and sieved for the particle size of 710 μm. Chromium (III) nitrate nonahydrate (99.5 %), terephthalic acid (98 %), and ethylene glycol (99.8 %) were

Table 1
Pretreatment conditions, Log Ro value, TRS yield and furfural concentration.

Run	MIL-101 MOF (mg)	Reaction temperature (°C)	Reaction Time (min)	Log Ro	TRS (mg/g)	Furfural (mg/mL)
1	0	160	30	3.244	40	0.16
2	0	160	60	3.545	52	0.17
3	0	160	120	3.846	92	0.20
4	5	160	30	3.244	55	0.18
5	5	160	60	3.545	76	0.19
6	5	160	120	3.846	112	0.22
7	0	180	30	3.833	80	0.16
8	0	180	60	4.135	126	0.18
9	0	180	120	4.435	72	0.24
10	5	180	30	3.833	124	0.19
11	5	180	60	4.135	185	0.20
12	5	180	120	4.435	105	0.27
13	0	200	30	4.421	45	0.35
14	0	200	60	4.723	88	0.41
15	0	200	120	5.024	60	0.55
16	5	200	30	4.421	90	0.38
17	5	200	60	4.723	102	0.43
18	5	200	120	5.024	85	0.60
19	0	220	30	5.010	55	0.50
20	0	220	60	5.311	68	0.61
21	0	220	120	5.612	42	0.64
22	5	220	30	5.010	70	0.55
23	5	220	60	5.311	80	0.68
24	5	220	120	5.612	50	0.69
25	0	240	30	5.599	30	0.60
26	0	240	60	5.901	45	0.65
27	0	240	120	6.201	25	0.68
28	5	240	30	5.599	45	0.70
29	5	240	60	5.901	52	0.78
30	5	240	120	6.201	35	0.82

acquired from Blulux Laboratories Pvt. Ltd., India. Dinitro salicylic acid, potassium hydroxide (>85 %), sodium hydroxide (>98 %) obtained from HiMedia Laboratories Pvt. Ltd., India. Sulfuric acid (98 %) purchased from LOBA Chemie, India.

2.2. *Compositional analysis*

The proximate analysis and chemical composition (Extractives, cellulose, hemicellulose, and lignin content) of teff straw was determined using the NREL procedure [32].

2.3. *Synthesis of chromium-based metal-organic framework*

MIL-101(Cr) MOF was synthesized following a previous method with some modification [33]. In brief, 0.83g of terephthalic acid and 2 g chromium nitrate nonahydrate were mixed in 50 mL of de-ionized water (DI water). The mixture was kept in autoclave reactor (Baoshishan 100 mL hydrothermal autoclave reactor, polytetrafluoroethylene lined, safe temperature: 220 and pressure: 3 MPa) and heated in an oven at 220 °C for 8 h. Followed by cooling the reaction to room temperature, the MIL-101(Cr) MOF crystals were separated and cleaned with DI water and ethanol repeatedly.

2.4. *Design of experiment*

The effect of MIL-101(Cr) MOF, hydrothermal temperature, and time were assessed based on the total reducing sugar and furfural yield employing 2 × 5 × 3 full factorial design by Minitab 18 software a total of 30 combinations (Table 1). MIL-101(Cr) has 2 levels (0, 5 mg), the temperature has 5 levels (160, 180, 200, 220, & 240 °C) and time has 3 levels (30, 60, &120 min). The model's terms ANOVA was done and the models suitability were analyzed by the value of R^2. The analyzed solubilized sugars were expected from deconstruction of the amorphous structured hemicellulose polymer as a result of the hydrothermal condition and MOF assisted catalysis. Furfural is a degraded product from pentose sugars and its significant amount of accumulation can inhibit the down stream process, hence the pretreatment with low furfural yield and high-solubilized sugar is optimum condition.

