Characteristics and tanning potential of *Hagenia abyssinica* tannin extracts and its possible use in clean leather production

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Characteristics and tanning potential of *Hagenia abyssinica* tannin extracts and its possible use in clean leather production

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**Abstract:** Hagenia abyssinica, a tannin material, was employed for tanning the sheepskins into crust leathers and then compared its performance with the leather that was tanned with commercial mimosa. Characterizations of *H. abyssinica* extract revealed that it possesses condensed tannin having a pH: 4.7. Tannin, non-tannin, and tannin strength were found to be 15.49%, 7.52%, and 2.06% respectively. Fourier transforms Infrared and UV–Visible spectroscopic studies were also carried out to find the structural characteristics of the *H. Abyssinica* tannins. The results of the physicomechanical characteristic of crust leathers showed that the tensile strength of the sample was ranged from 10.2 to 11.9 N/mm², but the control mimosa tanned leather was found to be 19.8–19.9 N/mm². Elongation at break was 45.7–45.8% against control (36.7–37.5%). Tear strength was found as 26.9–27.3 N/mm² (expt.) and 26.9–27.8 N/mm² (control). The chemical properties of prepared scab leathers were tested and the obtained data met

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the desires. In addition, *H. Abyssinica* tanned leather exhibited the highest shrinkage temperature of about 78.5°C. Analyses of organoleptic properties showed that the *H. Abyssinica* crust leathers were much better than mimosa-based crust leather. The effluence masses of tanning liquors existed also assessed and the findings mostly demonstrated that there was a statistically significant difference (with p-values: 0.000) except total suspended solid (p-value: 0.059) and BOD (p-value: 0.099) between the control and experiment liquors within the allowable limit. Thus, this study exhibited that *H. Abyssinica* tanning liquor does not influence the pollution load into the aquatic environment and soil.

**Subjects:** Agriculture & Environmental Sciences; Biodiversity & Conservation; Environmental Change & Pollution; Material Science; Industrial Engineering & Manufacturing; Materials Science; Production Engineering; Clean Tech

**Keywords:** Chrome-free tannins; *Hagenia abyssinica*; Mimosa; Phyto-tanning; Sheepskin

1. Introduction

Vegetable tanning (phyto-tanning) is viewed as a green tanning material and the most encouraging one on account of its biodegradability and consequently eco-friendly. It has numerous benefits on the tanned hides like great fullness, toughness, wear resistance, solidity, air porousness, and so on henceforth; it is of more prominent importance to diminish chrome contamination in leather making processes (Franco et al., 2019a; Koloka & Moreki, 2011). Phyto-tanning, the treatment of hide/skin with powdered plant parts, or it extricates reacts with collagen primarily via hydrogen bonding (Covington, 2009). Vegetable tannins (phyto-tannins) are water-dissolvable with relative molar masses in the scope of 500–3000 g/mol. what is more provides the typical phenolic responses; it is encouraging a few phytchemicals, and other's from protein. Phyto-tanning of light calfskins required 18–20 % tannins and that of heavy-cowhides requires 25–30 % tannins (Haslam & Dubaye, 1993). The plant species, ripeness, and sources of phyto tannin affect the quality of leather paying less attention to tanning and post-tanning operations. Phyto-tanned calfskin is utilized in making leathers, for example, furniture leathers; shoe upper leathers, and so forth (Musa & Gasmelseed, 2012; Roland, 2014). There still scientific debate on the right method for the extrication of tannins from the plant parts around the world, as these are fluctuated dependent on whether the extraction of the tannins proposed ought to be solids/powder or fluid. Customarily the tannins have been extricated with water as a dissolvable material. In any case, the gathering of phyto-tannin extricates depends on the suitable solvent employed (Covington, 2009).

Attributable to the yearly decrement of the plant tannins and without chrome tanning effort; new tannin materials should have been extricated from the powder of the bark of *Hagenia abyssinica* like plant materials that could be utilized for tanning of sheep or goat skins into crust leather contrasted with the standard commercial mimosa with intentions to diminish the number of pollutants being released alongside the prepared medium. The leather industry in Ethiopia creates a ton of leather items and employs many people groups. The greater part of the leather experts cannot buy commercial vegetable tannin material (mimosa); thus, it suggests alternative tanning materials, which are to be locally accessible. Besides, vegetable tannins are less polluting contrasted with chromium, and the eldest tanning materials.

Skins and hides tanned with vegetable tannins from various sources of vegetable tanning materials give leather with various properties. The nature of the leather is influenced by pretanning and post-tanning measures, the sort and sources of vegetable tanning materials affect the nature of leather. The kind of tanning materials utilized in leather creation influences the actual qualities of the leather which are delivered from the same origin (Nilay et al., 2014).

*H. abyssinica* is a monotypic genus in the family of Rosaceae. It is found in the highland rain forest at higher altitudes and is 20 meters in height with a short trunk, red-brown bark; it has thick
branches and the crown leafy and rounded (Azene, 2007). The tree is reportedly the native of eastern Africa especially in countries like Eritrea, Ethiopia, Uganda, Burundi, Tanzania, and Kenya. In Ethiopia, the tree is scattered in mountainous areas especially central, southwest, and southeast of the country. The tree is traditionally used for firewood, timber, poles, medicine, ornamental, mulch, green manure, soil conservation, leather softening, etc. (Biruktyey et al., 2010).

*Hagenia abyssinica* (African redwood) is a newly emerging vegetable tannin material that is being used in leather technology either alone or in combination with other vegetable tannins. *H. abyssinica* was found mostly practiced in Kenya by neighborhood tanners with less logical documentation, which were accounted for by Alex Kuria et al. (2016). Be that as it may, the examination was not done to the chemical composition of tannins and the pollution load of its effluent. Along these lines, this current research was examined to fill this research gap through the extraction and chemical characterization of *H. Abyssinica* tannins, which was utilized for sheep (preserved by ash salt) crust leather production. Further, the current research considered the pollution load of *H. Abyssinica* effluent compared with mimosa (commercial vegetable tannin) effluent that gathered during the sheepskin prepared into leather.

2. Methodology

2.1. Sample collection

The freshly matured bark of *H. abyssinica* (estimated 25–30 years aged, 18–20 m height) was collected from Gerese Woreda, Gamo Zone, Ethiopia. The readily pickled sheep skins and mimosa tannin material (control) were collected from Leather Development Institute, Addis Ababa, Ethiopia. Some laboratory-grade chemicals were used for the processing and characterizations in this study.

