Textile & Leather Review

ISSN 2623-6281 | www.tlr-journal.com | 10.31881/TLR

Conversion of Tannery Solid Wastes into Fuel Briquettes Using Wastepaper as a Binder

Desbelom Welegebrial Hagos, Mebrahtom Gebresemati Weldehans, Gebreyohannes Gebrehiwot Tesfay, Teklemariam Negash Reda

How to cite: Hagos DW, Weldehans MG, Tesfay GG, Reda TN. Conversion of Tannery Solid Wastes into Fuel Briquettes Using Wastepaper as a Binder. Textile & Leather Review. 2023; 6:701-717. https://doi.org/10.31881/TLR.2023.124

How to link: https://doi.org/10.31881/TLR.2023.124

Published: 18 November 2023

Conversion of Tannery Solid Wastes into Fuel Briquettes Using Wastepaper as a Binder

Desbelom Welegebrial HAGOS[1], Mebrahtom Gebresemati WELDEHANS[2,3]*, Gebreyohannes Gebrehiwot TESFAY[1], Teklemariam Negash REDA[1]

[1]Department of Chemical Engineering, Ethiopian Institute of Technology-Mekelle (EiT-M), Mekelle University, Mekelle, Tigray, 7000-231, Ethiopia

[2]Technology Sector, Tigray Institute of Policy Studies (TIPS), Mekelle, Tigray, 7000-902, Ethiopia

[3]Department of Chemical and Biological Engineering, Gachon University, Seongnam-si, Gyeonggi-do, 13120, Republic of Korea

*mebrahtomgw@gmail.com

Article

https://doi.org/10.31881/TLR.2023.124

Received 6 September 2023; Accepted 13 November 2023; Published 18 November 2023

ABSTRACT

The disposal of tannery solid waste (TSW) and the need for clean and affordable energy are two pressing issues. Converting TSW into briquettes could be a solution to both problems. This paper focuses on preparing and characterizing fuel briquettes from TSW using a wastepaper as a binder. Raw TSW samples were obtained from the nearby leather industry, sun-dried, treated, carbonized, and reduced to a size of less than 2 mm. The carbonized TSW was mixed with a wastepaper binder (WPB) in different combinations (100:0, 80:20, 60:40, 40:60, 20:80) and converted into briquettes using a hand-press briquette machine. Five briquettes were produced, and sun-dried for one week. The proximate analyses and calorific values of the resulting briquettes were determined in accordance with ASTM analytical methods. The briquettes had a moisture content of 1.30±0.01–5.30±0.10%, volatile matter of 4.01±0.09–10.21±0.18%, ash of 2.80±0.04–5.50±0.13%, fixed carbon of 79.00±0.54–91.90±0.36%, and calorific value of 20.48±0.08–21.09±0.04 MJ/kg. Results showed that a briquette comprised of 80% TSW and 20% WPB has a higher calorific value of 21.09±0.04 MJ/kg. This study demonstrates the feasibility of producing affordable and clean briquettes from an admixture of TSW and WPB. It also shows that briquette production can help reduce solid waste disposal in the tannery industry.

KEYWORDS

tannery solid-wastes, fuel briquette, carbonization, binder

INTRODUCTION

Leather tanning is a major industry in many countries, including Ethiopia, where it contributes significantly to export earnings and employment. The process is complex and involves several physical, biological, mechanical, and chemical transformations to convert raw animal hides and skins into durable and versatile materials. However, despite its proven worth and long history, leather tanning is a highly polluting industry that generates large amounts of solid and liquid waste [1-3]. Depending on the leather processing technologies installed in the tannery, approximately 750-800 kg of solid waste and 30 m^3 of wastewater are generated from the processing of one metric ton (MT) of raw hides and skins that produce 200-250 kg of leather [4,5]. Globally, leather processing generates 6 million MT of solid waste annually with 23.33% and 2.50% contributions coming from China and India, respectively [2,4,5]. The improper disposal of tannery solid waste (TSW) remains a major environmental problem worldwide, especially in developing countries where chromium-based tanning is prevalent and wastes are often discharged untreated [6,7]. Sustainable waste-to-energy (WTE) technologies can help mitigate the environmental impacts of TSW and maximize its benefits.

So far, several studies have explored different valorization technologies for converting TSW into valuable products. Research has been reported on the use of TSW for compost [8], packing materials [9], adsorbent [10], and enzyme [11] productions. Moreover, TSW's high heating value makes it a promising source for biofuels (biogas, biodiesel, bio-oil and bio-char) productions [12-16]. While those studies are promising, several challenges must be overcome before their findings can be applied in practice, especially in low-income countries like Ethiopia, where it is essential to utilize waste in economically feasible and sustainable ways.

Currently over 30 tanneries are in operation in Ethiopia, most of which use the conventional chromium-based tanning method [6,17]. It was reported that the country generates 70,104 MT of pre-tanned leather waste annually, disposing of it using conventional methods such as landfills and incineration [18]. Additionally, Ethiopia faces a shortage of clean and affordable energy alternatives as the population and economy grow [19]. In 2020, the energy mix was heavily reliant on traditional solid biomass fuels (87.1%), followed by imported gasoline (10.0%), and a small fraction (2.9%) of electricity [20]. The vast majority of households use traditional wood biomass, which is inefficient and polluting, with negative impacts on health, the environment, and the economy. In addition, despite its rich biomass waste potential, only 0.6% (25 MW) of Ethiopia's total electricity generation capacity comes from municipal solid wastes-based WTE technologies [21,22]. Hence, Ethiopia needs to modernize and diversify its energy mix to meet its growing energy needs.

To this end, converting TSW into fuel briquettes can help manage tannery waste, generate affordable energy, and reduce reliance on wood fuel, all of which are important goals for sustainable development. Briquetting biomass sources requires the addition of strong, non-polluting, and thermally neutral binding materials to hold the briquettes together during transportation, forming, and storage [23]. Despite numerous investigations, researchers continue to seek the ideal binding material for briquetting biomass sources.