2.5. *Pretreatment of Eragrostis tef straw biomass*

Pretreatment of teff straw was carried out in the autoclave reactor, heated in an oven. 1 g of powder straw biomass was soaked in 10 ml DI water in the presence or deprived of 5 mg MIL-101(Cr). Then, the pretreatment was carried out at the designed temperature and time conditions described in section 2.4. After completing the planed pretreatment, the reaction was cooled to room temperature. The supernatant prehydrolysate and solid residue was separated by centrifugation.

The severity factor, Ro, is defined in equation (1):

$$Ro = t \exp \underline{(T_H - T_R)}\ 14.75 \tag{1}$$

Where t**:** hydrolysis time (min), T_H: hydrolysis temperature (°C), and the reference temperature T_R is 100 °C [12]. The constant term14.75 is typical activation energy for hydrolysis of glycoside bonds of carbohydrates, supposing a hydrothermal process overall conversion is first order [34].

2.6. *Total reducing sugar and furfural analysis*

The total reducing sugars (TRS) were analyzed spectrophotometerically using P9 Double Beam UV–Visible Spectrophotometer, VWR. The dinitrosalicylic acid reagent was mixed with the prehydrolysate samples for UV analysis. The furfural concentration in the samples was known by HPLC (Agilent 1200 Infinity series, USA) equipped with a reverse phase C-18 column and UV detector. Suitably diluted and cleaned 25 μL samples were injected into HPLC operated at flow rate (1 mL min^{-1}), column temperature (25 °C), mobile phase (acetonitrile: DI water: acetic acid (11:88:1, v/v/v)) and the detection was done at 276 nm.

2.7. *X-ray diffraction analysis*

The crystallographic nature of the teff straw was characterized by an X-ray diffractometer (XRD-7000, DRAWELL). The diffractometer was operated with CuKα radiant source, 40 kV energy, 30 mA current, 3^o min^{-1} scanning speed. Biomass percent crystallinity index, CrI (%), was calculated from equation (2).

$$CrI\ (\%) = \underline{I_{002}\ \text{-}\ I}_{am}\ \text{x}\ 100\ I_{002} \tag{2}$$

where I_{002} is the crystalline intensity at $2\theta = 22.5^\circ$ and I_{am} is the amorphous intensity at $2\theta = 18.7^\circ$ [35].

The powder XRD of the MIL-101(Cr) MOF was analyzed following the Pertiwi et al. [36]. In brief the PXRD patterns were recorded on the XRD-7000, DRAWELL diffractometer with CuKα radiant source and $2\theta = 5-50^\circ$ (step size 0.02° in 2θ), operated at 40 kV energy and 40 mA current.

2.8. *Scanning electron microscopy analysis*

SEM analysis was performed using SEM JCM-6000Plus with the aim to observe the uniform octahedral geometry of the synthesized MOF; and to understand the structure and morphology of native and pretreated teff straw.

2.9. *Brunauer-Emmett-Teller (BET) analysis*

The surface areas of the synthesized MIL-101(Cr) MOF, native and MOF pretreated Teff straw biomass were analyzed using the Brunauer-Emmett-Teller (BET) method using Horriba surface area analyzer with model number SA9603 (USA).

2.10. *Fourier-transform infrared spectroscopy analysis*

FTIR analysis of MIL-101(Cr) MOF crystals was done to recognize the functional groups by a Nicolet 6700 Thermal Scientific spectrometer. In the same way the native and MOF aided hydrothermally pretreated teff straw biomass were analyzed. The samples were recorded from 4000 to 500 cm^{-1} with 2 cm^{-1} resolutions in transmission mode. Sets of 64 scans were collected.

3. Results and discussion

3.1. *Teff straw biomass composition*

The compositional analysis of teff straw was 41.7 wt% cellulose, 36 wt% hemicellulose and 17.0 wt% lignin in a dry basis (Table 2). These results were in agreement with the previous report on the same biomass [9]. The finding indicated the potential of Teff straw for biorefinery due to high structural polysaccharides content (Table 2). Teff straw acquired equivalent amount of lignin and higher cellulose content in comparison with wheat straw. The proximate values analyzed for native teff straw biomass were 67.4 % volatile matters, 7.4 % fixed carbon, 5.2 % moisture content and 20 % ash content (Supplementary material, Table S1).