2.2. Methods

2.2.1. Extrication of tannin from *Hagenia abyssinica* powder

The tannin was extricated in aquatic medium. The prepared bark powder was dissolved in water according to powdered bark–water ratio, 1:10 (w/v) with different soaking times (6–48 hours); the solution was boiled for one hour each at different temperatures ranged 60–80°C (the best five extraction conditions were mentioned in Table 1 according to the response, % yield) . Then, the solution was filtered with cotton fabric and concentrated under vacuum by an employed rotatory evaporator to obtain a thick extract. It was then transferred into crucibles and kept to dryness in a hot air-oven at 60°C to another 1 hour (Isam & Christina, 2016).

2.2.2. Tanning and other processing of sheep skins

Two pieces of readily pickled sheep skins were used (targeted their butt parts) for vegetable tanning and other required leather processing for the production of bio-tanned leather. This processing was carried out on four samples (that chosen as two control samples (cont. I, cont. II) and two experimental samples (expt. I; expt.II). In this current study mimosa and *H. abyssinica* were used as tanning agents for control and experimental samples respectively. In these control and experimental samples, cont.I and expt.I was preserved by NaCl (existing in leather industries); whereas cont.II, and expt.II was preserved by ash salt, which was reported by authors (Franco et al., 2019b). All the processing steps (Kuria et al., 2016) for both control and experimental samples were functioned under in similar circumstances (recipes, pH, time, temperature, etc.) which are shown in Table 2.

2.2.3. Characterization of *Hagenia abyssinica* tannins

A qualitative test was carried out to characterize the type of tannins present in *H. abyssinica* bark extracts (Bureau of Indian Standards (BIS), 2007; Yisa, 2009). Moisture content, total solids and total soluble-solid of the tannins were also determined by Bureau of Indian Standards (BIS) (2007). Chrome-hide powder method of tannin examination was used for the estimation of non-tannins. The amount of tannins available on the bark extricate was estimated according to the method described by Bureau of Indian Standards (BIS) (2007).
Table 1. The extraction conditions and percent yield of tannin from the bark powdered of *Hagenia abisinica*

| S/No. | Amount of filtrate employed (Liter) | Boiling time (Hours) | Soaking time (Hours) | Temperature (°C)* | Tannins obtained (g) | Yield (%) |
|-------|-----------------------------------|----------------------|----------------------|-------------------|----------------------|-----------|
|       | 1.40                              | 1                    | 24                   | 65                | 33.33 ± 0.01<sup>a</sup> | 20.83 ± 0.05<sup>d</sup> |
|       | 1.40                              | 1                    | 6                    | 70                | 29.65 ± 0.14<sup>e</sup> | 18.53 ± 0.03<sup>a</sup> |
|       | 1.40                              | 1                    | 48                   | 80                | 36.82 ± 0.22<sup>o</sup> | 23.01 ± 0.16<sup>a</sup> |
|       | 1.60                              | 1                    | 24                   | 85                | 34.15 ± 0.03<sup>c</sup> | 21.34 ± 0.23<sup>c</sup> |
|       | 1.60                              | 1                    | 48                   | 75                | 35.55 ± 0.02<sup>b</sup> | 22.22 ± 0.03<sup>b</sup> |

Note: Means in columns in dependent variables that do not share a same superscript letter are significantly different with p < 0.05.

* indicates that the best runs were selected and compared with the effect of soaking time and temperature upon the optimization of extraction conditions.
Table 2. Recipe and other processing conditions of vegetable tanning for sheepskin

| Operations        | Name of recipes                      | Amount (%) | Time   | Remarks                          |
|-------------------|--------------------------------------|------------|--------|----------------------------------|
| **Tanning**       | Water (at 30°C)                      | 100        |        |                                  |
|                   | Mimosa (control), 3 portions         | 5.0        | 2 hours|                                  |
|                   | H. abyssinica (exp), 3 portions      | 8.0        | 2 hours|                                  |
|                   |                                      | 8.0        | 2 hours| pH: 3.8–4.5 leave over night     |
| **Next day**      | Fat-liquor (lipol J-622)             | 2.0        | 1 hour |                                  |
|                   | Formic acid (1:10)                   | 1.0        | 2 hours| pH: 3.8–4.2 collect water for tests |
|                   | Water (at 37°C)                      | 100        | 20 min.| Wash twice separately then drain |
|                   | Fungicides                           | 0.05       | 40 min.| Drained, pile & left 2 days for aging |
| **Post tanning**  | Wet back                             | 200        | overnight | Drained                          |
|                   | Wetting agent                        | 1.0        |        |                                  |
|                   | **Neutralization**                   |            |        |                                  |
|                   | Water                                | 50         | 1 hour | pH: 5–6                          |
|                   | Sodium formate                       | 1.0        |        |                                  |
|                   | Genetan neutro A2                    | 1.0        |        |                                  |
|                   | Sodium bicarbonate                   | 0.5        | 1 hour |                                  |
|                   | **Re-tanning**                       |            |        |                                  |
|                   | Water                                | 50         | 2 hours| Drained and washed               |
|                   | H. abyssinica for exp. Mimosa for control | 4.0   |        |                                  |

(Continued)
| Name of recipes | Amount (%) | Time   | Remarks                                      |
|-----------------|------------|--------|----------------------------------------------|
| Water           | 70         | 1 hour | Check dyeing by cutting                      |
| Leather blue BR (for both exp. and control) | 1.0        | overnight |                                              |
| Syntan 50       | 2.0        | 2.0    | Check liquors exhaustion                     |
| Retoil MD 80    | 2.0        | 1 hour | Drained, rinsed,ammed and set to dry         |
| Hot water (at 55°C) | 100       | 45 min. |
| Lipol J622      | 3.0        | 1.0    |                                              |
| Syntal FL 329   | 3.0        |        |                                              |
| Formic acid (1:10) | 1.0       |        |                                              |
2.2.3.1. Determination of moisture. Moistness and the total solid of the tannin sample were carried out according to Bureau of Indian Standards (BIS) (2007). About 2 g of H. Abyssinica tannin sample was weighed ($W_1$) and transferred into a moisture-free pre-weighing crucible and it was reweighed again with a sample taken as $W_2$. The sample container was heated up at 105°C in hot air-oven for 3 hours, and cooled in desiccators for 20 minutes, and reweighed again ($W_3$). The moisture content and total solid were calculated as:

$$\text{Moisture percent by weight} = \frac{(W_2 - W_3)}{W_1} \times 100 \quad (1)$$

$$\text{Total solid percent by weight} = \frac{W_2}{W_1} \times 100 \quad (2)$$

where: $W_1$ - the sample weight (g); $W_2$ - crucible weight + sample weight before drying (g)