Therefore, this study aims to produce cost-effective and environmentally friendly briquettes using wastepaper as a binder from TSW sourced from a local leather industry in Ethiopia. To the authors' understanding, briquette production from TSW remains scarcely explored, and no study has investigated briquetting TSW with wastepaper binder (WPB) to produce briquette fuel. In one study, starch has been investigated as a binder for TSW briquettes [24], but its high cost and impact on the food supply make it an impractical option. In this regard, despite its poor fuel properties, wastepaper is a viable binder for biomass-based fuel briquettes due to its adhesive properties [25], low sulfur contents and nitrogen oxide emissions [26,27], and abundance. Hence, this study aims to explore the briquetting of TSW using wastepaper as a binder with desirable physical and thermal properties for alternative energy use in low-income communities. The briquettes produced in this study were compared to other reported briquettes.

EXPERIMENTAL

Raw materials collection and preparation

The solid wastes were collected from the post-tanning operation units (tanning, buffing, and shaving) of Sheba Leather Industry PLC in Wukro town, eastern Tigray, Ethiopia. As shown in Figures 1a, b, and c, mixture samples in equal amounts from each operation unit were treated by sorting to remove any trace of impurities (bones, metal, and wood) and other unwanted materials, followed by sun-drying and oven-drying at 105 °C to reduce moisture content [24]. Next, the raw material was analyzed for proximate analysis (volatile matter, fixed carbon, ash content) and calorific value. For the TSW carbonization, a kiln drum fabricated at Mekelle University was used. The drum has a chimney on the top with holes at the bottom. The treated TSW were placed inside the drum, burned from the bottom and waited until the smoke from the drum stopped. Then, the carbonized sample was reduced to a uniform size of less than 2 mm (Figure 1d) using a grinder by passing through a series of sieves arranged vertically.

On the other hand, WPB samples were collected from Mekelle University's student residence and staff office bins located in Mekelle City, Tigray, Ethiopia. About 500 g wastepaper sample was manually shredded into small pieces, mixed, and soaked in a small bath jar containing 1.5 L water for three days, followed by maceration to form a uniform slurry as displayed in Figure 1e.

Briquette preparation

In this study, a manual press moulding machine designed to have 5 MPa [26] pressure with a cylindrical mould, having a 7 cm outer diameter and 20 cm height was used. Briquette preparations were conducted at the laboratories of the Department of Chemical Engineering, and the School of Mechanical and Industrial Engineering at Mekelle University. A total of five briquettes were developed using a total weight of 400 g of combined raw materials at different proportions of TSW:WPB (100:0, 80:20, 60:40, 40:60, 20:80). After mixing, the raw materials were then placed in the mould and hand pressed for six min. After the production process, the briquettes were carefully ejected from the mould and sun-dried for one week to reduce their moisture content. Finally, the briquettes were ready for further characterization, as shown in Figure 1f.

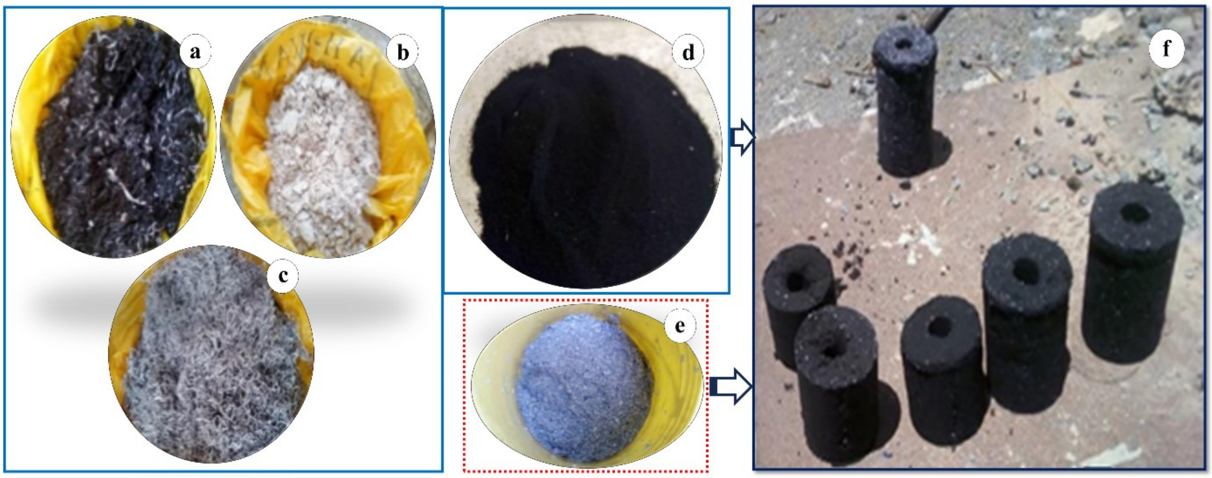

Figure 1. Solid wastes of the tanning unit (a), buffing unit (b) shaving unit (c), and carbonized TSW (d), wastepaper binder (e), and produced TSW-wastepaper -based briquette (f)

Briquette characterization

The proximate analysis test was conducted in accordance with the ASTM standards outlined in Afsal et al. [28]. By adhering to the ASTM standards, the physical properties (density, porosity index, shatter resistance and combustion rate) were evaluated to measure the quality and durability of the produced briquettes. Additionally, the moisture, volatile matter, fixed carbon, and ash contents were determined to assess the quality of the briquettes. Furthermore, the calorific value of the briquettes was measured using bomb calorimetry at the laboratory of Messebo Cement Factory PLC, Mekelle, Ethiopia. Below are detailed explanations of physical properties, proximate analysis, and calorific value determinations.

