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Abstract: Chrome tanned leather accounts for 90% of leather in the world. However, chromium is a global environmental disaster and puts the health of millions of leather workers and ordinary citizens at risk. The use of natural materials that is eco-friendly on leather as vegetable tanning is therefore, a matter of significant importance. Thus, the current study focused to investigate the potential effectiveness of the extracted tannin from Sodom apple (Solanum Incanum) fruit as vegetable tanning agent on goatskins. It was extracted with distilled water, methanol, petroleum ether and ethanol by using Soxhlet extraction method. Although the amount of material extracted was significant in all extracting solvents, water was a more efficient solvent (extraction yield of 16.71%) than the others. The qualitative analysis and structural characterization of the extracts were done using thin-layer chromatography (TLC), Ultraviolet (UV) spectrometer and Fourier Transform Infrared (FT-IR) spectrometer which confirmed the presence of condensed tannins in the extract. The Scanning Electron Microscope (SEM) was carried out to study the effect of the tannin system on the structural and morphological characteristics of the tanned leathers. Similarly, the organoleptic and strength properties of the tanned leathers were evaluated in comparison with the control ones. Finally, the pollution load of tanning liquors in Sodom apple tanning was significantly reduced as compared to the control (mimosa). Hence, from the current

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PUBLIC INTEREST STATEMENT

Greener Approach for Goatskin Tanning: Leather processing and manufacturing industry involves a variety of harmful chemicals that released to the environment during leather processing and adversely affect the human life and other organisms. Among chemical species that used in the leather processing industry is chromium in which it is used for leather tanning process. Chromium in the highest oxidation state (CrVI) is highly carcinogenic and therefore, designing a means of replacing the chemical tanning agents with green and environmentally safe vegetable tanning agents is unquestionable issue. Hence, the current work is focusing on the evaluation of the tanning potential of Sodom Apple (Solanum Incanum) fruit extracts for goat skin tanning processes, which was found to be a very effective and safe to the environment as well. The result of current study was compared with the mimosa (commercially available vegetable tanning agent) extracts and it was found be better in both tanning efficacy and safeness to the environment.
study, it is possible to conclude that Sodom apple fruit extract is a cleaner alternative and promising pathway for goatskin tanning.

Subjects: Production Systems; Manufacturing & Processing; Manufacturing Engineering; Chemical Engineering

Keywords: goatskin; Sodom apple; pollution load; vegetable tannins

1. Introduction

Leather industry is the environmental concern of all over the world as it releases huge amounts of chemical effluents to the environment especially during tanning step of the process. In Ethiopia there are large number of leather industries which are commonly using chemicals for tanning process and release tremendous amounts of chemical pollutants to the environment. Tanning is a process in which the leather-making protein is completely stimulating against heat, enzymatic biodegradation, thermomechanical stress by converting the fibrous protein of raw hide or skin into stable material and making the leather suitable for a wide variety of end uses (Everton et al., 2020). In tanning processes tanning materials are able to crosslink with reactive site of fibrous protein, and it involves the conversion of putrefiable skin or hides to a non-putrefiable material (Alex & Arthur, 2016). Tanning is considered as one of the important steps that protect the leather against microbial degradation. There are a wide variety of tanning agents that are available at the market today. Some of these include vegetable, alum, chrome, oil and aldehyde tanning agents. Among the tanning agents, chrome tanning is the dominant and widely used in the leather industries. Chrome tanned leather accounts for 90% of leathers in the world. Although chrome tanning has gained importance in leather manufacture, its advantage is over shadowed by its negative impact on the environment. It is a global environmental disaster and puts the health of millions of leather workers and ordinary citizens at risk (Abul et al., 2015).