$W_2$ - the weight of the crucible with residue left after drying (g)

2.2.3.2. Total soluble solid in tannin. Accurately weighed 20 g ($W_1$) of H. abyssinica extract was added into the 500 mL flask that contains 100 mL of distilled water ($V_1$). The solution was heated to a boil for about 20 minutes; filtered employing Whatman No.1 filter paper, and collected the filtrates in a fresh beaker. About 50 mL of the filtrate ($V_2$) was pipetted out into a silica basin and heated to the water bath. Then, allowed to dry and weighed till it obtains a persistent weight ($W_2$). The total soluble solids were calculated as per Bureau of Indian Standards (BIS) (2007):

$$\text{Total soluble solid} = \frac{W_2}{W_1} \times \frac{V_1}{V_2} \times 100 \quad (3)$$

where: $W_1$ - sample weight (g); $W_2$ - residue weight (left after drying, g)

$V_1$ - the volume of the solution made up originally (mL)

$V_2$ - the volume of the solution taken or pipette out (mL)

2.2.3.3. Determination of non-tannins

2.2.3.3.1. Hide powder preparation. The pickled hide was found ready and collected from Leather Development Institute where the sheepskins processed into upper-crust leather took place; and was ground into powder by using a grinder according to Alex Kuria et al. (2016).

2.2.3.3.2. Test for Non-tannins. The prepared hide powder (6.25 g) was weighed ($W_1$) and transferred into a 300 mL volumetric flask containing 100 mL of the unfiltered tannin mixture prepared; distilled water (20 mL) was added to it. The bottle was tightly closed with a stopper and shaken vigorously first by hands for 20 seconds and then transferred into a mechanical rotary shaker and was shaken well for 10 minutes at 60 rpm/minute. The powdered solution was then poured on a clean dry cotton filter cloth supported by a funnel, then drains and squeeze by hand. About 50 mL ($V_2$) of the filtrate was taken and evaporated in a tarred porcelain dish in an oven at 102°C, and then it was cooled and weighed until a constant weight ($W_2$) was observed. The residual weight was multiplied by 1.2 to correct for the 20 mL of water which was introduced into 100 mL of tannin solution for dilution according to the Bureau of Indian Standards (BIS) (2007) method; the non-tannin content was calculated as:

$$\text{Non tannins, (\%w)} = \frac{W_2}{W_1} \times \frac{V_1}{V_2} \times 100 \quad (4)$$

where: $W_1$ - the weight of the sample used (g); $W_2$ - weight of the residue left after drying (g)

$V_1$ - volume made up originally (mL); $V_2$ - the volume of the test solution to be taken (mL)
2.2.3.4. Determination of tannins. The determination of the tannin contented was carried out (Bureau of Indian Standards (BIS), 2007). It’s determined by finding the difference among the total soluble solids and the soluble non-tannins.

\[
\text{Tannins (%w)} = \frac{\text{Total soluble solids} - \text{Soluble nontannins}}{\text{Sample weight}}
\]  

(5)

2.2.3.5. Measurement of pH. The pH of extricated *H. Abyssinica* tannins was noticed by using a pH-meter (Jenway digital pH meter model: 3505) according to the official method Bureau of Indian Standards (BIS) (2007). Sample pH was measured after calibration of the pH meter in buffer solutions with pH 4 and 7.

2.2.4. UV-visible and Fourier transformation infrared (FTIR) spectroscopic study

Sample (*H. abyssinica*) extract was analyzed by using UV-Visible spectroscopy (model: Specord 50 PLUS, Germany) at 190–600 nm wavelength against a blank sample (Maria & Lina, 2013; Musa & Gasmelseed, 2012).

Structural identification of the extracted tannin sample was carried out by employing the KBr sample disc method using FTIR spectroscopy (model: IR Affinity-1S, Shimadzu, Japan). The fine grounded powder of the extracted tannin sample was mixed with KBr (FTIR grade) at a ratio of 1:100 and it pressed into a pellet and scanned at the range of 4000–600 cm\(^{-1}\) (Maria & Lina, 2013; Musa & Gasmelseed, 2012).

2.2.5. Physicomechanical characterizations and organoleptic properties of sheep leather

Evaluation of the physicomechanical characterization of the presently studied phyto-tanned leather was evaluated by employing international standards (International Union for Physical Testing (IUP2), 2000a, International Union for Physical Testing (IUP6), 2000b, and International Union for Physical Testing (IUP8), 2000c). The studied samples of all leathers were accustomed at 21.8°C and relative humidity 62.5% for 48 hours; all important physico-mechanical properties were evaluated. The outcomes of the study were compared to mimosa tanned leather (control). Hand evaluation assets (fullness, softness, grain-tightness, smoothness, color, and overall appearances) were also carried out by ten leather experts who rated their performance on a scale of 1–10 points.

2.2.6. Thermal stabilization of sheep leather

Specimens of leather samples (50 mm × 2 mm) were cut lengthways and crosswise the back bone of the bio-tanned leather. Holes were stamped at two ends of the cut sample to allow for vertical hanging in the test chamber. The filled water was heated to boiling at 100°C by using the outer heating system. The leather started to shrink that temperature was taken as shrinkage temperature of the study samples (IUP/16, 2001).

2.2.7. Chemical analyses of leather

Chemical analysis of the crust upper leathers of samples were evaluated by concerning moisture content (gravimetric method), ash content, oils/fats content (using Soxhlet extraction), and water-soluble matters (by oven method) were studied according to Bureau of Indian Standards (BIS) (2007).