Density: The density of briquette samples was determined by dividing the sample mass (m) by the mould volume (V) [24].

$$Density\ (\frac{g}{cm^3}) = \frac{m}{V} \tag{1}$$

Porosity index: Each briquette sample was immersed in water to determine the percentage of porosity index (PI) by calculating the difference between its mass after immersion and its initial dry weight.

$$PI\ (\%) = \frac{\Delta W}{W_d} x100 \tag{2}$$

where, ΔW and W_d are the weight difference after immersion and dry weight briquette samples, respectively.

Shatter resistance: The shatter resistance (SR) value was estimated by weighing the briquette sample before shattering (W_b) followed by dropping it from a constant 2 m height and recording the weight after shattering (W_a). Then, SR was obtained as follows.

$$SR\ (\%) = \frac{W_a}{W_b} x100 \tag{3}$$

Combustion rate: The combustion rate (CR) is a crucial parameter that measures the time taken for a specific amount of briquette sample to burn in the air. To determine this rate, 100 g of each briquette sample was placed separately on a traditional burner for 30 min. Afterwards, the retained sample was weighed to calculate CR as follows.

$$CR = \frac{m_b}{t} \tag{4}$$

where m_b is the mass of burned briquettes and t is the time of burning.

Moisture content: The percentage of moisture content (MC) was determined by measuring the difference between the initial weight before drying (W_1) and the weight of the briquette after oven drying (W_2) at 105 °C for 2 hr.

$$MC\ (\%) = \frac{W_1 - W_2}{W_1} x100 \tag{5}$$

Volatile matter content: For the volatile matter content (VMC) determination, a 2 g sample of oven-dried briquette was placed in a furnace at a temperature of 550 °C for 10 min. Then, the VMC percentage was calculated from weight loss during heating divided by the initial weight of the sample using the following equation.

$$VMC\ (\%) = \frac{W_2 - W_3}{W_2} x100 \tag{6}$$

where, W_2 and W_3 are the weight of oven-dried briquette sample and weight after furnace drying at 550 °C for 10 min., respectively.

Ash content: The percentage of ash content (AC) was determined by taking 2 g of oven-dried briquette sample with known weight (W_2) and furnace drying at 550 °C for 4 hours. The retained ash was then weighed, and the percentage of AC was calculated using the following equation.

$$AC\ (\%) = \frac{W_4}{W_2} x100 \tag{7}$$

where W_4 is the weight of the sample after furnace drying at 550 °C for 4 hours.

Fixed carbon content: The percentage of fixed carbon content (FCC) was calculated by subtracting the total percentages of moisture, volatile matter, and ash contents from 100, as follows.

$$\text{FCC}\ (\%) = 100 - (\%\text{MC} + \%\text{VMC} + \%\text{AC}) \tag{8}$$

Calorific value: Finally, the calorific values (CV) of each briquette sample were determined by bomb calorimetry (MFPM4000030) at Messebo Cement Factory PLC, Mekelle, Tigray, Ethiopia. The test was carried out following the ASTM method as described in [26].

RESULTS AND DISCUSSION

Proximate analysis of raw tannery solid waste sample

Proximate analysis is a useful tool for assessing a fuel's performance and characteristics. From the experimental analysis, the density of the raw TSW sample was determined to be 0.40±0.04 g/cm^3 using equation 1, and the content of moisture was found to be 19.50±0.50%, indicating that moisture content reduction is necessary before carbonization or densification. Additionally, the volatile matter was determined to be 46.37±0.33% using equation 6, and the ash content was calculated to be 5.10±0.10% by dividing the weight of ash by the weight of the dry sample using equation 7. Table 1 presents the results of the proximate analysis conducted on the TSW sample material. These findings suggest that TSW possesses properties that fall within the range of biomass raw material standards suitable for briquette fuel production. The results also highlight the importance of continued research in this field to identify and develop TSW-based alternative energy as viable sources of renewable energy that can help mitigate the impact of industrial wastes.

Table 1. Proximate analysis and calorific value of tannery solid waste (dry basis)

Parameter name	Value
Density (g/cm^3)	0.40 ± 0.04
Moisture content (%)	19.50 ± 0.50
Volatile matter content (%)	46.37 ± 0.33
Ash content (%)	5.10 ± 0.10
Fixed carbon content (%)	29.03 ± 0.03
Calorific value (MJ/kg)	16.82 ± 0.23

Physical properties of the TSW-WPB-based briquettes

The briquette density was determined from the mass-to-volume ratio. The variation in the composition of the briquettes affects their homogeneity and size. Figure 2 shows the results of the measured density of the TSW-based briquettes.

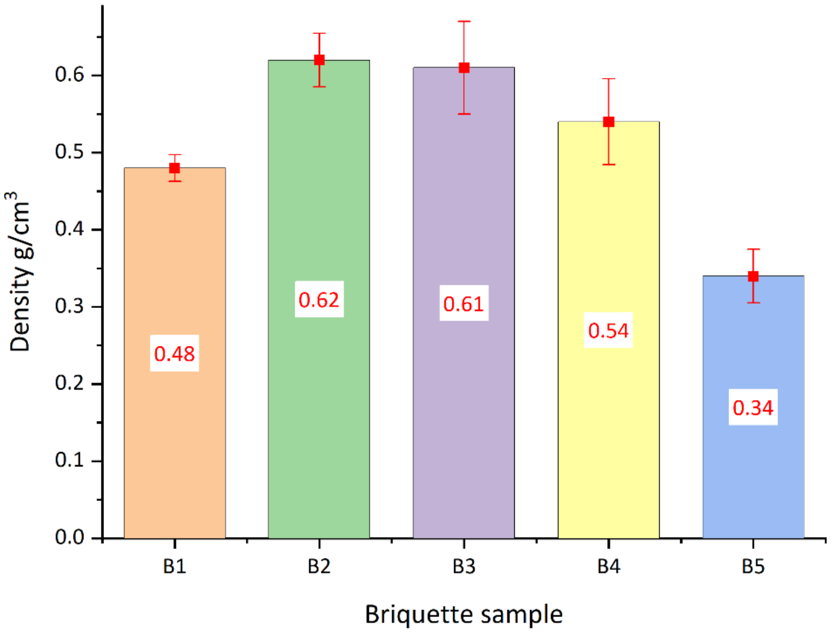

Figure 2. Density of briquette samples B1 (100% TSW), B2 (80% TSW + 20% WPB), B3 (60% TSW + 40% WPB), B4 (40% TSW + 60% WPB), and B5 (20% TSW + 80% WPB)

