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Assessing the effectiveness of traditional wool scouring for small-scale farmers in South Africa: a study on detergents and scouring time

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Abstract

Purpose – The South African wool industry is integral to the country's agricultural sector, particularly sheep farming and wool production. Small-scale farmers play a vital role in this industry and contribute to employment and food security in rural communities. However, these farmers face numerous challenges, including a lack of funding, poor farming practices and difficulty selling their wool at fair prices. This study aims to address these challenges, the University of Free State launched a wool value chain project for small-scale farmers.

Design/methodology/approach – In this project, one of the studies conducted assessed the effectiveness of different detergents suitable for traditional wool scouring methods for small-scale farmers who lack access to sophisticated machinery. The investigation was conducted by scouring 160 wool samples using three different detergents and filtered water as a control. The wool samples were then evaluated for their cleanliness, brightness and fibre properties through a combination of scanning electron microscopy, spectrophotometry and statistical analysis at different scouring times (3, 10, 15 and 20 min, respectively).

Findings – The results showed that the combination of scouring time and the type of scouring solution used could significantly impact wool quality. It was found that using a combination of standard detergent or Woolwash as a scouring solution with a scouring time of 10–15 min resulted in the best outcome in terms of fibre property, wool colour and scouring loss.

Originality/value – This study demonstrated that traditional wool scouring methods could be an option for small-scale farmers and anyone who want to learn how to scour wool without expensive machinery to make wool products.

Keywords Wool scouring, Small-scale farmers, Detergents, Wool weight, Wool colour change, SEM

Paper type Research paper

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1. Introduction

South Africa is one of the top wool-producing countries in the world, with the majority of the wool being Merino wool. The South African wool industry is primarily made up of small-scale farmers and commercial farmers, many of whom have been farming sheep for generations. Based on the report produced by the National Wool Growers Association (NGWA, 2022), the wool sheep population in South Africa is estimated to be around 15 million. Notably, within this population, approximately 4 million sheep are owned by the emerging and communal sectors. Small-scale farmers from the various provinces of South Africa form a vital component of the country's agricultural industry, particularly in sheep farming and wool production, and contribute towards employment and food security for many rural communities (Cheteni and Mokhele, 2019). Most small-scale farmers farm Merino sheep, a breed known for its high-quality wool and shear their sheep once a year. The farmers then sell the wool to wool brokers, who sell it to large wool industries (Zenda *et al.*, 2022). Despite the importance of their role, small-scale farmers in the Free State face numerous challenges within the wool industry. These include a lack of funding and support from the government, poor farming practices that make sheep susceptible to diseases (Mahashi *et al.*, 2019), a lack of knowledge about wool processing, sorting and quality maintenance (Mahashi *et al.*, 2019) and difficulty in selling their wool at higher prices or finding buyers.

To support and promote wool production and improve the livelihoods of small-scale farmers, the University of Free State launched a wool value chain project that provided training in sheep farming, wool selling, wool processing and product development to small-scale farmers and the community (Bolleurs, 2022; Muller, 2021). The project included people from surrounding communities, industries, academic researchers and small-scale farmers from the Free State province (Muller, 2021). The wool project involved researchers and managers that performed tasks related to various aspects of the overarching project. As part of the training, farmers were taught traditional wool scouring processes, which are typically automated in wool industries, such as hand scouring wool using hot water and detergent, air drying and using carding combs to remove grass from the scoured wool.

The innovative wool products developed through this project (Bolleurs, 2022), along with the insights gained from the research, can provide managers with helpful information on how to optimise human resource management practices, develop analytical skills to improve knowledge management practices and encourage the creation of new ideas for the project (Parwita *et al.*, 2021). Additionally, the project's emphasis on creativity as a mediator for the effects of knowledge quality and knowledge sharing on employees' innovation capability, as well as the moderation of time sufficiency on the relationship between knowledge quality and innovation capability (Arsawan *et al.*, 2022), highlights the importance of investing in training and development for small-scale farmers to enhance their innovation capability and increase their potential for economic growth.

1.1 Wool souring

Wool scouring is the process of cleaning raw wool, which involves removing impurities such as dirt and grease from raw wool fibres (Allafi *et al.*, 2022). There are various methods of scouring wool, such as solvent scouring, where fibres are treated in an organic solvent medium to remove impurities (Czaplicki and Ruszkowski, 2014), enzymatic scouring, also known as bio-scouring (Patil *et al.*, 2022), ultrasound scouring and mechanical scouring (Bahtiyari and Duran, 2013). Furthermore, in industries, wool is mainly scoured through large-scale machinery, unlike traditionally using hands to scour wool with warm/hot water and detergent (Li, 2014). Industrial scouring is efficient but requires significant investment in machinery and infrastructure, whereas traditional scouring is less efficient but less expensive and does not require the same infrastructure level (Allafi *et al.*, 2022). Traditional scouring can also be time-consuming and labour-intensive, and the quality of the wool may depend on the skills of the person performing the scouring. This method is mainly used by people who might need access to industrial equipment or the financial resources to invest in it.

In industrial wool scouring, the wool goes through multiple steps, such as grease removal, where raw wool is treated with a detergent solution to remove any dirt, sweat and grease that may have accumulated on the raw wool (Li, 2014). In the next step, the wool is carbonised with sodium hydroxide and sodium sulphide to remove any remaining grease or impurities (Halliday, 2002). After carbonising, the wool is rinsed thoroughly with water to remove any remaining chemicals (Halliday, 2002). The final step is drying, where the wool is oven dried in a mechanical dryer. The wool scouring process ensures that the wool is clean, pure and ready for further processing, such as carding, combing, dyeing and spinning (Jayalakshmi, 2014).

Regarding traditional wool scouring, hot water and detergents are essential in cleaning raw wool by breaking down the bonds between the impurities and the wool fibres (Wood, 2012; Simpson and Crawshaw, 2002). Detergents used for wool scouring vary depending on the impurities present, the desired level of cleanliness and the type of wool being scoured (Simpson and Crawshaw, 2002). These detergents include anionic, cationic and non-ionic detergents. Anionic detergents are the most common type used in wool scouring, as they are effective at removing impurities and have minimal effect on the wool fibres (Wood, 2012). Cationic detergents are also sometimes used, as they can help increase the wool fibres' lustre (Simpson and Crawshaw, 2002).