2.2.7.1. Oils and fats content. The sample (5 g) was kept in a Soxhlet extractor attached to a pre-weighed flask and was extracted the oils/fats from the leather sample with 250 ml Ethanol, 97% (CH\(_3\)CH\(_2\)OH) at 90°C for 5 hours. After extraction, the solvent was separated from the fatty residue using a rotatory evaporator. Then dried the extract at 100°C in a hot air-oven up to 4 hours, cooled, and weighed dried extract. The fat content (%) was calculated as (Bureau of Indian Standards (BIS), 2007):

\[
\text{Amount of fat} = \left( \frac{\text{Extract weight}}{\text{Sample weight}} \right) \times 100
\]  

(6)
2.2.7.2. Total ash content. Accurately weighed 5 g of crust leather of the study sample was kept in a pre-weighed moisture-free porcelain dish; it was carefully heated on the hot plate until it was carbonized. The further ashing process was completed in a hot muffle furnace, at 800°C until all carbon might be consumed. Then, it’s kept in a desiccator for cooling and weighed the amount of ash obtained, which was estimated as (Bureau of Indian Standards (BIS), 2007):

\[
\text{Ash(\%)} = \frac{\text{Ash obtained (g)}}{\text{Original amount of sample used (g)}} \times 100
\]  
(7)

2.2.7.3. Water soluble matter. After the extraction of fats, the air-dried sample of the presently studied leather was introduced in 500 mL of de-ionized water and shaken well by employing a mechanical shaker at 55 rpm for 2 hours at 25°C in a wide-necked flask. Then, the content of the flask was filtered into the dried flask. Then, 50 mL of the filtrate was measured and transferred into the dried pre-weighed dish and evaporated the water on the water bath until dryness. The drying was continued until the weight of residue became less than 2 mg. Total water-soluble matter in the sample was calculated as (Bureau of Indian Standards (BIS), 2007):

\[
\text{Total water soluble matter (\%)} = \frac{\text{weight of dry residue (g)} \times 10}{\text{Sample weight (g)}} \times 100
\]  
(8)

2.2.8. Evaluation of pollution loads in tanning liquors

2.2.8.1. Total dissolved solid (TDS). Moisture-free empty porcelain dish was weighed (initial weight) and the sample was taken and filtered by employing Whatman No.1 filter paper. Then, filtrate (100 mL) was kept in a water bath to dry. It was kept in a hot air oven at 103°C for 1 h; cooled in desiccators and measured the final weight of the dish with residue; TDS was calculated as (AOAC, 1996):

\[
\text{Total dissolved solids (mg L}^{-1}) = \frac{(A - B) \times 1000 \times 1000}{\text{Sample volume mL}}
\]  
(9)

where: A - -the dried residue + dish weight (mg); B - the weight of empty dish (mg)

2.2.8.2. Total suspended solids (TSuS). A well-mixed sample (100 mL) was taken and residue was filtered by using a pre-weighed filter paper. The filter paper holding the suspended solid that was wrapped in an aluminum foil was kept for drying in a hot air-oven at 105°C about a 1 h. Then, filter paper was chilled in a desiccator and re-weighed it. Increase in weight of filter paper represents the amount of TSuS (in mg/L), it was calculated according to the AOAC (1996):

\[
\text{Total suspended solids (mg L}^{-1}) = \frac{(A - B) \times 1000}{\text{Sample volume mL}}
\]  
(10)

where: A - weight of filter paper + dry residue (mg); B - pre-weighed filter paper weight (mg)

2.2.8.3. Chemical oxygen demand (COD). About 100 mL of the sample (sheepskin process effluent) was diluted with distilled water and was transferred to a refluxing flask (500 mL); 1 g of mercuric sulphate and H2SO4 (5 mL) were added on it, mixed thoroughly, and cooled to room temperature. Accurately 0.0417 M K2Cr2O7 (25 mL) solution was added to the mixture, stirred well and connected the flask with the condenser, and turn on cooling water. Additionally, H2SO4 (70 mL) was added through the open-end of the condenser with churning and mixing. The solution was refluxed for 2 hours, cooled, and then washed down the condenser with distilled water to double the volume of contents. About 2 drops of ferroin indicator were added to the refluxing mixture and titrated with standard ferrous ammonium sulfate (FAS) that drained from a burette, the remaining un-reacted potassium dichromate was titrated until a color change from bluish-green to reddish-brown. Distilled water (blank) was also refluxed and titrated with FAS. COD of the samples was calculated as (AOAC, 1996):
2.2.8.4. Biological oxygen demand (BOD). The biological oxygen demand was determined according to AOAC (1996). About 100 mL of diluted samples were taken, saturates with air by shaking in partly filled bottles by sparkling with organic-free filter air, and measured the dissolved oxygen (DO); after five days of incubation measured (at 27°C) the DO of the samples. The DO consumption was measured as follows:

$$\text{BOD} \left( \frac{\text{mg}}{\text{L}} \right) = \frac{\text{DO}_1 - \text{DO}_2}{\text{P}}$$

(12)

where: DO1-dissolved oxygen in diluted sample (mg/L); DO2-dissolved oxygen in diluted sample after 5 days incubation at 27°C (mg/L); P-decimal volumetric fraction of sample used.

2.2.9. Statistical data analysis

The analysis of the data of tanned leathers of both control and experimental groups was carried out by using a statistical package for social science (SPSS); means and standard deviations with confidence limits (p-value) were set at $p \leq 0.05$.

3. Results and discussions

3.1. Percentage yield of tannins from Hagenia abyssinica bark powder

Water (solvent) was used in this study for the extraction of tannins. The results demonstrated that 24 hours of soaking time with various temperatures produced fewer yields without significant differences among triplicates. In this present study, the highest percent yield (23.01%) was achieved in 48 hours (shown in Table 1) of soaking time at 80°C however the inferior percentage yield (18.53%) was recorded at lower soaking time (6 hours) at 70°C. Thus maximally, 0.23 g of dried extract was obtained per each gram of H. abyssinica powdered sample used. Thus, it concludes that soaking period and temperature are key factors affects the percent yield during H.abyssinica tannin extraction. Musa and Gasmelseed (2012) reported that 33–35% of extract which contains 11.12% of tannins from henna leaves by co-current spray dryer apparatus. But, in this current study (Table 3) higher yield of tannin (15.49 ± 0.11 %) was obtained from the 23.01 % yield of extract under soaking (maceration) method with the appropriate extraction conditions.

3.2. Characterizations of Hagenia abyssinica extract

3.2.1. Qualitative analysis

The characteristic blue color was observed upon the addition of a few drops of ferric chloride into the sample solution that confirms the presence of tannins that are suitable for tanning of leather (Bureau of Indian Standards (BIS), 2007).

