

Article

Determination and Characterization of the Wool Fiber Yield of Kenyan Sheep Breeds: An Economically Sustainable Practical Approach for Kenya

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Abstract: The aim of this paper is to study wool fiber resources from Kenya that have been obtained from different breeds in order to characterize the basic properties of their wool to help improve the economic value of Kenyan wool. The Kenyan sheep industry has received less attention in terms of research and development when compared with large livestock. Wool quality and yield are essential to obtaining good returns in the international market. This study was conducted to analyze the wool yields and qualitative index of Kenyan sheep. The wool samples were taken from 95 crossbreed Dorper sheep comprising 23 males and 72 females between the ages of one and five years. Wool samples from the shoulders, flanks, back belly and legs were taken for analysis. The mean fleece weight was 2.04 ± 0.06 kg, with coefficient of variation of 37% for all the selected sheep; the average for the males was 2.06 ± 0.06 kg and the average for females was 2.02 ± 0.08 kg. The variation in the fleece weight was in the range of 0.7–3.3 kg. The yield percentages and impurities were analyzed and reported. The wide variations in fleece weight, the increase in sheep population and the trend of raw wool export suggests that there is potential for improving economic traits. Kenya can obtain trade benefits related to the wool industry by becoming a member of International Wool Trade Organization and by following economically sustainable practical approaches. It is essential to have good international and regional cooperation with countries that can share knowledge and training as well as marketing and information.

Keywords: Kenya; wool; yield; natural fibers

1. Introduction

The research into agriculture, natural raw materials and agro-industry, facilitated through institutions such as universities or research centers, is an important part of the economy. Due to wool, the sheep industry is one of the major resources for a country to develop, among other livestock [1]. The establishment of policies in developing countries such as the African Growth and Opportunity Act (AGOA), which provides most Sub-Saharan African (SSA) industries duty-free and quota-free trade access to the United States, offers a substantial competitive advantage over other exporting countries of textiles and apparel [2]. Kenya is not a member of the International Wool Textile Organization, which would require, among other things, the ability to certify wool fibers to internationally-accepted standards, to make sheep farming more viable and profitable to farmers and commercial stakeholders

in the wool trade. Global marketing strategies should be followed to sell Kenyan wool and wool products in foreign countries [3].

Kenya has a tradition of wool production in Nauru, Uasin Gishu, Keiyo, Marakwet, West Pokot and Nandi in the Rift Valley region. Other potential areas include highlands such as Nyandarua in the Aberdare Mountain Ranges, and the Mount Kenya regions in the central and eastern provinces. Figure 1 shows a map of Kenya showing high potential regions for wool sheep breeds. Wool production in these regions declined some years ago and herders dropped out of the market in reaction to marketing problems and unattractive prices. The Rift Valley province has the highest sheep population [4] and has been one of the major producers of wool in Kenya, as shown in Figure 2.



Figure 1. Map of Kenya showing high potential regions for wool sheep breeds.

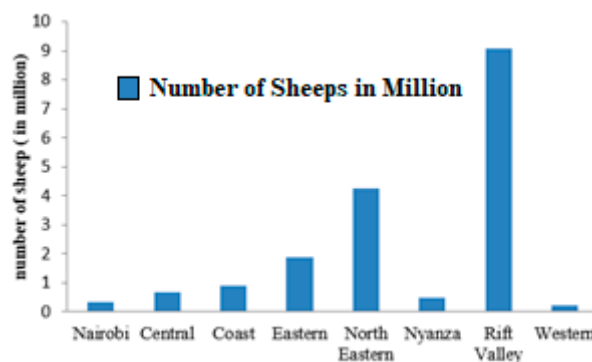


Figure 2. The number of sheep in all provinces of Kenya.

In the past, the sheep industry has received relatively little attention in terms of research and development when compared to large stock. Around 80% of the world's wool goes into garment production, leaving 20% to be used in some surprising and interesting ways, and people are constantly developing new applications. This fiber has a number of advantages, including durability and flexibility. Varying grades of wool can range from extremely soft fibers that can be used against the skin, to coarser fibers that are more suited for tasks such as stuffing, insulating, soundproofing, carpets, and carpet padding [4,5]. The huge potential of sheep for industry has not been fully exploited. The current government priority development policy strategy is geared towards poverty reduction. Among the strategy for smallholder farmers in the high potential areas will be dual purpose sheep production.

The annual domestic exports in the Kenya National Bureau of Statistics reveal that there has been an annual increase in the export of raw wool from Kenya. The trend in the quantity of exported wool every year is illustrated in Figure 3.