3.2. *MIL-101(Cr) characterization*

The XRD patterns of the synthesized MIL-101(Cr) MOF affirmed its purity (Fig. 1). The peaks $2\theta^{o}$ and intensities were well fitted with the MOF's single crystal structure theoretical data [33]. And the diffraction patterns were in agreement with the formerly reported MIL-101(Cr) [37]. The octahedral geometry of the MIL-101 was clearly seen on the SEM image (Fig. 2) and the BET surface area was 1002.5 $m^2\ g^{-1}$. The stability of the synthesized MIL-101(Cr) in the hydrothermal environment was checked by its well-kept XRD patterns after keeping it at 160 °C–240 °C for 3hr. The MIL-101(Cr) FTIR (Supplementary material, Fig. S1) depicted the presence of benzene dicarboxylate linker from O–C–O symmetric vibrations of dicarboxylate. The expected benzene ring bands were observed between 585.55 and 1600 cm^{-1} including stretching vibrations (C=C) at 1399.97 cm^{-1} and deformation vibrations (C–H) at 1017.62 cm^{-1}. The moderate band prevailed at 742.97 cm^{-1} possibly indicating mono substituted benzene and the band at 585.55 cm^{-1} is ascribed to Cr–O stretching vibration [38].

3.3. *Teff straw biomass morphology*

The CrI (%) of native teff straw was 66.7 % whereas that of MIL-101(Cr) hydrolyzed teff straw treated at Log Ro 4.435 (representing conditions of 180 °C, 120 min) was 77.8 % and at Log Ro 6.201 (240 °C, 120 min) was 47.7 % calculated from the XRD described in Fig. 3. The CrI (%) of MOF assisted hydrothermally pretreated Teff straw treated at Log Ro 4.435 was higher than the native teff straw owing to partial separation of hemicellulose and amorphous components of cellulose. Similar remark was reported for rice straw confirmed that the pretreated rice straw with the aid of using dilute acid had higher crystallinity while in comparison to native rice straw [39]. In general terms, the MIL-101(Cr) assisted hydrothermally pretreated teff straw at Log Ro 4.435 produces well resolved and intensified XRD signals than the native one. This event indicates the removal of amorphous portions, mainly hemicellulose, added to a slight enhance in the indicator of crystalline cellulose. The CrI (%) of MOF assisted hydrothermally pretreated Teff straw at Log Ro 6.201 is lower than that of the native teff straw possibly from considerable deconstruction of crystalline cellulose and the enhancement of surface area.

Table 2
Results for chemical composition analysis of Teff straw compared with other biomass sources.

Biomass	Extractive (Wt %)	Cellulose (Wt %)	Hemicellulose (wt %)	Lignin (Wt %)	References
Teff straw	5.3	41.7	36.0	17.0	Present study
Wheat straw	3	45.4	36.5	21.6	[46]
Rice straw	–	36.1	27.2	19.7	[47]
Switch grasses	–	39.4	20.2	21.2	[48]
Sugarcane bagasse	5.6	42.2	27.6	21.6	[49]
Barely straw	–	33.8	20.7	29.7	[50]