Several studies have been conducted exploring alternative sources of detergents. These include detergents that are efficient and yield a faster turnaround time in terms of cleaning (Hassan and Shao, 2016; Wood, 2009a, 2009b), detergents that are cost-effective and detergents that are more environmentally friendly such as catholyte and anolyte (Pan *et al.*, 2020). Catholyte and anolyte are typically derived from electrochemically activated water (ECA). ECA is a type of water that has been treated through an electrochemical process, which uses electricity and salt water to create an electrolytic solution (Deasy *et al.*, 2018). This solution that results in anolyte and catholyte can be used for various applications, including cleaning, disinfection and sterilisation. The anolyte is the acidic water produced during the electrolysis. It usually has a lower pH level and contains oxidising agents such as hypochlorous acid and chlorine dioxide (Ersoy *et al.*, 2019). Anolyte is known for its strong antimicrobial properties and is commonly used as a disinfectant and sanitiser in various industries, including health care, food processing and agriculture (Rebezov *et al.*, 2022; Figueroa *et al.*, 2016). While the catholyte is the alkaline solution with a higher pH level and dissolved hydroxide ions (Ersoy *et al.*, 2019). It is often used for cleaning, sanitising and disinfecting purposes. Catholyte has antimicrobial properties and can be used as an environmentally friendly alternative to chemical-based cleaning agents (Rebezov *et al.*, 2022). According to Ignatov (2015), catholyte provides excellent cleaning and degreasing properties, whereas anolyte gives excellent oxidising, disinfecting and sterilising capabilities. Some research suggests that catholyte can be used as a cleaning agent (Cronje *et al.*, 2013), but further study is necessary to determine whether catholyte can be used for wool scouring. ECA water is considered a sustainable and eco-friendly solution because it eliminates the need for conventional chemical-based cleaning agents and disinfectants, which can have adverse environmental impacts.

Wool is scoured differently according to the desired outcome of the final wool product. However, several tests are typically performed on the wool to ensure it has been adequately cleaned and to measure its quality. These tests include the following:

- fibre testing, which involves measuring the diameter, length and strength of the wool fibres (Müssig *et al.*, 2010);
- yield testing, which measures the weight of the wool before and after scouring to determine the percentage of impurities that have been removed (Mahar and Sommerville, 2012);
- colour testing which measures the colour of the wool fibres using a spectrophotometer (Crowe and Wood, 2014);
- staple testing which measures the length and uniformity of the wool fibres; and
- crimp testing which measures the crimp, or wave-like pattern, of the wool fibres (Zhang, 2014).

These tests can give a clear picture of the quality of the wool after scouring and help determine the best use for the wool or if it needs further processing (Botha and Hunter, 2010). Moreover, these tests can also help farmers and wool processors to identify the appropriate price of the wool and to determine if the scouring process was done correctly.

In this study, we will compare the effectiveness of different wool scouring detergents and time using the traditional wool scouring method, as it is suitable for small-scale farmers scouring wool in their farms.

2. Methodology

2.1 Research design and methodology

This study used a quantitative approach, as it involved numerical data collection and analysis. The study compared four wool scouring agents over different time intervals on randomly selected Merino wool fleece samples. The experiments evaluated the effectiveness of the different detergents in traditional wool scouring to determine which detergent yields the best scouring results in terms of wool fibre properties, scouring loss (wool weight) and wool colour. This was chosen because it is the most likely methodology used by small-scale farmers who do not have access to sophisticated wool scouring machinery used in industry (Wood, 2009a, 2009b). To empirically measure the impact of the traditional process on the wool, a variety of techniques and statistical analysis were used, including scanning electron microscopy (SEM), spectrophotometry and a statistical mixed effects model to determine the impact of the interaction between different target variables. We conducted this research at a laboratory scale without using industry-specific machinery such as jet scours, drum scouring bowls or industrial drying ovens (Wood, 2009a, 2009b). The purpose of this method of scouring was to demonstrate to small-scale farmers how to scour wool as simply as possible, as well as to understand the changes in wool colour, weight and wool fibre surface after scouring.

2.2 Materials

All the wool samples in this study came from the same source, and the selected raw merino fleece wool samples were used because the fleece gives a good indicator of essential characteristics of the wool fibre, such as wool colour, yield and fibre structure (Scobie *et al.*, 2015). The wool was obtained from small-scale farmers in the Mangaung area (Free State, South Africa). The scouring agents used were catholyte (referred to as ECA in this study), Woolwash [WW; produced at Chemay (Pty) Ltd in South Africa] and ECE Non-Phosphate Reference Detergent Type A without optical brightener, produced by James H. Heal and Co. Ltd, Halifax, England. Filtered water (FW) was used as a control for all scouring solutions.

2.3 Wool scouring

For scientific accuracy, the wool samples were preconditioned in standard controlled conditions (± 21°C; 65% relative humidity) for 24 h, after which each sample was weighed at 12 g (~3 g) for 160 wool samples. FW was used to prepare all scouring solutions, and one litre of scouring solution was prepared for each 12 g wool sample. Four different scouring solutions were prepared, namely, FW, ECA (Catholyte), Woolwash (WW) and Standard Detergent (SD) (Liman and Islam, 2022). The ECA was produced through an electrolysis machine (Hoshizaki Electric Co., ROX-10WB-E uni) with a FW solution and 5% NaCl concentration. As this study involved traditionally scouring wool without machinery to suit the standards of the farmers, the wool scouring process included using four scouring bowls. The first and second bowls contained the scouring solution and were maintained at 52 (± 3)° C. The third and fourth bowls were rinsed with FW only, maintained at a temperature between 35 and 45°C. After scouring, the samples were dried at room temperature (Ali *et al.*, 2011). For each of the experiments, the scouring time varied. As a result, the amount of time the wool was suspended in the detergent solution was measured at different intervals for each sample. The different time intervals used to test each detergent were 3, 10, 15 and 20 min, respectively (Bozaci, 2017). These scouring times were used to determine whether scouring wool for longer times would be more effective. The authors note that the consistency of raw wool colour might vary slightly, and as a result, the samples were taken from the same wool fleece with the same colour. The scouring process was repeated ten times to ensure the effectiveness of each scouring solution, and the scouring method was the same for all wool samples (Figure 1).

2.4 Evaluation and data analysis

The analysis used in this study consisted of both descriptive and associational statistical analysis (Forouharshad *et al.*, 2013; Krause, 2018). The descriptive statistical analysis included measuring wool scouring loss, colour changes and wool fibre damage. Wool scouring loss was determined by differences observed in wool weight before and after scouring (Bahtiyari and Duran, 2013). Wool colour changes were determined by using

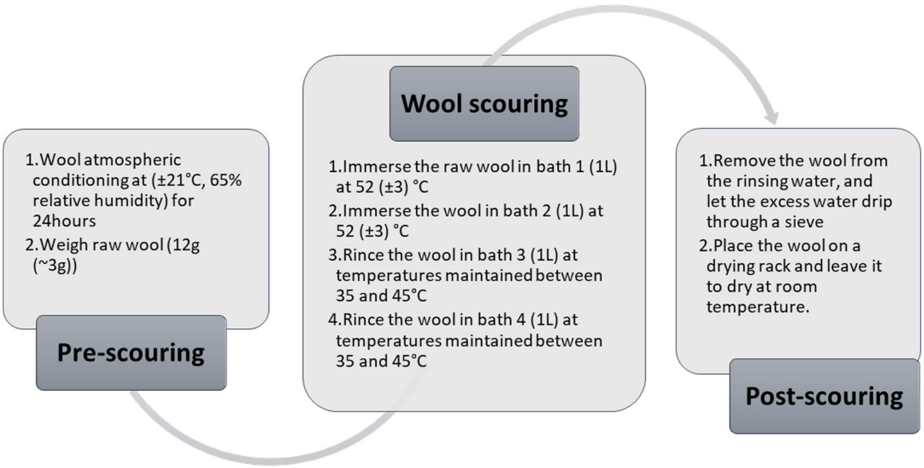

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Figure 1.
The wool scouring flowchart

the spectrophotometer, and wool fibre damage by SEM (Bozaci, 2017). The associational statistical analysis was applied in the results mentioned above to determine which variables contributed to changes in the wool's outcome (Krause, 2018). This was conducted using a mixed model that combined the treatment and time-fixed effects with the random effect of having multiple measures per sample for each of the different colour measures (Gałecki *et al.*, 2013).