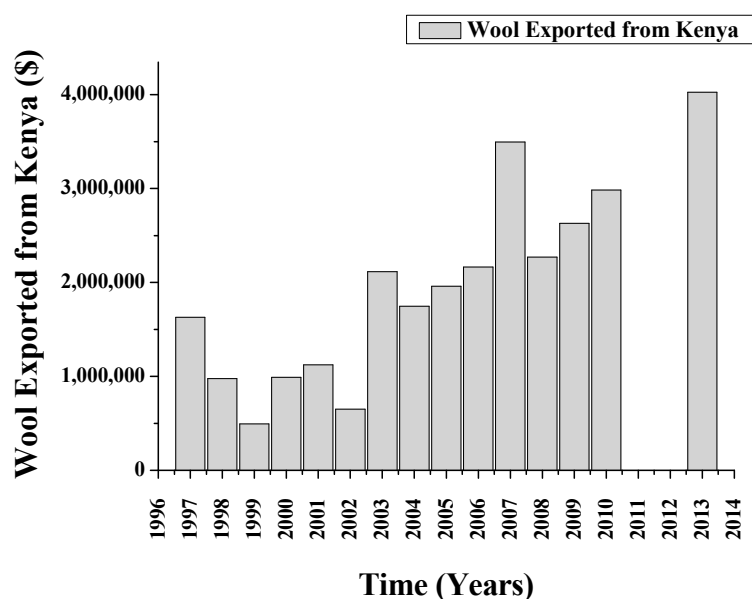


Figure 3. Wool exports from Kenya over the past years.

Sheep farming in Kenya is a part of the socio-economic setup for large and smallholders in many regions. It is an important resource of mutton and wool production, while in some areas it is also considered a source of milk. There has been a significant increase in the sheep population over the past years; this was also the trend for livestock in general. In addition to this increase in sheep population, the trend of wool exports per year from Kenya has also been increasing [6]. For instance, in the year 2007, 1973 tons of wool was exported, but this increased to 2288 and 2279 in the years 2013 and 2014, respectively. Kenya has a good climate and ecological conditions that favor wool sheep rearing, especially over 5000 m in the highlands [7]. The mean annual rainfall in the high potential areas nourishes a species of grass that is in abundance for feeding the animals.

The unchecked quality of the wool, the increasing use of synthetic fibers, and high competition from key wool-producing nations may result in wool going from a resource for income generation to a problem to solve. The wool produced in tons yearly will be considered and handled as a waste if the industry is neglected and the wool is not destined to profitable applications due to a weakened supply chain and the poor quality of the fibers. This situation may force farmers to get rid of their wool as quickly as possible in ways that may not be environmentally and economically acceptable. Therefore there is a need for research and development to offer solutions to problems in sheep farming, wool production, the innovation of novel wool products and the introduction of high-quality fibers such as super-fine wool.

2. Sample Collection and Preparation

2.1. Sample Collection

The samples were sourced from Rift Valley farms in Kenya. Kenya lies between latitudes 4° N and 4° S and between longitudes 34° E and 42° E and has a humid tropical environment with an annual rainfall of over 1000 mm and a mean temperature of 22 °C. Mostly, sheep are kept in mixed herds with other livestock such as goats and cattle. Sheep are sometimes milked, but the practice is neither regular nor widespread. Otherwise, small ruminants are kept for subsistence meat production and are also sold for cash [8].

Herd sizes vary greatly and are run mainly in natural pastures throughout the year. Nearly all smallholders practice arable agriculture and keep a mixture of ruminant and non-ruminant livestock. In general, sheep and goats are grazed in small paddocks with cattle, but in some areas, they will graze communally. Minerals and veterinary products such as anthelmintic to control internal parasites and anti-tick bathing are used. The sheep are grazed on pasture but a complementary ratio containing crop residues, hay and wheat straw may occasionally be fed, for instance during the dry season. Breeding is not controlled and lambs are born all year round and sheep production for wool and meat is kept as part of a mixed farming system on both small- and large-scale farms [9]. Most of these areas have well-established dairy grade cattle, sheep, and wheat and pyrethrum mixed farming. The pasture on the grassland is predominantly Kikuyu grass and Themeda grass in natural association with legume clovers such as Kenya purple and white clovers and Louisiana white clover [7]. Other fodder crops used include oats, kales, fodder beets, and turnips. The natural flora contains a number of useful pasture species such as *Setaria*. Useful fodder species include Napier grass, giant *Setaria*, Sudan grass, Columbus grass, maize and sweet potato. The sample collection was carried out during the shearing of the herds on various farms and the samples were taken from a total of 95 sheep, comprising 23 male and 72 female sheep varying from 1 to 5 years old. Wool shearing was carried out using a carbon steel tempered cutting blade. Wool fibers from different sheep body parts, or about 20 g from each part, covering the anterior area to the head area and midway between the belly and top lines, were taken during shearing and were labeled according to the body parts from which they came. A schematic diagram of wool fleece from various sheep body parts is presented in Figure 4. The wool shorn from the flanks was labeled RBS, that shorn from the back area was labeled BCK, wool shorn from belly and legs were labeled BLS and wool shorn from the shoulder as SHR.