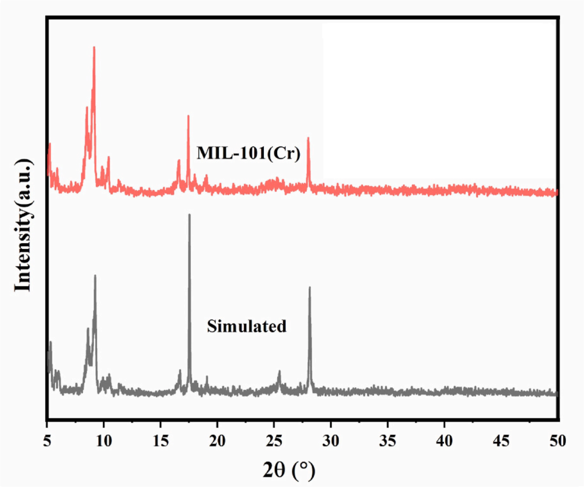

Fig. 1. XRD pattern of MIL-101(Cr), the simulated pattern of MIL-101 was produced from the original MIL-101 (Cr) paper (Ferry et al., 2005).

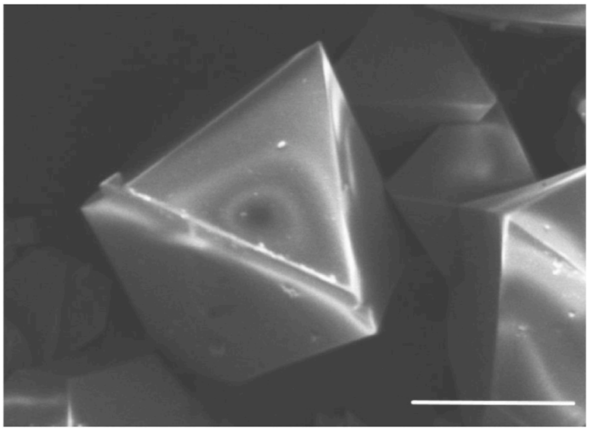

Fig. 2. XRD pattern of native and treated Teff straw biomass.

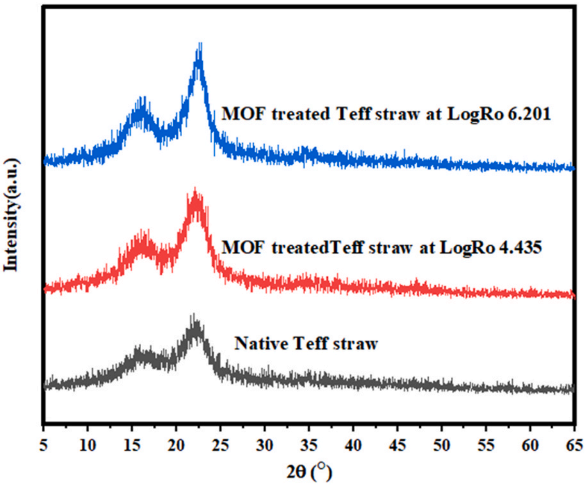

Fig. 3. FTIR spectra of Native teff straw, MIL-101(Cr) treated teff straw (Log Ro 4.435 at 180 °C, 2 h), and (Log Ro 6.201 at 240°C, 2 h).

Surface area is an important parameter for the subsequent processing of lignocellulose biomass into useful chemicals. In this study, the surface area of the teff straw improved with the Log Ro enhancement. The natural teff straw BET was 1.05 $m^2 g^{-1}$, following MIL-101(Cr) aided hydrothermal pretreatment at Log Ro 4.435 the BET became 2.97 $m^2 g^{-1}$. At Log Ro 6.201 the BET value reached 10.56 $m^2 g^{-1}$. Such a raise can be attributed to the removal of the amorphous components of the biomass. The BET of common hydrothermally pretreated teff straw at Log Ro 6.201 was 9.43 $m^2 g^{-1}$ which is lower than the BET of MOF assisted hydrothermally pretreated biomass at the same severity. The observed event agreed with the hypothesis that MIL-101(Cr) can improve the hydrolyzability of teff straw biomass.