The crude extract was tested to distinguish the types of tannins (condensed or hydrolyzable) by the addition of few drops of aqueous KOH into the extract that forms red precipitate that clearly shows the presence of condensed tannins similar to mimosa and quebracho (Yisa, 2009).
3.2.2. Quantitative determination

Quantitative analysis of tannin extract was carried out and the results obtained are given in Table 3. The result shows that the extract of *H. abyssinica* contains total moisture, total solids, and total soluble solid as 4.2 ± 0.13%, 96.13 ± 0.05%, and 23.01 ± 0.14% respectively, and the extract also contained tannins (15.49 ± 0.03%) and non-tannin contents (7.52 ± 0.11%). The level of tannin strength was found to be 2.06 ± 0.08% and the pH of the extract was 4.70 ± 0.04, which is within the required range (pH 4–6) for most of the tannins to be active for tanning (Eaton et al., 1995; Hougham, 2006). Thus, *H. abyssinica* is a newly emerging vegetable tannin material that could be used in leather industries. It has higher total solids, closer amount of tannins, and tannin strength was obtained (shown in Table 3) in the present study when compared with the results reported by Obiero (2016), which was studied *Plectranthus barbatus* tannins (have 20% tannin from leaves, 8% in stem, and 10% tannin in its combinations) that collected from different locations in Kenya; and the presently studied results (Table 3) were also found as higher total solids, tannins, tannin strength that reported by Musa and Gasmelseed (2012) in *Lawsonia inermis* (Henna) tanning material has tannin content (11.12%), non-tannin content (22.64%), total soluble solid (33.76%), total solid (56.66%), moisture (9.58%) and pH (4.5). Nevertheless, the standard commercial mimosa had a greater amount of moisture content (6–9%), total soluble solid (73–94%), tannin (63–66%), non-tannin content (24–29%), tannin strength (2.2–2.8%) and lower total solid (91–94%), comparable pH (4.6–4.7) with presently studied *H. Abyssinica* tannins. Comparatively, there were found some differences in tannin, non-tannin, total soluble solids, and total solid. This may be due to the plant species, soil type, climate, plant age, plant origin, pH of the soil, and the bark size in addition to solvent type and extraction methods (Latif et al., 2015).

| Properties characterized | Composition of *H. abyssinica* bark extract |
|---------------------------|------------------------------------------|
| Moisture content (%)      | 4.20 ± 0.13                              |
| Total solid (%)           | 96.13 ± 0.05                             |
| Total soluble solid (TSS, %) | 23.01 ± 0.14                           |
| Non-tannin (NT, %)        | 7.52 ± 0.11                              |
| Tannin (% T = TSS - NT)   | 15.49 ± 0.03                             |
| Tannin strength (% TS = T/NT) | 2.06 ± 0.08                           |
| Purity ratio (T/TS, %)    | 0.16 ± 0.02                              |
| pH                        | 4.70 ± 0.04                              |

3.3. UV-visible spectroscopic study

UV-visible spectroscopy was used as a complementary qualitative technique to FTIR to analyze tannin extracts. The classes of tannins from different plant sources show different characteristic absorption bands based on their constituents (Maria & Lina, 2014; Musa & Gasmelseed, 2012). The absorbance is proportional to the concentration of tannin and also related to the purity level of tannins. The lesser absorbance indicates the existence of non-tannin materials (carbohydrates, fats, salt, etc.) (Maria et al., 2018; Maria & Lina, 2014). The UV-visible spectrum of *H. abyssinica* aqueous extract is presented in Figure 1.

The spectrum displayed the intensity of absorption bands around 211 nm, which is a wavelength of a minimum absorbance (λ_{min}) between 210–220 nm; two maximum absorbencies λ_{max,1} and λ_{max,2} at 308 nm and 348 nm. Some peaks of absorbencies also appeared at 230 nm and 258 nm (Ramesh et al., 2020). It shows that the absorbance band directly started declining from 350 nm through the visible region. This may be due to the presence of non-tannins (carbohydrates, fats, salt, acid, etc.) in the sample. A similar study conducted by Jiongjiong
et al. (2019) reported that condensed tannins (mimosa and Quebracho) were consistent; they presented strong absorptions around 200–220 nm, an inflection point (λ_{min}) between 258–259 nm and (λ_{max}) between 279–281 nm. Thus, the presently studied extract of *H. abyssinica* contains condensed tannins, which were used as bio-tannins.

**3.4. Fourier transformation infrared spectroscopic study**

Fourier transform infrared (FTIR) spectroscopic study is one of the common and powerful analytical techniques used for the identification of functional groups in the samples. FTIR spectroscopic study of the presently studied *H. abyssinica* tannin sample was perfectly achieved at a range of 4000–400 cm\(^{-1}\) and the corresponding FTIR spectrum is presented in Figure 2.
It demonstrated the informative result of intensified spectra in the range of 1500–1000 cm⁻¹. These wavenumbers are in the fingerprint region and they are typical absorbance of phenolic molecules that are useful for better sample identification (Jiongjiong et al., 2019). But sometimes it is difficult to identify functional groups in the fingerprint region. There were several absorption bands present in fingerprint region at 505.13 cm⁻¹, 781.05 cm⁻¹, 816.79 cm⁻¹, 885.18 cm⁻¹, 1049.53 cm⁻¹, 1106.17 cm⁻¹, 1318.98 cm⁻¹, 1366.72 cm⁻¹, 1455.40 cm⁻¹, and 1511.33 cm⁻¹ most of which are strong sharp bands. By considering FTIR spectra; the bands intensified around 400 cm⁻¹, stretched, and peaked out at 505.13 cm⁻¹ were stretching vibrations that are not informative for condensed tannin analysis.

Based on the results are displayed in Figure 2, the spectrum of absorption characteristic bands has indicated that the studied sample consists of condensed tannin materials. This was evidenced by the distinct absorption bands at 1106.17–1049.53 cm⁻¹, 1366.72–1318.98 cm⁻¹, and 1511.33–1455.40 cm⁻¹ these bands are assigned to an asymmetric stretching ester (C–O) indicating the presence of condensed tannin; strong stretching band appeared at 1620.00 cm⁻¹ referred as aromatic ring (C = C) bonds, and absorption band present at 1736.41 cm⁻¹ associated with C = O stretching i.e. aromatic ester groups in the *H. Abyssinica* extract. Another absorption peak at 2940.50 cm⁻¹ was observed, it is to be assigned to—CH₃ and CH₂ bonds and the medium broadband appears at 3422.50 cm⁻¹, which indicates a typical—OH bond. This result matched with the previous study that the band that appears in the region of 3500–3000 cm⁻¹ is assigned to OH stretching vibration in the phenolic and aliphatic structures (Ramesh et al., 2020; Sartori et al., 2018). Hence, the studied FTIR spectrum established that the occurrence of condensed tannins in the presently studied *H. abyssinica* bark sample.