As displayed in Figure 2, the density of the briquette samples ranged from 0.34±0.03 to 0.62±0.03 g/cm^3, which is in the range of agro-wastes and wood residues-based briquettes [29]. The highest density was observed in the sample containing 80% TSW and 20% WPB, which could be attributed to the amount of adhesive that meets the void ratio formed by the particle size [30]. From the highest point onward, the density of the briquettes decreased with the wastepaper amount. This can be associated with the fact that wastepaper is made up of lightweight materials such as cellulose that can easily compressed.

As shown in Table 2, the PI value of the briquettes produced ranged from 25.10±0.17 to 34.50±1.32%. Adding binder content decreased the PI values, likely because the porous cellulose in the wastepaper fills the void spaces in solid waste. The large decrease in PI for the sample with 20% WPB suggests that this proportion of binder could be optimal. Furthermore, the SR ranged from 87.94 to 93.46%. The SR values increased to a maximum at 40% binder (93.2±0.26%) and then decreased with increasing binder content, likely due to the weak properties of the wastepaper. In addition, the rate of combustion increased with wastepaper addition (Table 2). Longer burning time is reported to be an indication of high briquette fuel density [29]. The produced TSW-based briquettes were generally found to have satisfactory physical properties, with WPB percentage influencing them. These findings provide valuable insights into the potential use of TSW briquettes as a sustainable alternative to traditional fuels. Details of these results are given in Table 2.

Table 2. Physical properties of the TSW-WPB-based briquettes

Briquette sample	TSW (%)	WPB (%)	Density (g/cm^3)	PI (%)	SR (%)	CR (g/s)
TSW1	100	0	0.48±0.02	34.50±1.32	89.97±0.66	0.009
TSW2	80	20	0.62±0.03	27.30±0.44	92.5±0.89	0.011
TSW3	60	40	0.61±0.06	25.40±0.36	93.2±0.26	0.011
TSW4	40	60	0.54±0.06	25.23±0.25	90.5±0.26	0.014
TSW5	20	80	0.34±0.03	25.10±0.17	88.4±0.46	0.018

TSW = Tannery solid wastes, WPB = Wastepaper binder, PI = Porosity index, SR = Shatter resistance and CR = Combustion rate.

Proximate analysis of TSW briquette samples

Proximate analyses were performed on the tannery wastes and wastepaper-based briquette. When it comes to briquettes, proximate analysis can provide insight into the chemical and physical properties of the briquette in terms of its moisture, volatile matter, ash and fixed carbon contents. Table 3 summarizes the results in comparison to values reported in the literature.

Table 3. Proximate and heating value characteristics of tannery solid wastes and wastepaper-based briquettes in comparison with values reported in the literature

Briquette	MC (%)	VMC (%)	AC (%)	FCC (%)	CV (MJ/kg)	Ref.
TSW+WP	1.30±0.01 - 5.30±0.10	4.01±0.09 - 10.21±0.18	2.80±0.04 - 5.50±0.13	79.00±0.54 - 91.90±0.36	20.48±0.08 - 21.09±0.04	This study
TSW+CS	0.38-1.26	1.84-2.76	2.93-3.90	92.38-94.61	18.63-24.10	[24]
VMW+SD	3.40-6.80	71.72-83.20	1.40-3.22	13.60-21.66	14.00-15.72	[28]
BD+WP	5.31-7.45	38.57-61.19	10-38.23	17.84-22.77	14.70	[31]
AWWR	-	24.35-34.95	3.37-4.91	61.68-68.97	30.82-34.42	[29]
SA-RC	3.89-7.29	68.19-73.61	9.97-11.45	10.28-15.40	-	[32]
VAW	3.95	17.30	2.70	76.50	20.84	[33]
CP+SD	-	41.20-78.10	1.40-6.00	14.20-49.20	19.40-24.90	[34]
DWW	2.67-7.67	11.30-26.00	4.67-26.67	44.27-72.00	29.06-37.39	[35]
BL	7.51-8.11	77.40-79.00	5.81-6.65	15.20-16.00	17.40-18.00	[36]
RH	7.52-7.70	63.80-71.60	20.70-28.50	7.52-7.70	15.40-16.00	[36]

MC = Moisture content, VMC = Volatile matter content, AC = Ash content, FCC = Fixed carbon content, CV = Calorific value, TSW+WP = Tannery solid waste and wastepaper, TSW+CS = Tannery solid waste and cassava starch, VMW+SD = Briquettes made from vegetable market waste and sawdust, BD+WP = Fuel briquettes from biogas digestate and wastepaper, AWWR = Agro-wastes and wood residues, SA-RC = Briquette produced from the wastes of Senna auriculata and Ricinus communis using Tapioca starch, VAW = Charred briquettes derived from various agricultural waste, CP+SD = Fuel briquettes made from charcoal particles and sawdust agglomerates, DWW = Briquettes from disposed wood wastes, BL = Briquettes made from banana leaf, and RH = Briquettes from rice husk.