The FTIR spectral analyses on native teff straw and MIL-101(Cr) pretreated teff straw at Log Ro 4.435 and at Log Ro 6.201 (Fig. 4) were done to further comprehend the effect of pretreatment severity on the biomass. The impact was qualitatively analyzed based on the spectra behavior observed which might imply functional groups availability, appearance, absence or reduction. Accordingly the native teff straw biomass demonstrated various vibration signals indicating the availability of hydroxyl, amino, carboxyl, carbonyl, ether and amide functional groups. The band around 1700 cm^{-1} owing to carbonyl groups was not detected after MOF aided hydrothermal pretreated Teff straw. The event was possibly due to lignin removal from the biomass. Since characteristic C═C aromatic skeletal bands of lignin in the region 1508–1600 cm^{-1} and around 1433 cm^{-1} were absent in the MOF assisted hydrothermally pretreated biomass, it is possible to claim that the lignin was effectively separated by the assistance of MOF in hydrothermal pretreatment.

The SEM images of native (Fig. 5A) and MIL-101(Cr) assisted hydrothermally pretreated teff straw biomass (Fig. 5B) showed that after MOF pretreatment, the biomass had degraded structure in size, uneven and irregular structure which may be more helpful for subsequent application of the biomass.

3.4. Effect of pretreatment on sugars yield

The effects of pretreatment parameters (MIL-101(Cr), hydrothermal temperature and time) on TRS were considered (Table 1). The aid of MIL-101(Cr) on the produced TRS was obvious at mild severities which means the MOF effect on the teff straw was significant at severities below Log Ro 4.435 (Fig. 6). The MOF catalytic potential in sugar conversion was explained before [40].

The heightened Log Ro improved the TRS yield till reached highest (185 mg g^{-1}) at Log Ro 4.135 (analogous to 180 °C hydrolysis temperature and 60 min time). Previously 27 % reducing sugar recovery was achieved from coffee husk via combined biological pretreatment and steam explosion method [41]. Valorization of sugarcane bagasse by H_2SO_4 pretreatment yielded 8.4 % release of soluble reducing sugar [42]. In this study MOF assisted hydrothermally pretreated teff straw biomass at 180 °C for 60 min afforded a solubilization of about 51 % xylan in the form of reducing sugar.

The enhancements of hydrothermal temperature go together with Log Ro increment (Table 1) and increasing Log Ro turn down the TRS (Fig. 6). At severity Log Ro 3.244 (representing 160 °C and 30 min) 40 mg g^{-1} TRS from usual hydrothermal pretreatment and 55 mg g^{-1} TRS from MOF aided hydrothermal pretreatment was obtained. The TRS at Log Ro 3.833 (180 °C, 30 min) was 100 and 124 mg g^{-1} and reduced to 45 and 90 mg g^{-1} at Log Ro 4.421 (200 °C, 30 min) respectively. Very high temperatures broke the TRS yield owed to decomposition. For the case, 55 and 70 mg g^{-1} TRS yield at Log Ro 5.010 (220 °C, 30 min) was decreased to 30 and 45 mg g^{-1} at Log Ro 5.599 (240 °C, 30 min) from hydrothermal pretreatments without and with MOF assistance, respectively.

The yield of TRS was noticeably affected by lengthy pretreatment time. 40 and 55 mg g^{-1} TRS was obtained at Log Ro 3.244 (160 °C, 30 min) from simple hydrothermal and MOF aided hydrothermal pretreatments respectively and the yield increased to 92 and 112 mg g^{-1} at Log Ro 3.846 (160 °C, 120 min). While at higher severity lengthy reaction time had negative impact, for instance the 30

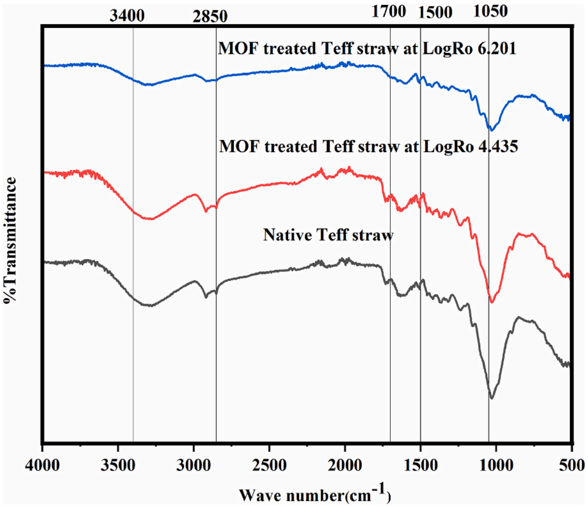

Fig. 4. SEM of the synthesized MIL-101 (Cr). Scale bar 50 μm.