Vegetable tanning is the most eco-friendly method as compared to chemical tanning process and it discharge minimum amounts of pollutants to the environment. Vegetable tannins are polyphenols with molecular weight ranging 500-20,000 Dalton. Vegetable tanning uses vegetable extracts (from leaves, fruits, seeds and barks) to process hides/skins into waterproof, non-putrefiable, soft and supple (Everton et al., 2020). As a result, many researchers have been focused on the development of a greener leather tanning processes using different plant extracts as a natural source of tannins. Vegetable tannins are plant-based polyphenols that are water soluble and capable of reacting with collagen. Up to now, a very limited number of plant species are exploited for the application of tanning processes. Recently attempts have been made to explore the use of new plant materials for tanning by different researchers (Frederik et al., 2011; Isam & Christina, 2016; Mohammed et al., 2016, 2020; Mohammed, Panda et al., 2017; Mohammed, Rames et al., 2017). However, there is no report showing the use of Sodom apple as a tanning agent. Sodom apple (Solanum incanum) is the wild plant that can easily grow in the hot and moderate temperature areas and has been producing fruits twice a year. The Sodom Apple fruits are small in size, spherical shape, green in nature and often turning yellow to orange when ripe (Mwonjoria et al., 2014; Nalankilli & Tadesse, 2018). Thus, the current study was focused on evaluating the tanning potential of Sodom apple with satisfactory hydrothermal stability and strength characteristics. Therefore, it was investigated that tannin extracted from Sodom Apple fruit was identified as potential tanning for goatskin processing and a green/safe material for the environment.

2. Materials and methods

2.1. Chemicals and reagents

The extraction of tannin from Sodom apple, and Chemical analysis were conducted at Arba Minch University chemistry laboratory. The characterizations of tannin, physico-mechanical analysis of
tanned leather and its effectiveness and measurement of pollution load were conducted at Leather Industry development Institute (LIDI)-Addis Ababa, using the standard analytical methods for leather technology. During this work, the chemicals and reagents were used were commercial grade chemicals and auxiliaries for leather manufacturing process and analytical grade chemicals for the determination of pollution load parameters and other chemical analysis. The SLTC official white hide powder obtained from LIDI was used for gravimetric analysis to measure the tanning capacity of the Sodom apple materials. Wet salted goat skins of similar sizes were used in the tanning for experimental and control samples.

2.2. Collection and preparation of Sodom apple fruits
A healthy fresh and matured Sodom Apple (Solanum incanum) fruit were collected from Arba Minch University, Arba Minch, Southern Ethiopia using purposive random sampling method. The collected samples were washed with distilled water and stored in refrigerator. Then the fruits were cut into coarse pieces to reduce their sizes and kept in room temperature to dry it for a week. The dried fruits were grinded into fine powder using laboratory star mill and the powdered samples were stored in dry vacuum and the prepared powder was used as a raw material for extracting the crude tannins. For comparison purposes with the existing industrial practices, commercial extracts of wattle obtained from Mimos Extract Company were used throughout the experiments.

2.3. The optimization of tannin extraction procedure
A 20 gram of powdered Sodom apple fruit was taken and added into the extraction thimble while 200 mL of solvent placed in the flask of Soxhlet apparatus. Then the Soxhlet extraction processes were conducted for all solvents used for optimization and the extracted material was collected in collecting flask. The extraction was done by using methanol, methanol, petroleum ether, ethanol and aqueous solvent. All Experimental analysis were repeated three times for each set of plan that helped to determine as mean with standard deviation. The obtained extract for each solvent was filtered through Whatman No. 1 filter paper and the solvent was removed by rotary evaporation under reduced pressure at a temperature below 45°C. The yield for each extract was determined based on the weight of the dried plant powder initially used. The results that gave high percentage yield were used for further study.

The selection of Sodom apple as a source of tanning agent was based on the preliminary test that was done in chemistry laboratory and the recommendation left by the people that were used in traditional way. After optimization of the extraction process it was identified that water was the best extraction solvent that gives best yield of tannin among solvents used and the vegetable bio-tannin was extracted from Sodom apple fruit powder by using water as a solvent. The prepared Sodom apple fruit dried powder a total of 1000 gram was exhaustively extracted using water as a solvent with powder-water ratio, 1:10 (W/V) by Soxhlet extraction method. The grounded fruit sample was added into the thimble and inserted into the soxhlet extractor tube and then distill water was placed into the round bottom flask after which the extractor was coupled. The temperature of the process was corresponded to the boiling point of solvent used and the extraction time was set for 12 hours. The extract was later concentrated into a thick paste using hotplate to dryness, then the dried extract was then crushed into powder using mortar and pestle then transferred to a pre-weighed vessel and the weight was determined.