2.4.1 Scanning electron microscopy analysis. The surface topology of wool fibres was analysed by using images derived from SEM to measure fibre cleanliness and damage. SEM is a preferred method for visualising microscopic surface alterations and detecting deviations from a preferred baseline image using visual comparison (Bozaci, 2017). The authors note that there are several methods to identify and classify anomalies from SEM; however, in this study, only a basic descriptive approach to interpreting the visual data was used (Pan *et al.*, 2018). SEM was performed on a sample of scoured wool for each of the wool scouring detergents and times to obtain an image. A total of 160 different samples (10x from each treatment regimen and time intervals for 3, 10, 15 and 20 min) were used in the SEM analysis. The researchers only analysed fibres in a lateral orientation and the same direction. Images were magnified up to 10 μm for the analysis and compared to a series of baseline images. The baseline images were obtained from raw Merino fleece wool before any wool scouring to ensure that the same baseline conditions were applied to the analysis. The Merino wool fleece samples used for SEM examination were cut and mounted on aluminium stubs (Cambridge pin type, 10 mm) using double-sided carbon tape and gold-coated (± 60 nm) with a Bio-Rad sputter coater (BIO-RAD, Microscience Division Coating System, London, UK; Au/Ar sputter coating @ 50–60 nm). Specimens were examined and imaged with a JSM-7800F Extreme-resolution Analytical Field Emission SEM (Tokyo, Japan). The Centre for Microscopy, University of the Free State, conducted the SEM and took the images used for further analysis by the researchers. For the SEM analysis, the researchers labelled and outlined the cleanliness, fat and damage (Figure 2).

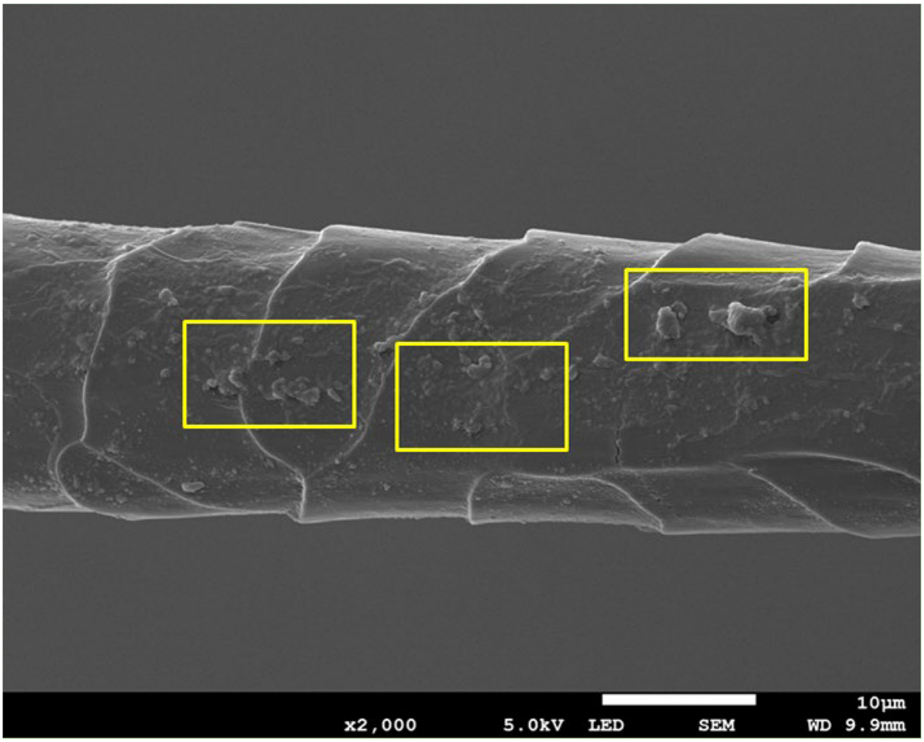
2.4.2 Scouring loss. All the wool samples were stored at standard atmospheric conditions for 24 h before measuring their weight. The wool samples were weighed using an electronic measuring scale, at 12 g, before scouring. After scouring, all the wool samples were dried at room temperature and remained in the standard controlled conditions (± 21°C; 65% relative humidity) again for 24 h before measuring their weights "after" scouring. All samples were compared (before and after) to calculate the weight loss percentage attributable to scouring. This experiment was completed according to the method and calculations devised by Hurren (2010). The equation is as follows:

$$SL\% = \left[(Mg - Ms)/Mg\right] x\,100$$

Where:

SL% = scouring loss in percentage;
Mg = mass of greasy wool expressed in grams; and
Ms = mass of scoured wool measured in grams.

2.4.3 Colour changes. The wool colour was measured by using a Konica Minolta spectrophotometer (Konica Minolta, 2001). This process was completed according to the AATCC evaluation procedure 6–2008 (AATCC test method for the instrumental colour measurement). The wool was measured under standard atmospheric conditions, and the spectrophotometer was calibrated before starting with colour measurements. Each wool sample was measured five times in different areas to determine the colours available in the



Source: Author's own creation

Figure 2. Example of a raw Merino fleece SEM image. The areas outlined in yellow are examples of fat deposits and debris found on the wool fibres

raw wool fibre before and after scouring. The total colour difference is calculated as ΔE (Mokrzycki and Tatol, 2011):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where:

L = the lightness (L = 0 shows black and L = 100 shows white);
a = conveys the red/green coordinates, (−a) values show green and (+a) values show red; and
b = measures the yellow/blue coordinates, where (−b) values show blue and (+b) values show yellow.

To evaluate the impact of the colour changes and the effect of different scouring times on the outcome of wool colour between the different scouring solutions used, a mixed effects model, analysis of variance and regression analysis were performed (Pinheiro and Bates, 2006). The mixed effects model and the analysis of variances were conducted with a few assumptions, namely, that the points of measurement were given as matched so that it could be differentiated within an analysis, that treatment regimens and different scouring time act as fixed effects and the different solution are random scouring effects and that colour change is for the better. This last assumption does not include a colour change as worse; therefore, a worse colour change cannot be inferred from the results, just the degree to which the change took place. All colour measurements were plotted according to the CIE colour space notations (Figure 3).