Moisture content

Briquette fuels are hygroscopic in properties meaning can easily absorb moisture from surroundings [37]. Hence, the value of water content needs to be determined as it affects the thermal efficiency and burning rate of the briquettes. The MC as a percentage of the initial weight of a briquette is shown in Figure 3. The MC of the TSW-based briquettes varied from 1.30±0.01 to 5.30±0.10%, which is within the range of reported biomass-based briquettes (Table 3). The highest moisture content was obtained for the briquette sample with 80% WPB. The moisture content increased as the percentage of wastepaper increased, likely due to the hydrophilic behaviour of the wastepaper. As higher moisture can reduce the calorific value of material and make it more difficult to burn, lower MC of a fuel source is good for improving its combustion efficiency and cleanliness. This is because moisture acts as a natural fire retardant, hindering the combustion process and producing more smoke and pollutants [24]. A further disadvantage of high moisture content is the facilitation of a breeding ground for fungi and other microorganisms [33].

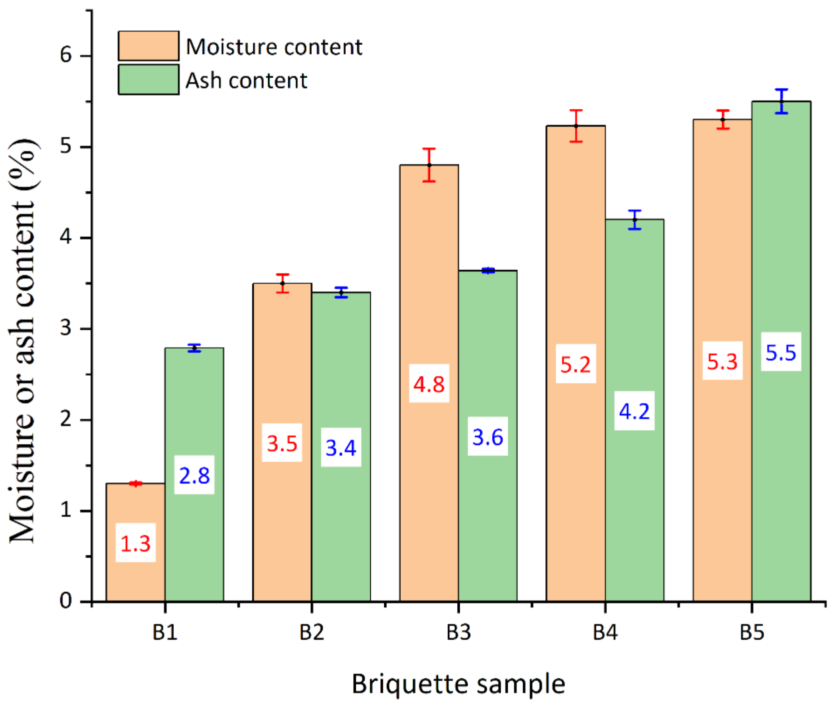

Figure 3. Moisture and ash contents of briquette samples B1 (100% TSW), B2 (80% TSW + 20% WPB), B3 (60% TSW + 40% WPB), B4 (40% TSW + 60% WPB), and B5 (20% TSW + 80% WPB)

Ash content

Ash is the amount of inorganic material that is left behind after the briquette is burned. High ash concentration lowers the calorific value of the fuel since the ash does not participate in the combustion [29]. The ash content for the produced briquettes ranges between 2.80±0.04 to 5.50±0.13% (Figure 3). A lower percentage of ash content was obtained for the briquette with no WPB and higher for the briquette sample with 80% WPB (Figure 3). The ash content of the briquette sample increases with increasing the amount of wastepaper, likely due to inorganic contaminants in the wastepaper that remain after incineration. A lower percentage of ash content has been obtained in this study in comparison to different biomass-based briquettes, which shows the produced briquettes have good quality [31,32,35,36]. Elevated levels of ash content can have a detrimental impact on the combustion behaviour of fuel, leading to the creation of hazardous chemicals that pose a threat to the environment. It is imperative to maintain low levels of ash content to ensure optimal combustion efficiency and minimize the release of harmful pollutants.

Volatile matter and fixed carbon contents

The percentage of volatile matter in a biomass source is a mixture of short and long-chain hydrocarbons such as combustible or incombustible gases or a combination of both mainly comprises carbon, hydrogen, and oxygen elements [29]. The lower the volatile matter the higher will be the energy value. On the contrary, with increasing the percentage of fixed carbon calorific value increases. A high percentage of fixed carbon is an indication of a high heating value of the briquette [34]. Figure 4 shows the variation of volatile matter and FCC of the produced TSW-based briquette fuels.

As shown in Figure 4, the volatile matter was obtained in the range between 4.01±0.09 to 10.21±0.18%. The briquette sample with no WPB has shown a lower percentage of volatile matter and higher for the briquette sample having 80% WPB. Percentages of VMC increased with the increasing amount of WPB. On the other hand, a lower percentage of fixed carbon (79.00±0.54%) was found for the briquette sample with 80% WPB and higher FCC was obtained on pure TSW briquette (91.90±0.36%). As illustrated in Figure 4, increasing the amount of wastepaper resulted in a decrease in the percentage of fixed carbon. A lower percentage of the volatile matter was obtained in this study, in comparison to other briquette materials produced from different biomass sources; such as a mixture of 25% vegetable market waste and 75% sawdust (71.72-83.20%) [28], a mixture of biogas digestate and wastepaper (38.57-61.19%) [31], disposed wood waste with paper (11.30-26.00%)[35], and rice husk (63.80-71.60%) and banana leaf (77.40-79.00%) [36]. This is an important consideration in the fuel production process as the energy value of a substance increases as its volatile matter decreases. This means that the less volatile matter a substance contains, the more energy it can provide.