2.4. Identification of compounds by using Thin-Layer Chromatography (TLC)
Thin layer chromatography (TLC) technique is recommended to determine the number of components present in a mixture and to identify the compounds and to know its purity (Bekro et al., 2008). In current work for TLC technique, a combination of ethyl acetate, ethanol and distilled water (50:30:20) was used as solvent mixture to separate the components in the extracted material. A 0.5 mg of the extracted material was dissolved in extracting solvent and spotted on
the surface of the TLC silica gel plate by using Thiele tube and placed into the chamber. The TLC plate was taken out while it reaches 75% on the top of the plate and the obtained color was circled. To detect the spots, the plate was taken and exposed to UV lamp and the spots were become visible. Finally the distance travelled by each component was recorded and the Rf value “retention factor” of the components were calculated.

2.5. Phytochemical screening of the extracts
A small portion of aqueous extract was dissolved in water used for the qualitative analysis and confirmation of the major phytochemical constituents’ viz., flavonoids and tannins, according to different methods (Bekro et al., 2008).

2.6. Determination of tannins and non-tannin
The quantitative analysis of tannins and non-tannins were analyzed using the gravimetric method which is based on the absorption of tannins by hide powder. For 6.25 g of dry hide powder, an equal volume of 3% chrome alum solution and 62.5 ml (10 times) of distilled water were added, stirred, and left overnight. The next day, the hide powder is transferred to a filter cloth and washed well with distilled water. After mixing and washing the chrome hide powder, the weight of the hide powder was taken and adjusted to 26.5 g by the addition of distilled water. The determination of moisture content present in the selected powder was carried out using the standard method. From the extract solution, unfiltered extract was used for the determination of total solids, and the filtered extract was used for the determination of total soluble solids. The difference between the percentage of total soluble solids and percentage moisture of the extracted material was used to determine the insoluble solids in the extract. The chrome tanned hide powder was used for the determination of non-tannins. The tannin matter absorbed by the hide powder was determined by taking the difference of the percentage total soluble solids and non-tannins.

2.7. Spectroscopic studies of the extracts
Fourier Transform Infrared Spectroscopy (FT-IR) study of the extract was carried out using FT-IR (Shimadzu IR Affinity 1, Japan). All spectra were recorded by absorption mode in the range of 4, 000 to 600 cm⁻¹. Ultraviolet (UV) spectrums were recorded using Specord 50 PLUS-Germany UV-visible spectrometer.

2.8. Goatskin sampling
Goatskin used for tanning was collected from semi-processed skin that was passed through soaking, liming, deliming, bating and degreasing processes at LIDI workshop. From this, the experimental portion (5 × 2 mm) of the part was taken and made ready for the next step (tanning).

2.9. Goatskins tanning using Sodom apple’s extract
Goat, sheep and cow are the primary sources of skins in leather processing industry. In this study, goat skin with average weight of 1 kg per skin were used for tanning (Eleanor & Dennis, 2011). Wet salted goatskins that were obtained from LIDI were used for both Sodom apple and the control (Mimosa)-based tanning. Table 1 shows formulations of the tanning processes using Sodom apple and mimosa extracts. After extracting and identifying tannin from Sodom apple fruit, the beamhouse operations was carried out until pickling process. After the beamhouse operation, vegetable tanning processes were employed in testing drum for both control and experimental pelts of the goatskins using that of normal recipes employed for vegetable tanning. In the current tanning process, each of the selected goatskin was cut into two halves. One piece was used for the experimental tanning which was Sodom apple fruit extract and the corresponding half piece of the goatskin was used for the commercially used mimosa (control) tanning for comparison purpose. The detail tanning formulations for the experimental and control samples are depicted in Table 1.
2.10. Characterization of tanned leather samples using SEM