Within the mixed effects model, ΔE was used as the target variable. The first iteration of the model was fitted with treatment and time effects as given, with interaction on ΔE. If the interaction between these fixed effects is insignificant, the model collapses. Next, we interpret the results of the model as significant if the treatment appears to be independent of the effect of how long the wool is treated. If the random effect is insignificant, then it implies that the effect of treatment and time did not make a difference between the different types of solutions used. The analysis of variance (ANOVA) system was used to interpret the different associations between the fixed variables, such as the variance comparison between treatment regiments and time. The ANOVA method explores the relationship between a dependent variable and one or more independent variables, where the independent variable is usually a quantity, while the dependent variable is typically a criterion (Christensen, 2001). Finally, the variable associations were compared using a regression analysis. This was performed to assess the extent to which the variability of different treatments has an effect on the various time steps used. All analyses were done on the R software using universally accepted statistical standards of analysis and interpretation (R Core Team, 2021).

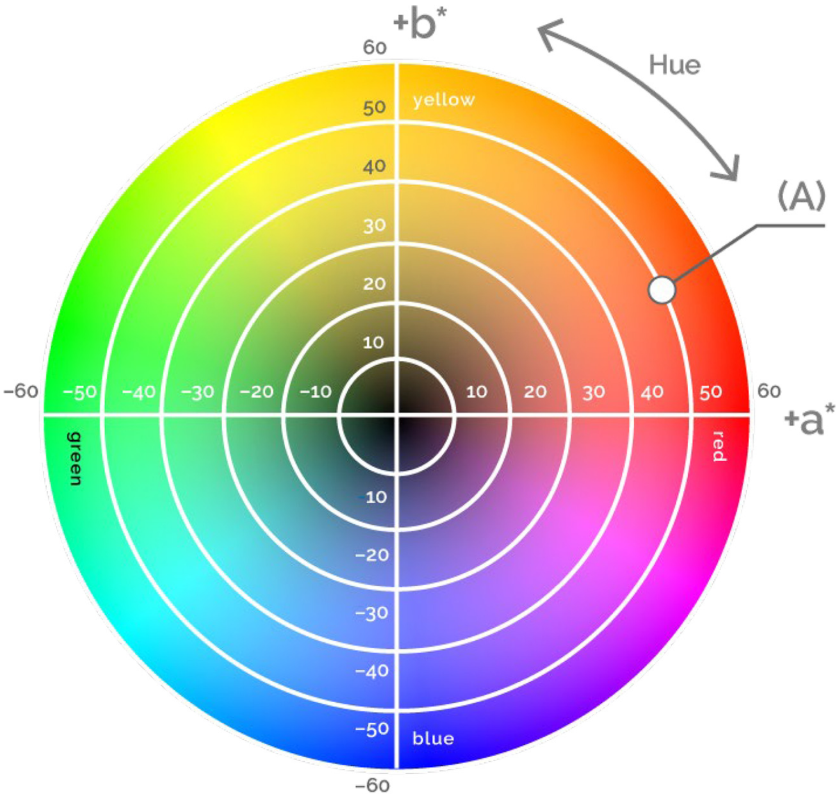


Figure 3.
CIE colour space notations

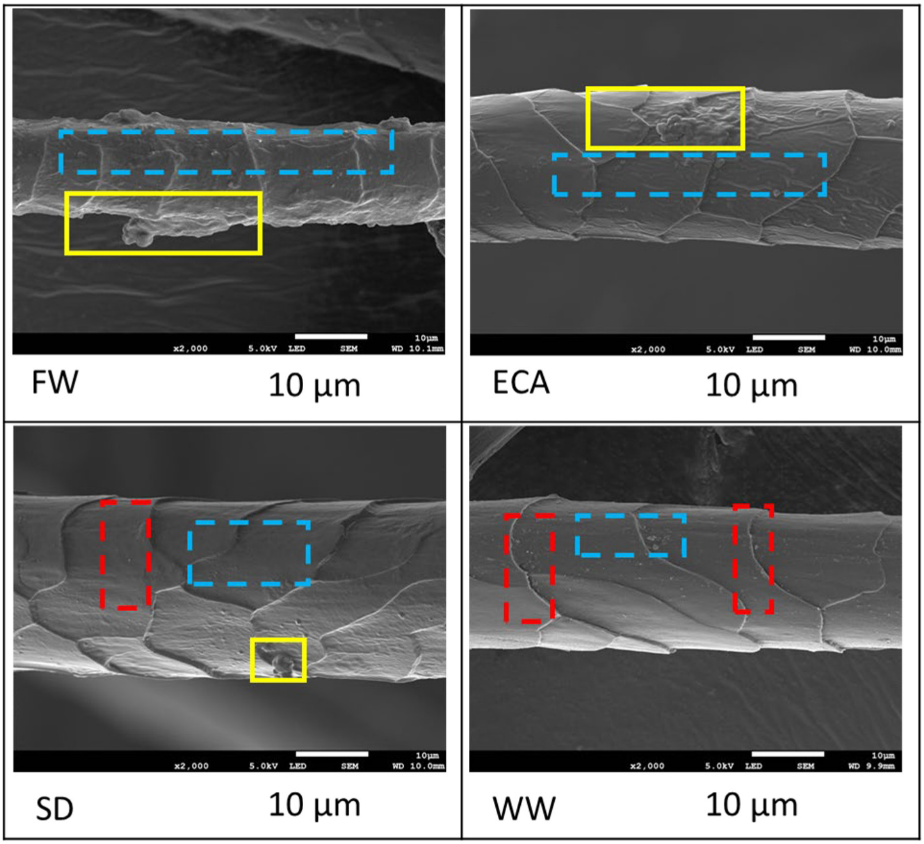
Source: BioconColors (2017)

3. Results and discussions

3.1 Scanning electron microscopy analysis of scoured wool fibre quality

The scoured wool was captured under the SEM to provide information on the wool microstructure and surface fibre properties resulting from scouring. This was to determine if the wool scouring time and solutions had any impact on the wool surface fibre property and to see if the wool would be clean and show any dirt particles under the SEM.

3.1.1 3 min of wool scouring. The findings illustrate that the FW and ECA-scoured fibres have the highest particles and dirt on their surfaces (Figure 4). The presence of lanolin on the surface of wool fibres makes it difficult to observe the surface fibre property such as scales of the fibres and assess any potential damage. Our findings indicate that the traditional scouring method using FW and ECA was ineffective in removing dirt and lanolin within three minutes. Although scouring with WW and SD for three minutes resulted in slightly less dirt and lanolin, the scouring solutions were only partially effective within the time frame. The data in Figure 4 support these observations.