https://doi.org/10.31881/TLR.2023.124

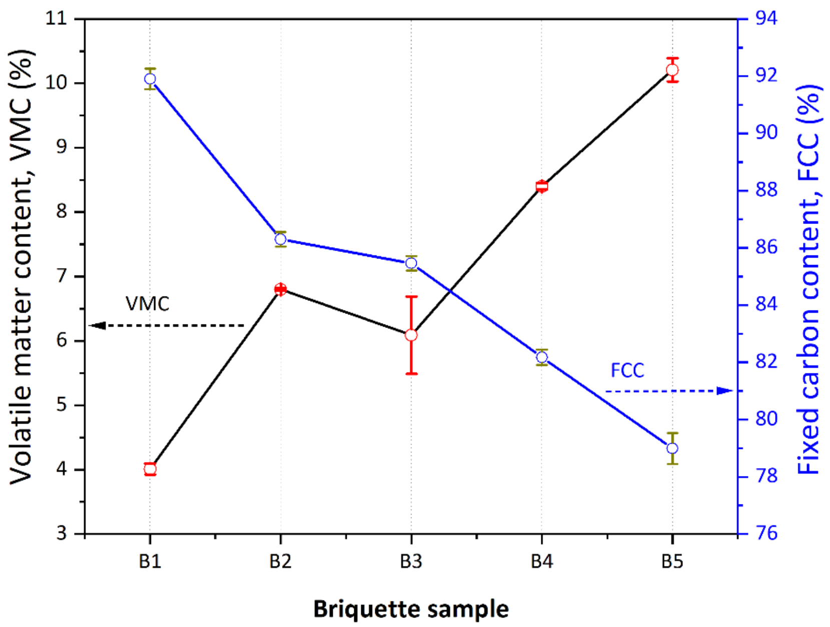

Figure 4. Volatile matter and fixed carbon contents of briquette samples B1 (100% TSW), B2 (80% TSW + 20% WPB), B3 (60% TSW + 40% WPB), B4 (40% TSW + 60% WPB), and B5 (20% TSW + 80% WPB)

Calorific value

Calorific or heating value is a measure of heat energy present in a material that depends on its chemical composition and can vary widely between different substances. The calorific value for the produced briquettes ranged between 20.48±0.08 to 21.09±0.04 MJ/kg (Figure 5). As displayed in Figure 5, the highest calorific value was obtained for the briquette sample with 80% TSW and 20% WPB (21.09±0.04 MJ/kg), and a lower value (20.48±0.08 MJ/kg) was obtained for briquette sample with 80% of WPB. The calorific value of TSW briquette increases up to 20% of wastepaper admixture and gradually decreases with increased wastepaper. The results suggest WPB has a significant effect on the heating value of the TSW-based briquettes, and about 20% adhesive is sufficient to fill the voids between the particles. A briquette sample with a higher heating value is more acceptable. The calorific values obtained in this study were better than some reported biomass-and waste-based briquettes [27,28,31,33,36], suggesting a more efficient and effective option for briquette fuel production, and in agreement with elsewhere reported TSW-based biomass briquette with cassava starch binder [24].

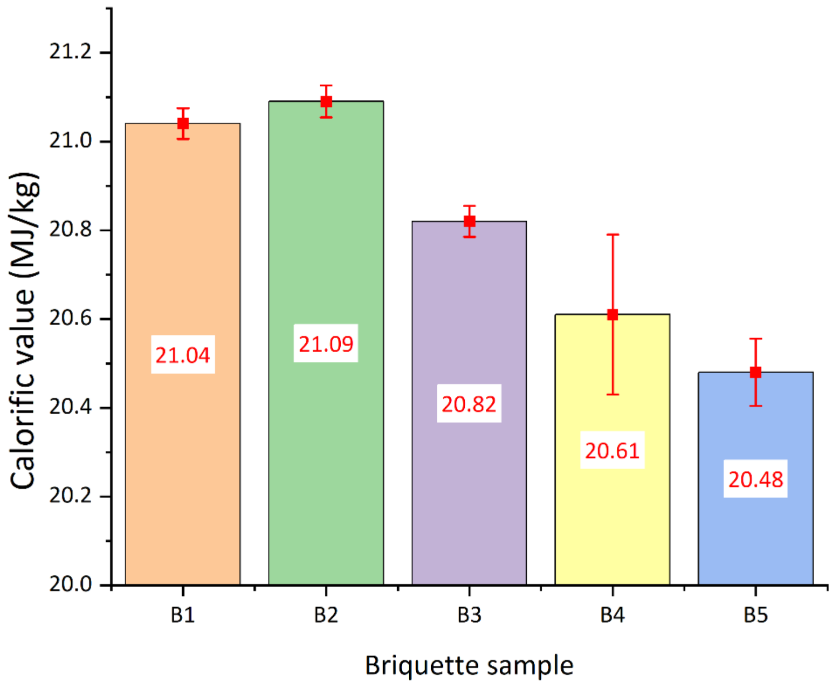

Figure 5. Calorific value of briquette samples B1 (100% TSW), B2 (80% TSW + 20% WPB), B3 (60% TSW + 40% WPB), B4 (40% TSW + 60% WPB), and B5 (20% TSW + 80% WPB)

All briquette samples in this study had sufficient calorific values to meet the energy requirements of household cooking and other small commercial applications [28]. TSW-derived briquettes can directly replace wood biomass in household cooking stoves, offering several advantages, such as higher energy density, lower emissions, and convenience. They can also be used for various commercial applications, such as fueling brickmaking kilns, boilers, crop dryers, and electricity generators. In addition, the briquettes are produced with lower moisture content, which is important for storage and handling. Briquettes with higher moisture content spoil and grow mould more easily, and are heavier and more likely to stick together, making them difficult to transport and handle. Moreover, using TSW-based briquettes can help to mitigate the environmental impacts of TSW while maximizing its benefits. Furthermore, it creates jobs and boosts the local economy.

CONCLUSION

This study confirms that briquettes produced from TSW have great potential for use as a viable and economical domestic fuel. The study presents an opportunity to combine TSW and wastepaper to create briquettes that can be used as a clean and cost-effective energy source in rural communities and small businesses. The briquettes showed calorific values that are significantly high and comparable to those of agricultural waste briquettes. The briquettes displayed an acceptable moisture content that had minimal impact on their calorific value. The relatively high shatter index of the produced briquettes indicates that they can be handled and transported with minimal risk of disintegration.