In order to study the effect of vegetable tanning agent on the structural characteristics of the goatskin tanned leathers, the analysis of surface morphology of goatskin was carried out using scanning electron microscope (SEM). From the tanned goatskin, samples of 5 mm × 2 mm were cut from the butt portion using fresh stainless-steel blades after dehydration using aqueous alcohol. The samples were mounted both vertically and horizontally on aluminium stubs using an adhesive. These were then coated with gold using an Edwards E-306 sputter coater. The stubs were introduced into the specimen chamber of FEI-Quanta 200 scanning electron microscope. The stubs mounted on the stage could be tilted, rotated and moved to the desired position and orientation. The scattered electron from the sample was then fed to the detector and then to a cathode ray tube through an amplifier, where the images are formed, which gives the information about the surface character and morphology of the sample. The micrographs for the image were obtained by operating the microscope at higher voltage of 15 kV (Maria & Lina, 2013).

2.11. Physico-chemical characterization of tanned leathers and organoleptic properties

The properties Viz., moisture content, oils and fats, hide substance, degree of tanning water-soluble matter, and total ash content were determined based on the standard methods. The Sodom apple tanned crust leathers and control samples were assessed for tensile strength, percentage elongation at break and tear strength properties were measured as per IUP6 and IUP8 standard methods, respectively. The samples were also assessed for the functional properties such as softness, fullness, grain tightness, smoothness, and general appearance rated as on a scale of 0–10 points. The organoleptic properties of the samples were carried out by four experienced researchers and tanners from the leather processing division of Leather Industry Development Institute, Addis Ababa, Ethiopia.

2.12. Degree of shrinkage temperature

The shrinkage temperature of the leather was studied according to International Union of Leather Technologist 2001 and Chemist societies (Belay et al., 2019).
2.13. Measurement of pollution load
The spent liquor from the experimental and control tanning process was collected and analyzed for pollution load parameters viz., Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) following the standard analytical procedures.

3. Results and discussions

3.1. Characterization of the extract as a tanning agent
The obtained yields of tannins were varied with the solvent types and time employed. From this the highest extraction yield was obtained when distilled water was employed as extraction solvent than when other solvents were used and the yield value of 16.71% was achieved within 12 hours extraction time whereas the lowest yield was obtained when petroleum ether was employed as extraction solvent with the yield value of 10.24% as shown in Figure 1. This is due to the polarity nature and size difference of the solvents. Since water is the most polar and small in size than other solvents, it has the ability to penetrate into the extraction environment and has strong interaction with polar group of tannin molecules. In the previous study (International Union of Leather Technologist and Chemist societies, 2001) extraction of tannin materials from other plant bark using different solvent was conducted and water as solvent has shown better yield than when other solvents were used that supports the results of current work. It is concluded that extraction time and solvent types are the main factors affecting the percentage yield of tannins.

3.2. Phytochemical screening of Sodom apple fruit extracts
The presence of tannins and flavonoids in powdered extract of Sodom apple fruit and mimosa (control) was confirmed using standard method of analysis BIS (Olayede et al., 2010) and the results were given in Table 2.

3.3. Physico-chemical analysis of Sodom apple fruit extract
The physico-chemical parameters like pH, moisture content, total solid, total soluble solid, tannin and non-tannin content of the extract were evaluated and characterized and the obtained results were given in Table 3.

The current results given in Table 3 are slightly different when compared with findings from other studies. The work done on Lawsonia Inermis (Henna) as vegetable tanning was reported that the amount of tannin obtained was 11.12%, non-tannin 22.64%, total soluble solid 33.76% and pH value 4.5 (BIS, 2007). In other study (Isam & Christina, 2014) that conducted on the barks of A. seyal, A. nilotica and A. Senegal shown that the tannin contents were 12.15%, 10.47% and 3.49% respectively. These variations might be due to variations of solvent types and extraction methods employed, the environmental conditions, plant species, soil types, plant age and origin,
water stress and the fruit or bark sizes used during the extraction processes. For any tanning material to be effective for tanning process the required range of pH is 4–6 (Everton et al., 2020), which is in a good agreement with the present study.