### 3.5. Chemical analyses of bio-tanned crust upper leathers

The chemical properties of the crust leathers of bio-tanned samples (control and experimental) are presented in Figure 3. Moisture content (%) of the bio-tanned leather expt.I sample has 5.25 ± 0.05 which was lower in comparison with mimosa tanned cont.I (7.6 ± 0.07); this is because the fibers of crust leather (expt.I) sample contained hydrophobic groups that de-absorb humidity from the surrounding (Abdul et al., 2018). In the case of expt.II, sample the moisture content was about 5.81 ± 0.08 %, which was found as compared to its cont.II (5.68 ± 0.22%) with no statistically significant (p-value is 0.361). This revealed that the *H. Abyssinica* has bio-tannins material like those found in mimosa.

The fat amount in the presently studied leather of expt.I has reported as 18.4 ± 0.38 % compared to cont.I (18.5 ± 0.27 %), shows no significant difference (p-value is 0.724). Hence, the
used tanning material in expt.I may have the comparable effect (with cont.I) on the distribution or absorption of fats applied in expt.I. However, a fat content of expt.II has 19.09 ± 0.05 % compared to cont.II (17.86 ± 0.09 %) with a statistically significant effect (p-value; 0.000); it shows that expt. II absorbed more fat than cont.II. This is due to the presently used tanning method that might have a good effect on the fat distribution on leather (cont.II). The findings in the present study agreed with the specification for shoe upper leather (Indian Standard (IS) Specification for Shoe upper leather for direct molding, 2003), displaying the elasticity and flexibilities of the leather with reports that high-fat content in leather could increase the tensile strength. The result affirmed that leathers tanned with H. abyssinica tannin material required fewer fats/oils compared to mimosa.

**Figure 3** describes also the total ash contents found in expt.I (7.56 ± 0.07 %), cont.I (5.75 ± 0.06 %), and in expt.II (7.61 ± 0.03 %), cont.II (5.81 ± 0.05 %). Both cases have statistically significant (with p-value: 0.000) that are compared with their controls. This is maybe because of H. abyssinica tanned leathers (expt.I and II) having absorbed more fats during fat-liquoring compared with the controls (Philipa & Ahamed, 1994). Total soluble matter resembles to the complex of tannins on the collagen and makes the stabilization of leather. The results (shown in **Figure 3**), confirmed that water-soluble matters of expt.I was found to be 8.66 ± 0.04 % and in cont. I found as 8.84 ± 0.03 % (with p-value: 0.005). This proved that there was a significant difference in the results (p < 0.05). In the case of expt.II, the water-soluble matters were reported to be 9.53 ± 0.03 % against its cont. II 8.99 ± 0.05 % has p-value: 0.000 (statistically significant). Hence crust upper leather treated with condensed tannins was confirmed that to have low water-soluble matter confers high stability because of proper fixation resulting from non-tannin, acids, and their salts. The soluble matter in expt.II was greater (99.53 ± 0.03 %) than the respective control because substances are not actively involved in tanning activities, dissolved out of the leather by water (Nouredine et al., 2017).

### 3.6. Physicomechanical characterizations of bio-tanned crust upper leathers

The results of tensile strength, elongation at break, tear strength, and thickness for control and experimental study on sheep leathers were presented in **Table 4**. Tensile strength in leather technology is referred to as an indication of the resistance of crust upper leather to break. Therefore, it is of greater importance to be considered for the determination of tensile strength after every tanning process. The tensile strength of bio-tanned sheep (**Table 4**) leather expt.I was found to be 10.25 ± 0.03 N/mm² but the corresponding cont.I had 19.80 ± 0.03 N/mm². Also the expt.II has a tensile strength of 11.91 ± 0.03 N/mm² compared to its cont.II has 19.91 ± 0.02 N/mm². There was a statistically significant difference with p-values: 0.000 (p < 0.05). This may not be attributed to the poor strength of fibers of the raw skin (expt.I & expt.II) because they were from two different sheepskins. It was found that the two samples (expt.I & expt.II) absorbed more fats (shown in **Figure 3**) from the pre-tanning system (pre-tanning by aldehyde-based syntan’s such as Syntal tan 40 ACC and Syntan SO) that exceeded the maximum limits which may prevent more tannin from penetrating skin tissues or from proper reaction with collagen. Another reason could be noticed that the tanned leather could not properly absorb moistures during 48 hours of conditioning due to the presence of many hydrophobic fibers resulted from more fats absorption in the leathers tanned with H. abyssinica tannin material. It was justified that, condensed tannins penetrate rapidly and aggregate more readily in the pelt fibers, and deposited very large molecules that cross-linking through a hydrogen bond to the peptide groups of the collagen (Alim et al., 2016). When phyto-tannins reacts with collagen, they improve the bonding between the fibers of the skin, and skin structure gets stabilized, it was confirmed through literature reported (Latif et al., 2015). Thus, the tensile strength of presently studied samples (preserved skins and bio-tanned skins) is lined up with the reported values.

A higher elongation value signifies that a good amount of tannin material has reacted with the collagen fibers. The mean values of the elongation at break attained on expt.I were about 45.71 ± 0.02% compared to cont. I (36.72 ± 0.03 %) and for expt.II and cont.II, findings were reached 45.81 ± 0.02% and 37.52 ± 0.03% respectively. Thus, the results were in the range of minimum requirement (40–65 %) except for all control results. The results are well agreed and stated that
Table 4. Physico-mechanical characterizations of crust leathers of controls and experiments of vegetable tanning

| Parameters                        | Experimental Method | Cont. I | Expt. I | ANOVA P-value |
|-----------------------------------|---------------------|---------|---------|---------------|
| Tensile strength (N/mm²)          | Cont. I             | 19.8 ± 0.03³ | 10.25 ± 0.03² | 0.000 |
| Elongation at break (%)           | Cont. I             | 36.72 ± 0.03³ | 5.71 ± 0.02² | 0.000 |
| Tear strength (N/mm)              | Cont. I             | 27.82 ± 0.02² | 26.90 ± 0.04³ | 0.000 |
| Thickness (mm)                    | Cont. I             | 1.10 ± 0.10² | 1.13 ± 0.13³ | 0.738 |

MR = Minimum requirement. Means in rows (each case) that do not share a letter are significantly different with p < 0.05.
elongation values are influenced by the large or small tannin material that penetrates and binds to collagen fibers (Untari et al., 2009). Hence, elongation at break of *H. abyssinica* bio-tanned leathers (expt.I and expt.II), upper leather have fulfilled the minimum requirements of elongation. So, this study confirms that ash salt-preserved sheepskins tanned with *H. abyssinica* tannins are might be used as a potential alternative bio-tanning material reported earlier by the authors (Franco et al., 2019a, 2019b).