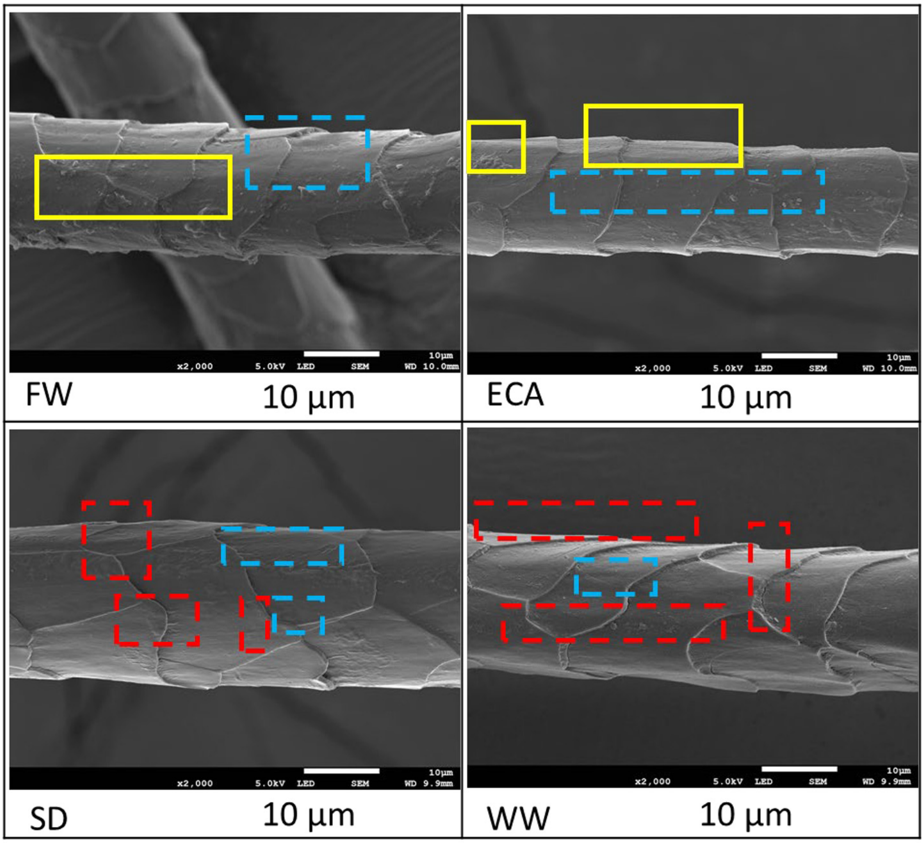
Notes: Yellow = Debris; Blue = Lanolin fat deposits; Red = Fibre damage

Source: Author's own creation

Figure 4. Comparison of different scouring solutions with 3 minutes of scouring time for FW, ECA, SD and WW

3.1.2 10-min of wool scouring. Scouring wool for 10 min with FW and ECA produced clearer scales with less lanolin compared to wool scoured for three minutes (Figure 5). Despite this improvement, the wool still showed dirt particles and cracks. The wool scoured with SD for 10 min showed less dirt compared to FW and ECA but had scales that slightly peeled from the fibre surface and displayed cracks and uneven scales. The wool scoured with WW showed the least amount of dirt and had elongated, uneven scales on its surface.

3.1.3 15-min of wool scouring. The wool scoured with ECA had a lanolin coating that obscured the presence of dirt on the fibre. This re-coating may have occurred when the wool was removed from the scouring bath. The wool scoured with FW had small dirt particles covered with melted lanolin, making it difficult to see the cuticle clearly or assess any surface changes and fibre damage. This is because the absence of detergent prevented the water molecules from entering the greasy layer of the wool fibre and removing dirt during scouring (Wood, 2009a, 2009b). The wool scoured with SD had a thin layer of lanolin, but the wool appeared clean and had well-defined scales on its surface. The wool scoured with WW had visible scales with small cracks between the fibres and cuticle edges and oddly shaped



Notes: Yellow = Debris; Blue = Lanolin fat deposits; Red = Fibre damage

Source: Author's own creation

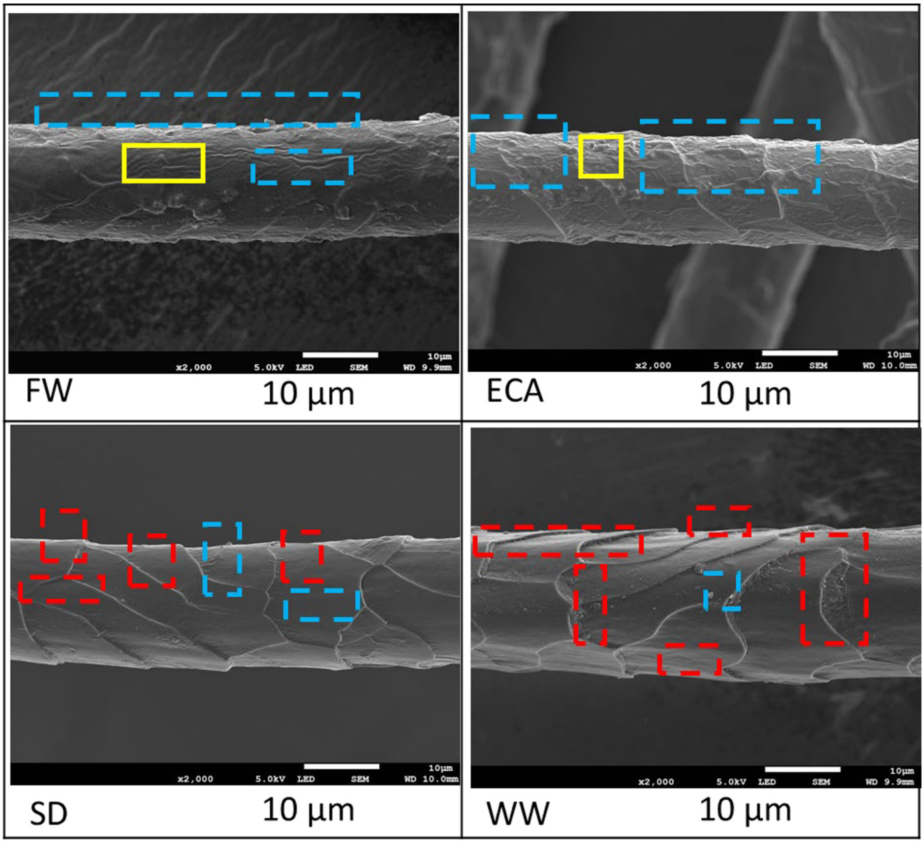
Figure 5. Comparison of different scouring solutions with 10 minutes of scouring time for FW, ECA, SD and WW

scales that did not follow the natural direction of scales. It had very little dirt on its surface compared to the other treatments. The wool scoured with SD, and WW showed the most fibre damage compared to wool scoured with ECA and FW (Figure 6).

3.1.4 20-min of wool scouring. The wool scoured with ECA for 20 min had little dirt on its surface and scales that appeared to be peeling away from the wool fibre surface. There were also cracks present on the surface of the scoured wool fibre. The wool scoured with FW still had the most dirt particles on its surface and showed cracks, but no lanolin was present. The wool scoured with SD had very little dirt on its surface and had a lanolin coating. The wool scoured with WW had the least amount of dirt particles and no lanolin coating, as shown in Figure 7. There was also some evidence of fibre damage on the wool scoured with WW, as observed in a study conducted by Pan *et al.* (2018) using SEM.

3.2 Wool scouring loss

Scouring loss percentage (SL%) was experienced between the different scouring periods and samples (Figure 8).