Additionally, this study also used office wastepaper as a binder, which does not compete with food sources and helps to reduce waste. The lower nitrogen oxide and sulfur contents of wastepaper have a great potential to reduce emissions during combustion. However, to fully assess the quality of briquettes made from TSW biomass material, the study recommends further research on TSW briquette preparation with other types of binder, production of briquette from TSW and other biomass admixtures, optimization of operating variables, including pressure, temperature and particle size, etc. Using these wastes for fuel briquettes can avoid landfill disposal, solve energy crises for communities, reduce pollution, and achieve cleaner production.

Author contributions

Conceptualization – Hagos DW, Weldehans MG, Tesfay GG and Reda TN; methodology – Hagos DW and Weldehans MG; formal analysis – Hagos DW, Weldehans MG, Tesfay GG and Reda TN; investigation – Hagos DW, Weldehans MG, Tesfay GG and Reda TN; writing-original draft preparation – Hagos DW, Tesfay GG and Reda TN; writing-review and editing – Weldehans MG; visualization – Hagos DW, Weldehans MG, Tesfay GG and Reda TN; supervision – Weldehans MG. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no competing interest.

Funding

This research received no external funding.

Acknowledgements

The authors gratefully acknowledge Mekelle University and Messebo Cement Factory PLC for the laboratory facilities, and Sheba Leather Industry PLC for providing the solid waste samples.

REFERENCES

[1] Sivakumar V. Towards environmental protection and process safety in leather processing – A comprehensive analysis and review. Process Safety and Environmental Protection. 2022; 163:703–26. https://doi.org/10.1016/J.PSEP.2022.05.062

[2] Muralidharan V, Palanivel S, Balaraman M. Turning problem into possibility: A comprehensive review on leather solid waste intra-valorization attempts for leather processing. Journal of Cleaner Production. 2022; 367:133021. https://doi.org/10.1016/J.JCLEPRO.2022.133021

[3] Teklay A, Gebeyehu G, Getachew T, Yaynshet T, Sastry TP. Preparation of value added composite boards using finished leather waste and plant fibers—a waste utilization effort in Ethiopia. Clean Technologies and Environmental Policy. 2017; 19:1285-1296. https://doi.org/10.1007/s10098-016-1327-4

[4] Mozhiarasi V, Natarajan TS, Karthik V, Anburajan P. Potential of biofuel production from leather solid wastes: Indian scenario. Environmental Science and Pollution Research. 2023. https://doi.org/10.1007/s11356-023-28617-3

[5] Moktadir MA, Ren J, Zhou J. A systematic review on tannery sludge to energy route: Current practices, impacts, strategies, and future directions. Science of The Total Environment. 2023; 901:166244. https://doi.org/10.1016/J.SCITOTENV.2023.166244

[6] Aregu MB, Asfaw SL, Khan MM. Developing horizontal subsurface flow constructed wetland using pumice and Chrysopogon zizanioides for tannery wastewater treatment. Environmental Systems Research. 2021; 10:31. https://doi.org/10.1186/S40068-021-00238-0

[7] Alemu A, Tegegne A. Assessment of chromium contamination in the soil and khat leaves (Catha edulis Forsk) and its health risks located in the vicinity of tannery industries; A case study in Bahir Dar City, Ethiopia. Heliyon. 2022; 8(12):e11914. https://doi.org/10.1016/J.HELIYON.2022.E11914

[8] Karak T, Kutu FR, Paul RK, Bora K, Das DK, Khare P, et al. Co-composting of cow dung, municipal solid waste, roadside pond sediment and tannery sludge: role of human hair. International Journal of Environmental Science and Technology. 2017; 14:577–594. https://doi.org/10.1007/s13762-016-1167-0

[9] Juel MAI, Mizan A, Ahmed T. Sustainable use of tannery sludge in brick manufacturing in Bangladesh. Waste Management. 2017; 60:259–269. https://doi.org/10.1016/J.WASMAN.2016.12.041

[10] Selvaraj S, Jeevan V, Rao Jonnalagadda R, Nishad Fathima N. Conversion of tannery solid waste to sound absorbing nanofibrous materials: A road to sustainability. Journal of Cleaner Production. 2019; 213:375–83. https://doi.org/10.1016/J.JCLEPRO.2018.12.144

[11] Ravindran B, Wong JWC, Selvam A, Thirunavukarasu K, Sekaran G. Microbial biodegradation of proteinaceous tannery solid waste and production of a novel value added product – Metalloprotease. Bioresource Technology. 2016; 217:150–156. https://doi.org/10.1016/J.BIORTECH.2016.03.033

[12] Sri Bala Kameswari K, Kalyanaraman C, Porselvam S, Thanasekaran K. Enhancement of Biogas Generation by Addition of Lipase in the Co-Digestion of Tannery Solid Wastes. CLEAN: Soil Air Water. 2011; 39(8):781–786. https://doi.org/10.1002/CLEN.201000408

[13] Tujjohra F, Alam MS, Rahman MM, Rahman MM. An eco-friendly approach of biodiesel production from tannery fleshing wastes by crude neutral protease enzyme. Cleaner Engineering and Technology. 2023; 14:100638. https://doi.org/10.1016/J.CLET.2023.100638

[14] Kubendran D, Salma Aathika AR, Amudha T, Thiruselvi D, Yuvarani M, Sivanesan S. Utilization of leather fleshing waste as a feedstock for sustainable biodiesel production. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2017; 39(15):1587–1593. https://doi.org/10.1080/15567036.2017.1349218

[15] Amdouni S, Ben Hassen Trabelsi A, Mabrouk Elasmi A, Chagtmi R, Haddad K, Jamaaoui F, et al. Tannery fleshing wastes conversion into high value-added biofuels and biochars using pyrolysis process. Fuel. 2021; 294:120423. https://doi.org/10.1016/J.FUEL.2021.120423