3.3.1. Thin layer chromatography
The TLC profile of the extracts was evaluated and the Rf values of each components were given in Table 4 and the results confirmed the presence of tannin in the extract.

Clear inhibition zone were observed at Rf of 0.755, 0.567, 0.322 and 0.178. Among these points, 0.322 and 0.567 Rf values indicate the presences of tannins in the extract which is in good agreement with result of previous work done in (Alex & Arthur, 2016). The TLC visualized with UV lamp also contains different spots with different colors of light blue and blue, which may correspond to multiple classes of secondary metabolites.

| Table 2. The phytochemical screening of extract materials in Sodom apple fruit |
|-----------------------------------|-----------------------------------|-----------------|-----------------|-----------------|-----------------|
| Phytochemical                     | Test method                       | Color observed  | Sodom apple     | Mimosa (control)|                 |
| Tannin                            | (a) Ferric chloride                | Green precipitate | +               | +               |                 |
|                                  | (b) Lead acetate test              | Yellow precipitate | +               | +               |                 |
| Flavonoid                         | Ferric chloride                   | Dark green       | +               | -               |                 |
| Tannin type                       | Hydrolysable                       | Potassium        | No              | -               | -               |
|                                   | Condensed                          | Hydroxide (aq)   | Red precipitate | +               | +               |

NB: *present; “absent

| Table 3. Physico-chemical analysis of Sodom apple fruit Extract |
|---------------------------------------------------------------|---------------------------------------------------------------|
| Parameters                                                                 | Sodom apple (Solanum incanum) fruit |
| pH                                                             | 5.20                                                           |
| Moisture                                                       | 7.59%                                                          |
| Total solid (TS) %                                             | 94.01%                                                         |
| Total soluble solid (TSS) %                                    | 21.45%                                                         |
| Non—tannin (NT) %                                              | 9.32%                                                          |
| Tannin (T)% = TSS-Non-tannin                                    | 12.13%                                                         |

| Table 4. Rf values of Sodom apple extract                      |
|---------------------------------------------------------------|---------------------------------------------------------------|
| Plant specimen                                               | Appearance (color) | Distance travelled by spots (cm) | Distance moved solvent (cm) | Rf values of the spots |
| Sodom apple fruit extract                                     | Light brown       | 6.8                             | 9                             | 0.755               |
|                             | Light blue        | 5.1                             | 9                             | 0.567               |
|                             | Yellow            | 2.9                             | 9                             | 0.322               |
|                             | Blue              | 1.6                             | 9                             | 0.177               |
3.3.2. Ultra violet-visible spectroscopy

UV-Vis spectroscopy was employed to identify the absorption maxima of the extracts within the wavelength range of 200–800 nm. To get the optimum absorption of the extract, different amounts of the sample were taken and analyzed using UV spectroscopy and the results were given in Figure 2. The lower absorbance peaks might indicate the presence of non-tannin materials (Sanjeet et al., 2013).

The optimum amount of extracted Sodom apple fruit that gives the maximum absorbance was the 1 g/100 ml of the sample which contains three inflection points at 258, 296 and 332 nm wavelength indicating the electronic transitions of pi-to-pi star (π → π∗) of benzene ring and that of carbonyls and none bonding electron to pi star (n→ π∗) energy levels respectively. The shift in the wavelength maximum absorbance of the extract was observed due to the difference in amounts of the extract especially in the case of 2 g/100 ml. Since the absorbance maxima of benzoic tannin is found in the range of 250–350 nm (Qiang et al., 2018), the current absorbance maxima obtained was confirming the presence of tannin in the extract which is in the agreement with the mention wavelength range. The work done in (Vetter et al., 2010) conveyed those condensed tannins were consistent the strong absorptions around 257 and 282 nm.