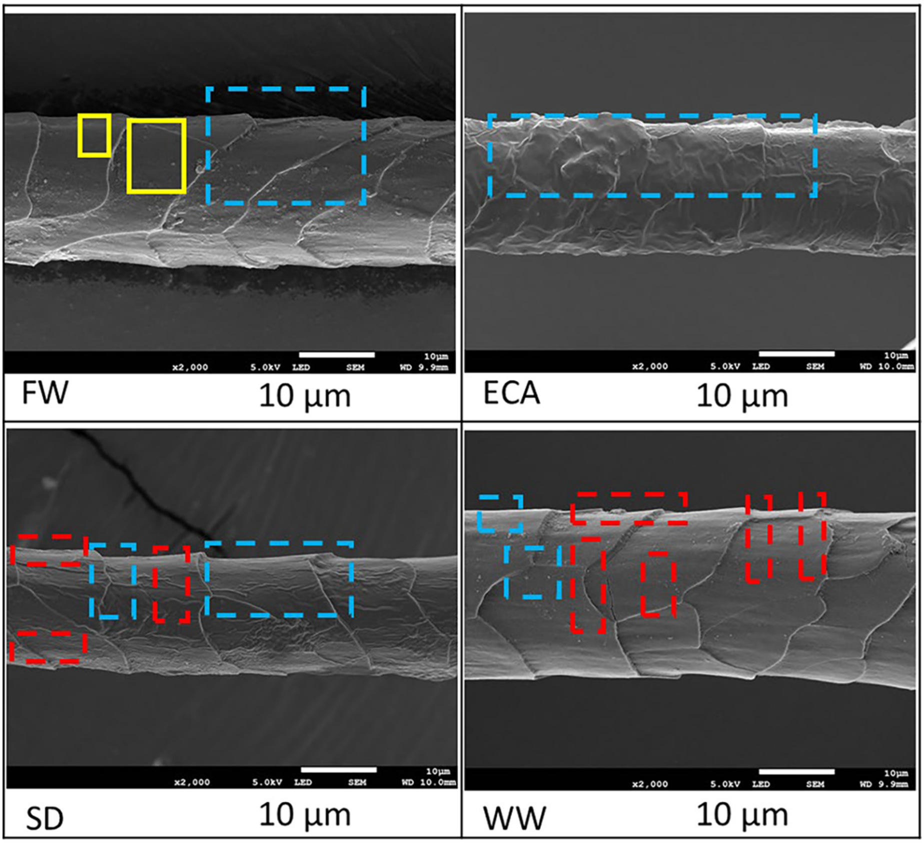


Notes: Yellow = Debris; Blue = Lanolin fat deposits; Red = Fibre damage

Source: Author's own creation

Figure 6. Comparison of different scouring solutions with 15 min of scouring time for FW, ECA, SD and WW

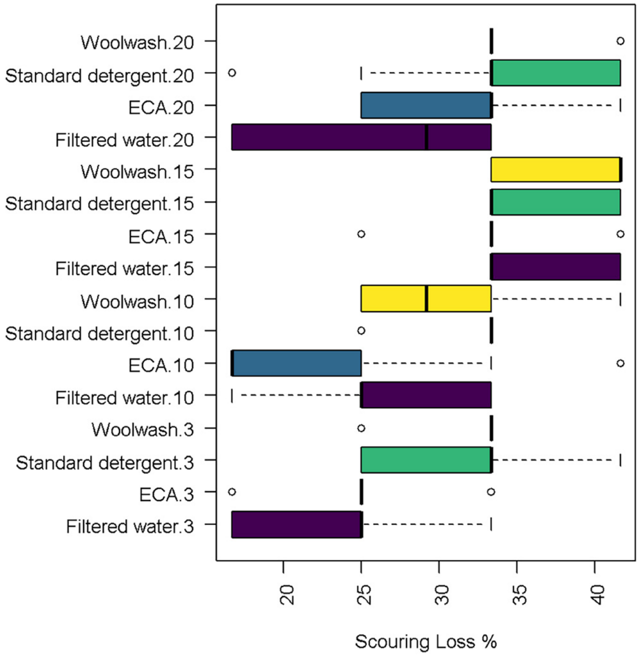
As a highly contaminated fibre, raw wool contains many impurities, including wax, grease, sweat, dirt and vegetable matter (Allafi *et al.*, 2022), and these impurities weigh only half of the raw wool itself (Bahtiyari and Duran, 2013). The process of scouring wool removes the wool's impurities, and this increases the weight loss incurred (Bahtiyari and Duran, 2013). The wool scouring loss (SL%) of wool samples was compared when cleaned with different scouring detergents (ECA, FW, SD and WW) for various lengths of time (3, 10, 15 and 20 min, respectively). It was found that the average weight loss was 25% for ECA and FW scouring solutions at time lengths of 3 and 10 min, respectively. Although the wool scoured with ECA and FW resulted in lower wool weight loss percentages, this process is still regarded as effective, as it removed some of the impurities on the wool fibre after scouring. The wool weight loss from scouring with SD and WW was also compared, and both solutions resulted in slightly higher weight loss (30% and 31%, respectively) than the baseline of 25%. In addition, an average SL% increased to 7.7% above the baseline for all detergents after 15 min scouring (32.7%). Similarly, an overall increase of 3.3% in SL% was



Notes: Yellow = Debris; Blue = Lanolin fat deposits; Red = Fibre damage

Source: Author's own creation

Figure 7.
Comparison of different scouring solutions with 20 minutes of scouring time for FW, ECA, SD and WW



Source: Author's own creation

Figure 8.
Wool scouring loss % for different samples

observed for all samples for 20 min (28.3%). These results agree with Kendra's (2014) explanation that the formulated scouring agents have chemical substances designed to remove wool grease, soil, vegetable matter and suint from the fibre. Hence, the wool scoured with WW and SD experienced a higher weight loss percentage due to the efficient removal of the dirt and vegetable matter from the wool fibre. The wool scouring times also showed a difference in weight loss after scouring, proving Wood's (2012) statement that scouring wool for a longer time maximises dirt removal. Scouring wool for 15–20 min (instead of 3–10 min) increases the scouring loss by 5.7% on average over the baseline. Overall, part of the study examined the impact of different scouring solutions and scouring times on the overall weight loss of samples. Based on these results, it was evident that scouring detergents (WW and SD) led to slightly higher weight loss (Tables 1 and 2).

The final model showed that the combination of treatment and time had the best results. It was found that using SD in scouring added 5% to the normal scouring loss, using WW added 6% and increasing the time added 5.7%. On average, the baseline scouring loss was 25%.

3.3 Wool colour evaluation

3.3.1 The wool colour changes after scouring. The effect of scouring agents and scouring time on wool colour change was measured and determined by comparing the raw wool and the scoured wool colour change (ΔE), expressed in L*a*b* terms. The colour changes from raw wool to scoured wool show that all the wool samples increased lightness (L*) after scouring (Figure 9).