[16] Mozhiarasi V, Natarajan TS, Karthik V, Anburajan P. Potential of biofuel production from leather solid wastes: Indian scenario. Environmental Science and Pollution Research. 2023. https://doi.org/10.1007/s11356-023-28617-3

[17] Abate TA, Desta AF, Love NG. Evaluating tannery wastewater treatment performance based on physicochemical and microbiological characteristics: An Ethiopian case study. Water Environment Research. 2021; 93(5):658–669. https://doi.org/10.1002/WER.1364

[18] Berhe S, Leta S. Anaerobic co-digestion of tannery wastes using two stage anaerobic sequencing batch reactor: focus on process performance of hydrolytic–acidogenic step. Journal of Material Cycles and Waste Management. 2019; 21:666–677. https://doi.org/10.1007/s10163-019-00837-1

[19] Tofu DA, Wolka K, Woldeamanuel T. The impact of alternative energy technology investment on environment and food security in northern Ethiopia. Scientific Reports. 2022; 12:10403. https://doi.org/10.1038/s41598-022-14521-2

[20] IEA. World energy balances 2020. IEA, electricity information. 2020. Available from: https://www.iea.org/countries/ethiopia#overview

[21] Benti NE, Gurmesa GS, Argaw T, Aneseyee AB, Gunta S, Kassahun GB, Aga GS, Asfaw AA. The current status, challenges and prospects of using biomass energy in Ethiopia. Biotechnology for Biofuels and Biproducts. 2021; 14:209. https://doi.org/10.1186/s13068-021-02060-3

[22] Weldehans MG. Optimization of distillery-sourced wastewater anaerobic digestion for biogas production. Cleaner Waste Systems. 2023; 6:100118. https://doi.org/10.1016/j.clwas.2023.100118

[23] Lubwama M, Yiga VA, Lubwama HN. Effects and interactions of the agricultural waste residues and binder type on physical properties and calorific values of carbonized briquettes. Biomass Conversion and Biorefinery. 2022; 12(11):4979-4999. https://doi.org/10.1007/s13399-020-01001-8

[24] Onukak IE, Mohammed-Dabo IA, Ameh AO, Okoduwa SI, Fasanya OO. Production and characterization of biomass briquettes from tannery solid waste. Recycling. 2017; 2(4):17. https://doi.org/10.3390/recycling2040017

[25] Romallosa ARD, Kraft E. Feasibility of biomass briquette production from municipal waste streams by integrating the informal sector in the Philippines. Resources. 2017; 6(1):12. https://doi.org/10.3390/resources6010012

[26] Kpalo SY, Zainuddin MF, Halim HB, Ahmad AF, Abbas Z. Physical characterization of briquettes produced from paper pulp and Mesua ferrea mixtures. Biofuels. 2022; 13(3):333–340. https://doi.org/10.1080/17597269.2019.1695361

[27] Lela B, Barišić M, Nižetić S. Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics. Waste management. 2016; 47(Part B):236-45. https://doi.org/10.1016/j.wasman.2015.10.035

[28] Afsal A, David R, Baiju V, Suhail NM, Parvathy U, Rakhi RB. Experimental investigations on combustion characteristics of fuel briquettes made from vegetable market waste and saw dust. Materials Today: Proceedings. 2020; 33(7):3826-3831. https://doi.org/10.1016/j.matpr.2020.06.222

[29] Falemara BC, Joshua VI, Aina OO, Nuhu RD. Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues. Recycling. 2018; 3(3):37. https://doi.org/10.3390/recycling3030037

[30] Aransiola EF, Oyewusi TF, Osunbitan JA, Ogunjimi LAO. Effect of binder type, binder concentration and compacting pressure on some physical properties of carbonized corncob briquette. Energy Reports. 2019; 5:909–918. https://doi.org/10.1016/J.EGYR.2019.07.011

[31] Lutaaya SM, Olupot PW, Wakatuntu J, Kasedde H. Effects of waste paper on fuel and mechanical properties of biogas digestate-derived briquettes. Biomass Conversion and Biorefinery. 2023. https://doi.org/10.1007/s13399-023-03929-z

[32] Velusamy S, Subbaiyan A, Shanmugamoorthy M, Thirumoorthy P. Characterization of solid biomass briquette biofuel from the wastes of Senna auriculata and Ricinus communis using Tapioca starch for sustainable environment. Environmental Science and Pollution Research. 2023; 30:10110-10127. https://doi.org/10.1007/s11356-022-22823-1

[33] Sunnu AK, Adu-Poku KA, Ayetor GK. Production and characterization of charred briquettes from various agricultural waste. Combustion Science and Technology. 2023; 195(5):1000-1021. https://doi.org/10.1080/00102202.2021.1977803

[34] Ajimotokan HA, Ehindero AO, Ajao KS, Adeleke AA, Ikubanni PP, Shuaib-Babata YL. Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. Scientific African. 2019; 6:e00202. https://doi.org/10.1016/j.sciaf.2019.e00202

[35] Shiferaw Y, Tedla A, Melese C, Mengistu A, Debay B, Selamawi Y, Merene E, Awoi N. Preparation and evaluation of clean briquettes from disposed wood wastes. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2017; 39(20):2015-2024. https://doi.org/10.1080/15567036.2017.1399175

[36] de Oliveira Maia BG, de Oliveira AP, de Oliveira TM, Marangoni C, Souza O, Sellin N. Characterization and production of banana crop and rice processing waste briquettes. Environmental Progress & Sustainable Energy. 2018; 37(4):1266-1273. https://doi.org/10.1002/ep.12798

[37] Adu-Poku KA, Appiah D, Asosega KA, Derkyi NSA, Uba F, Kumi EN, et al. Characterization of fuel and mechanical properties of charred agricultural wastes: Experimental and statistical studies. Energy Reports. 2022; 8. https://doi.org/10.1016/j.egyr.2022.03.015