3.3.3. FTIR analysis

FT-IR was also conducted to study functional groups found in the extracted materials using the instrument with spectra range of 4000–400 cm⁻¹ and the results were indicated in Figure 3. According to FTIR analysis of standard tannin (Nicoleta et al., 2006), the main peaks that are important to be considered will be 3423.03 cm⁻¹, 1620.02 cm⁻¹, 1520.87 cm⁻¹, 1350 cm⁻¹ and 1062.12 cm⁻¹.

The main bands that were important to specify the presence of Tannins in the extract are observed and indicated in the spectra that gives full information about the analyzed sample. The band above 3000 cm⁻¹ and that found in the range of 1750–700 cm⁻¹ region are considered the most informative about tannin (Tondi & Petutschnigg, 2014). Based on the results obtained in this study, the IR spectral bands have confirmed that the extract of Sodom apple sample contains condensed tannin. This was proved through the absorption bands found at 1036 and 1400 cm⁻¹ confirming the presence of asymmetric stretching of ester (C–O), band at 1598 cm⁻¹ referred to
stretches of the C = C bonds of the aromatic ring, weak band at 2927 cm\(^{-1}\) was indicating the stretching of C-H bonds of sp3 or sp2 (CH\(_3\) or CH\(_2\)) hybridized carbon atom and bonds, and the strong broad band at 3274 cm\(^{-1}\) indicating the stretching vibration of O-H bond. This information confirms the presence of condensed tannin in the extract.

3.4. Application of Tannins on Goatskin

After the characterization and identification of tannin of the Sodom apple extract were conducted, application of tannin on the goatskin was conducted in comparison with the previously used vegetable tanning (mimosa) as a control. The tanning efficiencies of both experimental and control were evaluated and the tanned leather products were shown in Figure 4. All the tanning processes for both cases were operated under the same conditions (chemical percentages, temperature and drum speeds).
3.4.1. Characterizing tanned leather using Scanning electron microscopy (SEM)
The scanning electron microscopic analysis provides information about the fiber compactness and
the grain surface patterns of the leather (Musa et al., 2008). In the current work, the grain images
of the surface of the vegetable tanned leathers for both experimental and control were taken
using the instrument with 15 kv magnification power and presented in Figure 5. It can be observed
that the fibers of Sodom apple tanned leathers were found in the form of fine bundles whereas
that of mimosa tanned leather appeared to have separated fiber bundles. This indicates that
Sodom apple tanning has greater strength to associate with the goatskin than that of mimosa
tanning material. Smooth grain surface is the indication of the interaction between vegetable
tannins and collagen of skin that modified grain surface without causing damage.

On the other hand, the distance between fiber bundles determines the number of pores in the
leather. Thus, the numbers of appearance of porosities in Sodom apple tanned leather were higher
than that of mimosa tanned leather showing a better performance of tanning for good quality
product. Vegetable tannins from different plant sources give different grain surface appearance,
suggesting variations in molecular characteristics of the vegetable tannins (Ali et al., 2019).

Generally, the surface image of the crust clearly shows that the experimental leather has less
number of hair pores, course surfaces and better fiber splitting and clean without any damage
than the control leather.

3.5. Physical strength and organoleptic properties of the leathers
For good quality leather products, quality standards have been established. Thus, the vegetable
tanned leather must be exposed to physical testing to evaluate their standard and qualities.

3.5.1. Tensile strength
The results of tensile strength for experimental tanned leather were showed an excellent strength
as compared to control tanned leather as 14.2 and 12.5 N/mm² respectively. The extent of tensile
strength depends on the quality of collagen fibers that the specific skin type contains. The
increasing of tensile strength is due to the reactivity of tanning agents to the collagen fibers.
The presence of —OH functional group in vegetable tanning agent favors the reaction with the
functional groups in the collagen (C = O or NH₂) that can alter the properties of leather collagen.
When vegetable tannins react with collagen, it improves the bonding between the fibers of the skin
and stabilizes its structure (Teklebrham et al., 2012). Hence, Tensile strength is the stress required
to fracture a test specimen of specified thickness, fiber orientation and location on the skin.