The increase in lightness indicates that the wool colour became brighter after scouring when compared with the original raw wool colour. The pattern of the results shows that the wool scoured with FW and ECA resulted in low *L values, compared with the wool scoured with formulated detergents such as SD and WW. Furthermore, impurities in the wool, such as sand, wax and vegetable matter, may cause a non-white colouration in the wool fibre (Allafi *et al.*, 2022). Hence, the wool scoured with ECA and FW resulted in lower *L values. On the other hand, chemically formulated detergents contain whiteners, surfactants and builders and can easily remove insoluble contaminants and grease (Hasan *et al.*, 2010); hence, the wool scoured with WW and SD showed higher *L values.

Furthermore, the L*a*b* colour space also provides the red-green (*a) and yellow-blue (*b) chromaticity to accurately represent a wide range of wool colours after scouring. There were outliers for *a change in all samples except SD and FW for 20 min, ECA 10 min and ECA 3 min (Figure 10). In contrast, there were outliers in the *b change for WW, SD and ECA for 3 and 10 min. Furthermore, for 15 min, the outliers were FW, ECA and SD. The results for WW and SD were similar. The same results can be seen for ECA and FW. This is due to the similarity in chemical composition between these different solutions. In addition, there is a contrast between the time steps taken from 3 to 20 min. The *b changes between the different samples ranged from −15 to 10 (25 light units), and the a* change ranged from −10 to 5 (15 light units). This means the colour changes in yellow-blue were more significant between the different scouring solutions than red-green (Figure 10).

The overall colour change (ΔE), as a consolidation of the previous results, needed to be contextualised regarding the impact treatment and time had on the overall colour change. The results from the mixed effects model indicate that time and treatment regimens have an impact on the different samples that were used. These results correspond with what was observed between the different samples for each of the L*a*b* colour changes. The additional multivariate analysis confirmed that treatment and time regimen have a statistically significant impact on the overall colour change between the different detergents used for all samples within this study. Finally, the relationship between the different treatment regimens and times used to the overall colour change (ΔE) indicated that there was a strong relationship between treatment regimen and time steps to the overall outcome of the colour change (ΔE) (Table 3).

Table 1.
Analysis of variance for SL%

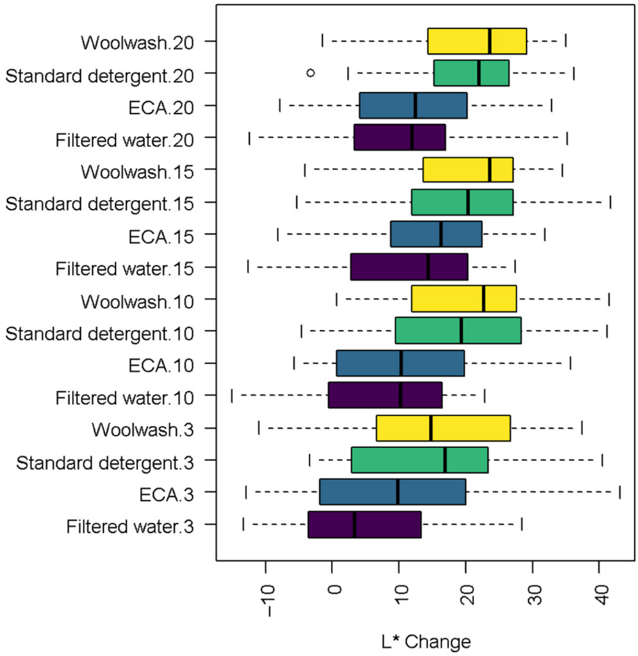
	Df	Sum sq	Mean sq	F-value	Pr (>F)
New treatments	2	1240.9	620.44	18.238	0.000000076238
New time	1	1312.9	1312.93	38.595	0.000000004539
Residuals	156	5306.9	34.02		

Source: Authors' own creation

Table 2.
t-value for SL%

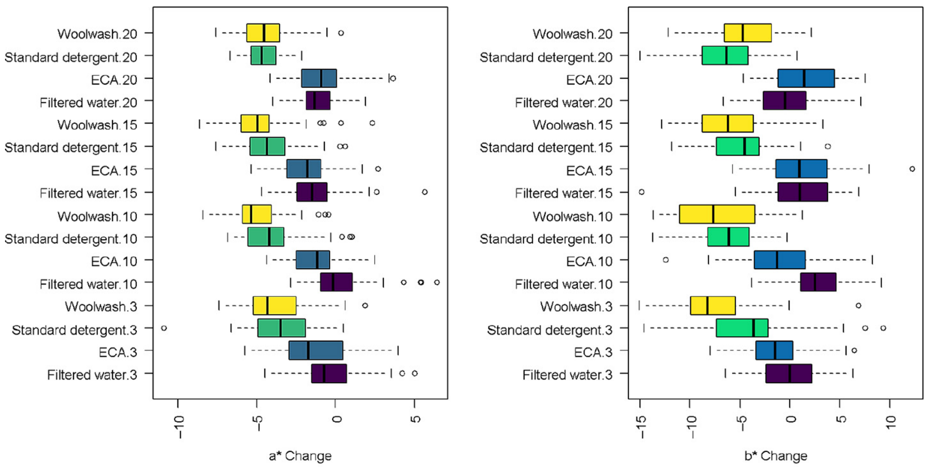
	Estimate	Std. Error	*t*-value
(Intercept)	25.2604	0.7987	31.629
New treatment (SD)	5	1.1295	4.427
New treatment (WW)	6.0417	1.1295	5.349
New Time 15–20 min	5.7292	0.9222	6.212

Source: Authors' own creation



Source: Author's own creation

Figure 9.
L* change in samples



Source: Author's own creation

Figure 10.
a* and b* change in wool fibres

Overall, FW yielded the least colour change (ΔE) for 3 min (10.6 units), followed by ECA (12.6 units), SD (18.9 units) and WW (20.3 units). All colour changes in the 3 min scouring cycle exceeded the minimum of 5 units, indicating a significant change from the original sample. This shows a subtle wool colour change despite the detergent used when scoured

Treatment	Estimate	Std. Error	df	*t* value	Pr(>|*t*|)
Intercept	10.490	0.804	793	13.052	0.000
ECA	2.115	0.859	793	2.461	0.014
SD	8.378	0.859	793	9.750	0.000
WW	9.834	0.859	793	11.445	0.000
Time 10	2.223	0.859	793	2.588	0.010
Time 15	3.249	0.859	793	3.781	0.000

Analysis of variance table

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Treatment	13615.418	4538.473	3	793	61.473	0.000
Time	1259.695	419.898	3	793	5.687	0.001

Source: Authors' own creation

Table 3.
Results of the mixed effects and ANOVA

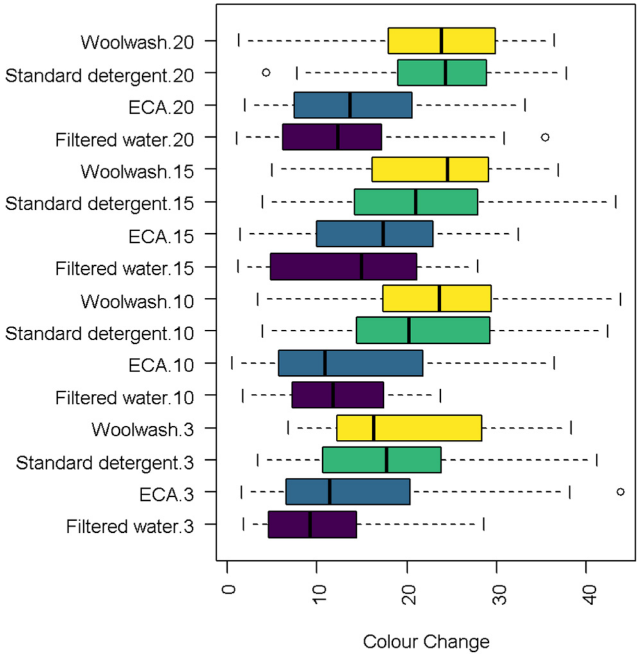
because raw wool samples contain soil particles and other debris that will be removed when exposed to water (Bahtiyari and Duran, 2013).