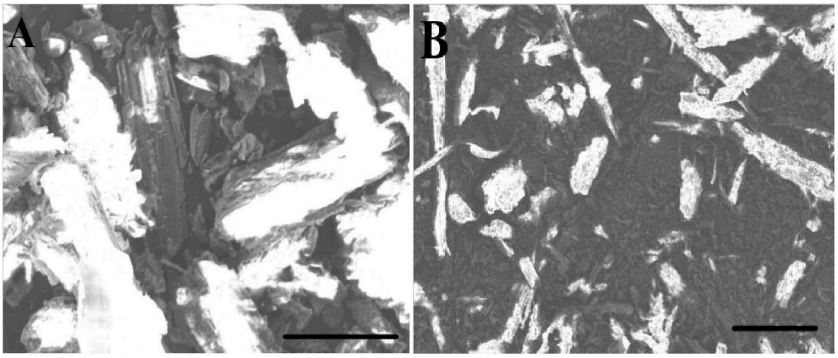

Fig. 5. The SEM images of native Teff straw (A) and, MOF treated Teff straw (B). Scale bar 100 μm.

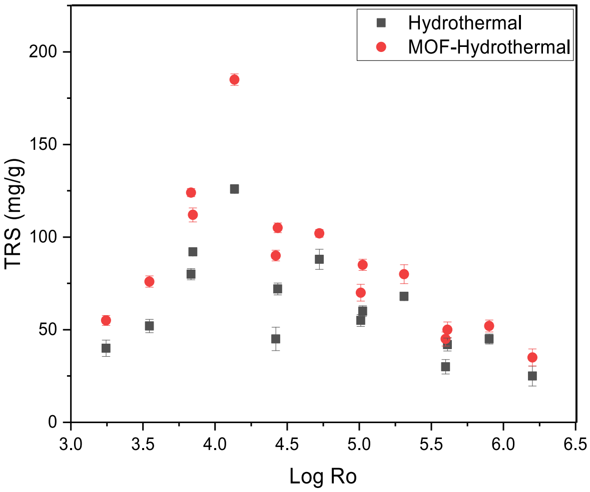

Fig. 6. The TRS from pretreatment of Teff straw biomass at various Log Ro ranges.

and 45 mg g^{-1} TRS at Log Ro 5.599 (240 °C, 30 min) was reduced 25 and 35 mg g^{-1} at Log Ro 6.201 (240 °C, 120 min) from the usual and the MOF aided hydrothermal pretreatments respectively. In summary the decline in the TRS yield as a result of pretreatment severity and MIL-101 (Cr) participation ascribed to the degradation of the sugars into other chemicals including furfural.

3.5. *Effect of pretreatment on furfural yield*

In the pretreatment stage furfural, hydroxymethylfurfural and other chemicals might be formed from the degradation of carbohydrate, and the aggregation of the degraded products have trouble in downstream processing [43]. It is known that the main monomeric sugars obtained from lignocellulosic biomass pretreatment are xylose and glucose. Minimal concentration of furfural (about 0.18 g L^{-1}), the main derived product of xylose, was analyzed at Log Ro 4.435. As the Log Ro was risen (Fig. 7) especially Log Ro > 4.435, noticeable amount of furfural was produced. At the most sever condition Log Ro 6.201 (240 °C, 120 min) of this study, about 0.82 g L^{-1} furfural was detected. During pretreatment the amorphous structured xylan of teff straw might be degraded into xylose, thus it is sensible to get furfural at Log Ro > 4.435 severities (Fig. 7). The analyzed furfural in this study was very low and below 1 g L^{-1} at all studied Log Ro ranges, which somehow comparable with other study [44].