Figure 5. Scanning electron micrograph of (a) experimental
(Sodom apple fruit) and (b) control (mimosa) vegetable
tanned leathers.
3.5.2. Elongation at break (%)
Leathers with higher tensile strength have higher percentage elongation and vice versa. Good quality leathers should have a percentage elongation of greater than 40% (International Union of Leather Technologist and Chemist Societies IUP 6). In this study, the percentage elongation of Sodom apple tanned leather (experimental) was found to be 43.7% which is an excellent result as compared with the valued obtained for mimosa tanned leather (control) which is 30.2%. Elongation of leathers is affected by pre-tanning, tanning and post tanning process which always differs from one tanner to another (Arife et al., 2017).

3.5.3. Leather thickness
The measured thickness values of Sodom apple tanned and mimosa tanned leathers were found to be comparable. Thickness of the leather greatly affects the stability of the skin by the formation of crosslinks between the tanning material and collagen fibers of the skin (International Union of Leather Technologist and Chemist Societies IUP 6).

3.5.4. Tear strength
As per recommendation of the standard guideline, the minimum tearing strength of tanned leather should be at least 20 N (International Union of Leather Technologist and Chemist
Table 5. Pollution generated in the tanning liquors of mimosa and Sodom apple tanning

| Parameters | Type of sample          | Mimosa (control) tanning | Sodom apple (experimental) tanning |
|------------|-------------------------|--------------------------|-----------------------------------|
| BOD<sub>5</sub> |                         | 13,560 ± 700             | 12,250 ± 803                      |
| COD        |                         | 35000.6 ± 400            | 33,567.5 ± 250                    |
| TDS        |                         | 29406.0 ± 1000           | 16,105.0 ± 900                    |

Societies IUP 6). For the current study, the tearing strengths of both Sodom apple and mimosa tanned leathers were higher than 20 N which are 23.4 and 21.5 N/mm respectively. Tear strength indicated the maximum limit of the skin to be torn. The skin that was tanned with high levels tanning agents would have a high tear resistance.

3.6. Assessment of organoleptic (visualization) properties of crust leathers

Leather inspections are not only done by physico-mechanical tests but also through hands and visual evaluations for the aesthetic properties. Organoleptic properties, therefore, enables us to evaluate the leathers produced for various applications for their requirements by experienced industrial experts. Accordingly, the leathers were evaluated for the properties viz., fullness, softness, grain tightness, smoothness, and general appearance rated on a scale of 1–10 points in which the one with higher values indicate better property and as per the standard, 5 and above is the accepted standard value. This evaluation was carried out by three experienced researchers and tanners working at Leather Industry Development Institute, Addis Ababa, Ethiopia. The results of the current evaluations are given in Figure 6, all of which are above the stated value for both experimental and control tanned leathers. All parameters evaluated were shown better values for experimental (Sodom apple) tanned leather than for that of control (mimosa) tanned leather.

3.7. Hydrothermal stability/shrinkage temperature of the leathers

Shrinkage temperature is a temperature at which leather starts shrinking in water or over a heating medium (Teklebrham et al., 2012). This is one of the most important parameters that characterizes the quality and stability of the leather. A high temperature value for shrinkage of leather is indicative of its hydrothermal stability. The shrinkage temperature observed for Sodom apple tanned leathers and mimosa tanned leathers were found to be 75 ± 0.2 and 78 ± 0.3°C, respectively as shown in Figure 7. Good-quality leather should have above 75°C of shrinkage temperature as indicated in (Chinelo et al., 2014).

3.8. Chemical analyses of the vegetable tanned leather

The chemical analysis (moisture content, ash, fat, soluble matter and hide substance and degree of tanning) of the tanned leathers was conducted for both experimental and control and approximately all parameters analyzed were found to be comparable for both of them as shown in Figure 7.