Tear strength is aimed at determining the resistance to tear of the upper leather due to stitches; when the leather is in regular use. The tear strengths of vegetable tanned leathers for a mimosa (control) and *H. abyssinica* (experiments) were presented in Table 4. The mean value obtained for expt.I was 26.90 ± 0.04 N/mm² in comparison to cont.I 27.82 ± 0.02 N/mm²; and in expt.II and cont.II, the results were found to be 27.27 ± 0.06 N/mm² and 26.80 ± 0.04 N/mm² respectively, which is to be found as statistically significant with p-values: 0.000 (p < 0.05).

Thickness is one of the important physical properties that affect the stability of the skin when the perfect skin cross-linkage formed between tannin materials and protein collagen of tanned leather. The results of cont.I, expt. I, cont.II and expt.II were revealed that all are almost uniform in thickness (shown in Table 3) about closed to 1.0 mm, with no significant difference (p > 0.5). The differences in thickness are due to the capability of tannins that can increase the content of the skin and fill the empty spaces of the fiber network so that it becomes thicker (Untari et al., 2009).

It was reported that the highest average thicknesses recorded by the skin butts were 1.23 mm (Alim et al., 2016). Therefore, the current study results were within the allowable limit; it’s proved and recommended that the *H. abyssinica* is been an alternative eco-friendly tanning material into leather industries.

### 3.7. Determination of the degree of shrinkage temperature

Shrinkage temperature ($T_s$) is a measurement of the breakdown of stabilizing linkages existing in the collagen matrix. The main aim of this component of the study is to understand whether the new tanning systems being tested have any effect on the destabilization of the collagen matrix or not. The shrinkage temperature of the experimental samples and corresponding controls for bio-tanned sheep leathers were measured and presented in Table 5.

The better $T_s$ was attained on expt.I sample that tanned with *H. abyssinica* was measured about 73.3 ± 0.05°C in comparison to cont.I 75.1 ± 0.03°C tanned with standard commercial mimosa. $T_s$ of Expt.II and cont.II was measured about 78.5 ± 0.06°C and 75.2 ± 0.11°C respectively. In expt.I and cont.I, have the minimum variation in temperatures could be because mimosa possessed high condensed tannins and tanning strengths compared to *H. abyssinica*. Whereas in expt.II, and cont. II has little wider variation, this could be attributed to the greater enhancement of the cross-linking reactions taken place between the collagen fibers and the *H. abyssinica* tannin materials, as a result, the shrinkage temperature of the crust leather was found as raised.

It was revealed that good-quality leather should have a minimum shrinkage temperature of 75°C (Alex Kuria et al., 2016). Apart from ionic interaction that brings the tannins close to collagen fibers, other factors like H-bonds and van der Waals attractions must be involved in tanning, the weak character of such binding forces could be well account for the relatively low shrinkage temperature of vegetable tanned leather (Purnomo, 1985). Accordingly, all the experimental leathers tanned with *Hagenia abyssinica* extracts attained that minimum requirement of shrinkage temperature. Researchers around had reported the highest wrinkle temperature of mimosa extract ranged 70–85°C (Abdella et al., 2018; Maria & Lina, 2013; Sofiane et al., 2014).

Research’s suggested that condensed tannin typically raises the shrinkage temperature of collagen to (80–85°C). In this context, the presently studied bio-tanned sheep crust leathers have the shrinkage temperature in line up with the reported literature, and it’s recommending to
suggest the *H. abyssinica* tanned sheep crust leathers can be used commercially in the leather industries (Abebe, 2019; Liu et al, 2013).

### 3.8. Assessment of pollution masses generated in vegetable tanning liquors

Pollution load generated in the tanning liquors of control and experimental samples was analyzed in terms of TS, TSS, TDS, COD, BOD, and the results were obtained which is shown in Table 6. Findings of the present study demonstrated that there was a significant difference (p < 0.05) obtained in the values of TS, TDS, and COD with p-values found as 0.000, whereas TSS (p:0.059) and BOD (p:0.099) that’s found as no statistically significant (shown in Table 6) between tanning liquors of mimosa (control) and *H. abyssinica* (expt.). Comparably, *H. abyssinica* tanned liquor has a lower load of TS, TSS, and COD but it has a slightly greater load on TDS and BOD (Table 6). Therefore, based on these proven results it is recommended that *H. abyssinica* be employed commercially for the tanning of leathers. Also, the pollution load of the tanning liquors discharged from the present study has lower COD and BOD than the spent liquor processed using stunt bark re-tanning (as re-tanning sample) liquor that studied earlier (Abdella et al., 2018; Abebe, 2019); also the pollution load of the presently studied results found as within the allowable limits, which compared with the Ethiopian pollution guideline (Abebe, 2019).

### 3.9. Characterization of organoleptic properties

The mean values on an organoleptic assessment by four expert leather technologists on the bulk properties such as fullness, softness, grain tightness, smoothness, color, and overall appearances for sheep crust leathers of both experimental samples (*H. abyssinica*) and controls (mimosa) are described in Figure 4.

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### Table 5. Shrinkage temperatures of vegetable tanned sheep leathers

| Sample type | Shrinkage temperature (°C) | ANOVA p-value |
|-------------|-----------------------------|---------------|
| Cont. I     | 75.1 ± 0.03<sup>a</sup>     | 0.000         |
| Expt. I     | 73.3 ± 0.05<sup>b</sup>     |               |
| Cont. II    | 75.2 ± 0.11<sup>c</sup>     | 0.000         |
| Expt. II    | 78.5 ± 0.06<sup>d</sup>     |               |
| Recommended value | 75                             |               |

Note: Cont. I & II = mimosa; Expt. I & II = *Hagenia abyssinica*.
Means in columns (each case) that do not share a letter are significantly different with p < 0.05.