3.6. *Fitting model*

The regression equations of the TRS, equation (3), and furfural, equation (4), with the variables MIL-101(Cr) (A), temperature (B), and time (C) were as follows:

$$\text{TRS (mg g}^{-1}) = -7607 + 4.61 \times A + 110.1 \times B + 11.96 \times C - 0.517 \times B^2 - 0.1149 \times B \times C + 0.000797 \times B^3 + 0.000270 \times B^2 \times C \quad (3)$$

$$\text{Furfural (g L}^{-1}) = -0.785 - 0.0347 \times A + 0.00825 \times B + 0.000448 \times C - 0.000010 \times B^2 + 0.000237 \times A \times B \quad (4)$$

The model R^2 were 98.87 % and 97.87 % indicating their suitability since $R^2 > 75$ % is acceptable [45]. From the ANOVA of the

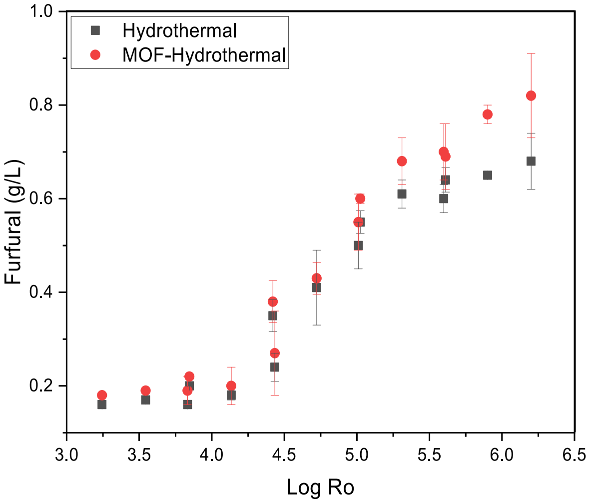

Fig. 7. The furfural concentration from pretreatment of Teff straw biomass at various Log Ro ranges.

equations (supplementary material, Table S2), the linear and interaction coefficient demonstrating $p < 0.05$ were considered in the model equation. The p values for all the linear and interaction coefficients show that all variables and the interaction coefficients in the equation have significant effect on TRS and furfural yield. The models indicated the optimum pretreatment conditions featured with the highest TRS yield and the lowest furfural formation (Supplementary material, Figs. S2 and S3). In summary the teff straw pretreated via MIL-101 (Cr) aided hydrothermal method at Log Ro 4.135 (analogous to the condition at 180 °C and 60 min) attained the highest TRS (185 mg g^{-1}) with very low furfural (0.18 g L^{-1}) accumulation. Appropriately the temperature of 180 °C and 60 min time was the best hydrothermal condition identified in this study.

4. Conclusion

Vast production of teff straw and its high cellulose content could make it a potential candidate for biorefinery. Metal-Organic Framework enhances the pretreatment potential of hydrothermal condition. The MOF may involve in the catalysis of glycoside bond cleavage of amorphous sugar hence the crystalline cellulose was kept for the subsequent processing. The optimum MIL-101 (Cr) MOF aided hydrothermal pretreatment condition of teff straw was at 180 °C and 1 h.

Data availability

Data will be made available on request to the corresponding author.

Ethical statement

This manuscript does not involve any ethical issues.

CRediT authorship contribution statement

Ruth Bezabih: Investigation. **Yakob Godebo Godeto:** Data curation. **Salah Hamza Sherif:** Writing – review & editing, Visualization. **Taju Sani:** Writing – review & editing. **Ibrahim Nasser Ahmed:** Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31341.

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