The moisture contents of Sodom Apple tanned leathers and mimosa were 9.038 ± 0.603 and 9.127 ± 0.514 respectively. Low-moisture content affects the tensile strength, flexing endurance and ball burst test of the leathers. But the moisture content of all leathers falls within the range for production of leathers (Musa & Gasmelseed, 2013).
The Ash contents of the experimental and control tanned leathers were found to be 2.874 ± 0.268 and 3.935 ± 0.095 respectively that were determined by using the furnace incineration method. These results were in agreement with the previous works (Musa & Gasmelseed, 2013; Oladunmoye, 2007). The Fat content of the crust leather of experimental was 11.02 ± 0.6142 as compared to control 11.54 ± 0.2412, in which the experimental shows relatively less fat content than the control one. High levels of oil/fat in the leather can cause discomfort to the wearer and it may also facilitate it undergo oxidative reaction that may lead to rancidity (decay; Musa & Gasmelseed, 2013). The result affirmed that Sodom apple tanned leather better as compared to mimosa tanned one.

Total soluble matter corresponds to the fixation of tannins on the collagen and makes the stabilization of leather. The results of the current work show that water soluble matters of experimental and control tanned leathers were 4.1516 ± 0.9977 and 4.553 ± 1.232 respectively. The hide substance of Sodom Apple and mimosa tanned leathers were 49.2% and 50.8% respectively, which is similar to the values in previously work done (Mahdi et al., 2009). And the tanning degree values of experimental and control tanned leathers were 54.2 % and 57.4% respectively, which both values show good agreement with standard minimum value of 50% (Maria & Lina, 2013).

3.9. Evaluation of pollution loads generated from tanning liquors

The pollution loads of the vegetable tanning processes for both experimental (Sodom apple) and control (mimosa) tanned leathers were evaluated in terms of BOD, COD and TDS after collecting the liquors of tanning effluents and the results are presented in Table 5. When the pollution load of Sodom Apple fruit (experimental) tanning process is compared with that of mimosa (control) tanning, it was found that the experimental tanning process has given lower levels of COD, BOD and TDS than that of controlled process. If it was compared with the chemical tanning processes, it would be significantly different showing the importance of vegetable tanning for the reduction of pollution load in environment, especially in reduction of chromium effect on the environment.

The cleaner production options using natural products as vegetable tanning materials during leather processing to reduce BOD, COD and TDS was recommended in the work (Azzizi et al., 2014). Therefore, the Sodom apple tanning leather process was proved and recommended to be employed commercially and used worldwide in tanning leathers. Furthermore, the results of the pollution load obtained in the current work are in good agreement with the results in (Abdella et al., 2018), the work done on the leather tanning process using Sunt bark.

4. Conclusions

In the present work, the extract of Sodom apple fruit was observed to be a good alternative for substituting the chemical tanning in leather manufacture. By using a minimum of 20% Sodom apple extract, it is possible to obtain a shrinkage temperature of 75°C. The leather characteristics including the tensile and tear strength for Sodom apple extract were observed to be promising results for leather manufacture. The organoleptic properties of the Sodom apple (Solanum Incanum) fruit extract and mimosa tanned leathers were also compared and the Sodom Apple fruit tanned leather was found to be better in almost all parameters than that of mimosa tanned leather. The pollution load of the tanning processes was also studied for both Sodom apple and the mimosa to evaluate reduction levels of COD, BOD and TDS released along with the wastewater during the tanning processes and it was found that the waste level reduction was seen in the Sodom apple (experimental) tanning than the mimosa (control) tanning. In general, as a conclusion, it is revealed that the quality of tanned leather with Sodom apple tanning material was better in almost all aspects of leather quality parameters as compared to that of the mimosa (commercially available) tanned one and can be considered as a greener alternative for tanning process in leather manufacture.

Nominated Images from the manuscript.
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Authors contribution
The author(s) read and approve the final manuscript.

Availability of Data and Materials
The authors declare that the manuscript contains the minimal dataset that is required to interpret, replicate, and build upon the methods and findings reported in the article. Raw data can be shared via correspondence upon reasonable request.

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Not applicable.

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