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### Table 6. Pollution load (mean±sd) in the tanning liquors of mimosa and *H. abyssinica* tanning

| Parameters     | Mimosa          | *Hagenia abyssinica* | ANOVA p-value | Allowable limits (as per Ethiopian standard) | Reference |
|----------------|-----------------|----------------------|---------------|---------------------------------------------|-----------|
| TS (%)         | 9.65 ± 0.05<sup>a</sup> | 9.25 ± 0.45<sup>b</sup> | 0.000        | N.A                                        | -         |
| TS<sub>u</sub>S (mg/L) | 6.37 ± 0.33<sup>a</sup> | 6.30 ± 0.20<sup>b</sup> | 0.059        | 50 mg/L                                    | Abebe, 2019 |
| TDS (mg/L)     | 58.70 ± 1.80<sup>a</sup> | 59.45 ± 1.15<sup>b</sup> | 0.000        | N.A                                        | -         |
| COD (mg/L)     | 8.30 ± 0.20<sup>a</sup> | 7.35 ± 0.85<sup>b</sup> | 0.000        | 500 mg/L                                   | Abebe, 2019 |
| BOD (mg/L)     | 3.85 ± 0.05<sup>a</sup> | 3.90 ± 0.05<sup>b</sup> | 0.099        | 200 mg/L                                   | Abebe, 2019 |

Note: Values are given in triplicate measurements; N.A—not available.
Means in rows that do not share a letter are significantly different with p < 0.05.
TS: Total solid; TS<sub>u</sub>S: Total suspended solid; TDS: Total dissolved solid; COD: chemical oxygen demand; BOD: biological oxygen demand.
Results exhibited that expt.I (7.5 points) and cont.I (7.45 points) comparably had better (Figure 4) in fullness. Both of them were having better absorption and fixation of vegetable tannins. On the other hand, expt.II (7.88 points) was better at fullness against the cont.II (6.75 points). *H. abyssinica* tanned crust leather had shown better fullness (better absorption) than mimosa tanned leather.

The results also signified that expt.I (8.13 points) was observed to have more softness than cont. I (7.5 points). This may be due to more absorption of fats during the fat-liquoring process. This result illustrated that to get comparable softness in all leathers; leathers tanned with *H. abyssinica* need less fat in the fat-liquoring process, hence felt was softer than control. In the case of exptt.II (7.88 points), the softness was compared higher to cont.I (7.13 points). This result illustrated that to get comparable softness in leathers; *H. abyssinica* tanned leathers need less fat in the fat-liquoring process. This is an advantage of *H. abyssinica* over the commercial mimosa.

The better grain tightness of experimental samples over its control is associated with good penetration and fixation in leathers tanned with *H. abyssinica*. Whereas penetration in the cases of cont.I and cont.II was not satisfactory to influence the grain tightness, this may be due to incomplete opening of the fibers in beam house operation. Better smoothness in samples studied against their corresponding controls was attributed to the fullness of crust leathers tanned with *H. abyssinica* than a mimosa.

The *H. abyssinica* tanned samples such as expt.I (8 points) and expt.II (7.25 points) have exhibited better smoothness compared to their corresponding controls (cont.I: 7.38 points and cont.II: 7 points). These results were attributed to the better fullness of crust leathers tanned with *H. abyssinica* than a mimosa.

Regarding color, all the studied samples (expt.I and expt. II) had a uniform and deepest colors (Figures 4 and 5) in comparison to all controls (cont.I and II) having light and uneven colors (Figure 5). Uneven color on the grains of control leathers indicated the reactivity nature of the tannins used. The uniformity in colors shown on expt.I and expt.II demonstrated the most advantage of *H. abyssinica* over commercial mimosa, i.e. to get the light color of dyed crust leather like that of mimosa, it needs only half of the percentage of dyestuff used for dyeing mimosa crust.
leather. The reason for the color uniformity on the experimental samples could be that they absorbed more fats from the pre-tanning system (pre-tanning syntan) that exceeded the maximum limits which may prevent more tannins from penetrating skin tissues or prevent a proper reaction, hence less astringency on the surface crust leathers. It was stated that condensed tannins penetrate rapidly and aggregate more readily in the pelt fibers and deposited very large molecules that cross-linking through a hydrogen bond to the peptide groups of the collagen (Alim et al., 2016).

In general, these results suggested that expt.I and expt.II of crust upper leathers tanned with H. abyssinica have excellent overall appearances compared to cont.I and cont.II of crust upper leathers tanned with commercial mimosa respectively. Crust upper leathers tanned with H. abyssinica exhibited excellent penetration, fixation, uptake of fats, and color uniformity due to less astringent of their grains. It was demonstrated that vegetable tannins are chosen based on their organoleptic properties such as fullness, filling, and softening that they provide to leather products (Nilay et al., 2014). Thus, the H. abyssinica bio-tanned leathers were rated based on the performances of the studied organoleptic properties as Expt.I > Expt.II > Cont.I > Cont.II.

4. Conclusions

The plant-based new tannin material was extracted from the bark powder of Hagenia abyssinica, which was used for tanning of sheepskins as a replacement for chrome tanning. Characterizations of H. abyssinica extract revealed that the plant has a higher condensed tannin type. UV-visible and FTIR spectroscopic studies were carried out and the resulting spectrums showed the characteristic wavelengths and bands, which confirmed that H. abyssinica has condensed tannins. Physicomechanical and chemical characteristics of all studied leathers were confirmed and the outcomes encountered the requirements. The highest shrinkage temperature attained by H. abyssinica tanned crust leathers was $78.5 \pm 0.06{\degree}C$ compared to $75.1 \pm 0.0{3}{\degree}C$ of mimosa (control).

Analyses of bulk properties shown that crust leathers of H. abyssinica performed much better than crust leather of standard commercial mimosa. The pollution load of the tanning liquors of H. abyssinica has a lower load in terms of TS (9.25 ± 0.45), TSS (6.30 ± 0.20), and COD (7.35 ± 0.85) but it has a slightly greater load on TDS (59.45 ± 1.15) and BOD (3.90 ± 0.05) than mimosa tanned liquor as TS (9.65 ± 0.05), TSS (6.37 ± 0.33) and COD (8.30 ± 0.20), TDS (58.70 ± 1.80) and BOD (3.85 ± 0.05).
Therefore, this study concludes that *H. abyssinica* is a suitable vegetable tanning material and should be considered for commercial tanning of leather that can promote cleaner production technology. Furthermore, these research results recommend to the research communities, tanners, and authority of novel material developers that are involved in leather production to support the development of novel alternative vegetable-based tannins.

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