The wool scoured with FW shows low Δ*E* values for 3, 10, 15 and 20 min of scouring. The colour changes of the wool scoured with FW is small as water alone cannot remove all the lanolin and most dirt particles (Wood, 2009a, 2009b). As previously mentioned, water molecules cannot enter the lanolin layer to detach lanolin from the fibre surface (Mazow, 2014). The wool samples scoured with ECA for 3, 10, 15 and 20 min showed higher Δ*E* values than the wool samples scoured with FW and low ΔE values, and also higher than the wool samples scoured with SD and WW. Wool scoured with ECA has low Δ*E* values and lightness because it still has dirt particles and lanolin over the wool fibres. Scouring wool samples with SD and WW for 3, 10, 15 and 20 min resulted in higher Δ*E* values than those scoured with ECA and FW. Mazow (2014) explained that combining water with detergents and solvents removes the trapped lanolin and dirt from the wool fibre. WW and SD agents removed most contaminants, vegetable matter, dirt and lanolin during wool scouring, resulting in high ΔE values (Figure 11).

Thus, increasing the scouring time to 10 min added an overall addition of 2.2 units change, whereas 15–20 min altered the colour by 3.2 and 2.9 units, respectively. Based on these results, the type of scouring had a more significant effect on colour change than time. However, time at 15 min yielded the best results out of all the time steps (Table 4).

4. Implications for small-scale farmers

The results of this study demonstrate that traditional wool scouring methods can be an effective option for small-scale farmers who lack access to sophisticated machinery. The researchers support this method, as it is suitable for effectively cleaning wool without the need for industrial equipment. The main contributor to the cleanliness of the wool is the type of detergent used (Vasconcelos *et al.*, 2006). In this study, WW was found to be the most suitable detergent, as wool is a sensitive fibre that does not react well with high alkali (Taleb *et al.*, 2020). In addition, the detergent suitable for wool needs to factor in all the properties that were measured in the study, such as fibre properties, wool colour and wool weight. The natural colour of wool is affected by sand and lanolin, which compromise the colour (Mortimer, 2009). When raw Merino wool was scoured at different time lengths, using different detergents, the colour changes were significant at 15 min. Wool scoured with chemical detergents was lighter due to the detergent stripping off lanolin from the wool fibre surface. It is important to note that if the wool was not correctly handled during scouring, it would tangle and be challenging to work with due to felting.



Source: Author’s own creation

Figure 11. Overall colour change between different scouring times and solutions

Treatment	Time (Minutes)	Before *L	Before *a	Before *b	After *L	After *a	After *b	ΔE
Filtered Water	3	69.4	4.1	17.4	74.8	3.8	17.3	10.7
ECA	3	69.0	3.9	18.1	79.0	2.7	16.7	14.1
Standard Detergent	3	69.1	3.9	16.3	83.5	0.4	12.3	17.5
Woolwash	3	71.6	3.3	17.0	87.6	−0.4	9.6	20.0
Filtered Water	10	67.7	3.8	15.4	75.6	4.1	18.1	12.3
ECA	10	68.8	3.6	17.0	79.9	2.3	16.0	13.8
Standard Detergent	10	66.9	4.0	16.7	85.9	0.0	10.5	21.7
Woolwash	10	67.0	4.3	16.8	87.2	−0.6	9.7	23.3
Filtered Water	15	65.9	4.0	15.3	78.5	2.7	16.2	14.5
ECA	15	63.9	4.4	15.4	78.7	2.7	16.7	16.4
Standard Detergent	15	67.2	4.0	15.7	86.3	−0.1	11.0	21.2
Woolwash	15	65.6	4.1	15.8	86.3	−0.5	9.9	23.2
Filtered Water	20	69.1	3.4	16.1	79.4	2.2	15.6	12.8
ECA	20	66.7	3.6	15.2	79.0	2.8	16.7	14.4
Standard Detergent	20	66.2	4.3	15.9	87.1	−0.2	9.3	23.3
Woolwash	20	65.8	4.1	14.9	87.3	−0.3	10.2	23.1

Notes: L* = lightness; a* = red/green coordinates; b* = yellow/blue coordinates
Source: Authors’ own creation)

Table 4. Comparison of CIE L*a*b* analysis of wool fibre before and after scouring

Based on the findings, it is recommended that small-scale farmers use detergents that are specifically designed for raw wool fibre, such as WW detergent, with an optimal scouring time between 10 and 15 min to achieve the best results between fibre property, wool colour and scouring loss. Clean wool allows for further processing, such as carding, spinning or felting, which can then be used to develop wool products to sell (Cottle, 2009). Although this study did not explicitly focus on the product development potential of such wool products, examples of this innovation include knitting and knitted products, felt products and sewn wool products. It is important to note that the traditional method of scouring may yield different results from the industrial method of scouring. Further exploration is needed to assess other parts of the wool value chain. Additionally, future research could focus on developing a comprehensive understanding of the product development potential of wool products produced through traditional wool scouring methods.

5. Conclusion

This study set out to evaluate the effectiveness of different scouring detergents for traditional wool scouring, with the goal of identifying the detergent that yields the best scouring results in terms of wool fibre properties, scouring loss (wool weight) and wool colour. This research has shown that a combination of time and the type of scouring agent used makes a significant difference in the outcome of wool quality. Based on the interpretation of the analysis, it can be concluded that the relative colour change used from both SD and WW had the most significant shift in wool colour change after scouring but also the highest degree of scouring loss. The authors note that wool scouring loss can vary depending on the type of wool scoured, the method of scouring and the level of impurities present in the raw wool. As this study used the traditional way of scouring, the results may vary significantly from the industrial method of scouring. The findings of this study can be used to inform small-scale farmers on best practices for wool scouring and enable them to produce clean wool for further processing and product development. The study highlights the importance of considering the unique properties of wool fibres when selecting appropriate detergents for scouring. While the focus of this study was primarily on the technical aspects, future research should explore the potential for product development and market strategies of wool products produced through traditional wool scouring methods. Such analysis will help develop a comprehensive understanding of the wool value chain and further enhance the economic potential of wool products in the Free State.

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