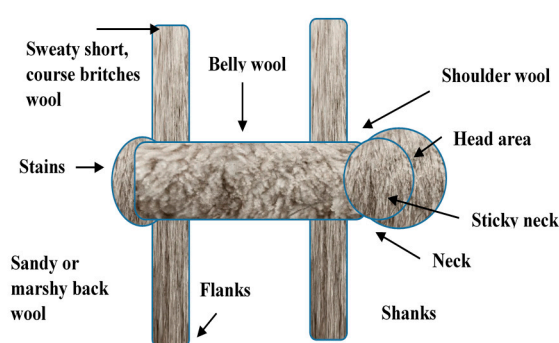


Figure 4. Schematic diagram of wool fleece from various sheep body parts.

The fleece weight (FW) of each sheep was measured by scale balance and recorded. Wool production is considered of secondary importance and shearing is done once a year and it is performed with hand blades, usually during the beginning of the dry season.

2.2. Sample Condition

The wool fiber samples were placed in an environment with a standard temperature of 20 ± 2 °C and humidity of $65 \pm 2\%$ for 24 h before and after the experiment. Wool fibers are hygroscopic and regain moisture well and therefore needs to be conditioned to obtain moisture balance and then reserved in dry sample bags for testing.

3. Experiments

3.1. Materials and Apparatus

The commercial grade nonionic detergent Wool detergent X100 was purchased from Tongxiang Yongjin Textile Auxiliary Factory, Tongxiang, China. The analytical grade sulfuric acid (H_2SO_4) was purchased from Pinghu Chemical Reagent Factory, China. The analytical grade sodium carbonate (Na_2CO_3) and caustic soda (NaOH) were provided by Sinopharm Group Chemical Reagent Co., Ltd., Beijing, China.

The electronic balance (FA2004A) was manufactured by Shanghai Jingtian Co. Ltd. (Shanghai, China) with an accuracy of 0.0001 g. The water bath (KUDOS SK3200H) was manufactured by Shanghai Branch Instrument Co., Ltd. (Shanghai, China) with temperature 90 ± 5 °C. The electro-thermal constant temperature blast drying oven (DGT-G80) was sourced from Shanghai Sen Xin Experimental Instruments Co. Ltd. (Shanghai, China) with an accuracy of ± 0.1 °C. The laboratory heating oven (PT-1700XT) was sourced from Zhengzhou Protech Technology Co., Ltd. (Zhengzhou, China) with an accuracy of ± 1 °C. The pH pen (SIN-PH-100) was manufactured by Hangzhou Automation Technology Co., Ltd. (Hangzhou, China) with an accuracy of ± 0.02 pH.

3.2. Wool Fiber Scouring

The conditioned greasy wool fiber subsamples weighing 120 g of the RBS, BCK, BLS and SHR samples were scoured using a liquor ratio of 1:50, a temperature of 60 °C with 2 g/L of Eco-nonionic detergent X100. The greasy wool fibers were immersed into the scouring solution and soaked for 20 min. After soaking for 20 min, the greasy wool fibers were removed from the scouring bath and then pushed gently into the warm water (i.e., 60 °C) to be washed for 10 min, then the water was drained out. The samples were again subjected to a second scouring bath with the same liquor ratio, temperature, quantity of detergent and duration as in the first bath and soaked for 20 min. The samples were then rinsed with water at a temperature of 60 °C and then the rinse water was drained out and then the samples were cold washed.

The wool fibers were then dried in an oven at 60 °C for 24 h, the dried scoured wool samples were then conditioned at 20 ± 2 °C, $65 \pm 3\%$ Relative humidity for over 24 h and then weighed using the electronic balance to obtain their final weight.

3.3. Testing of Moisture Regain of the Scoured Samples

The oven-dry testing method was used as specified by IWTO-33, "Method for the determination of oven-dry mass and calculated invoice mass of scoured or carbonized wool by International Wool Textile Organisation" and the moisture regain of the samples was obtained using the following formula.

$$\text{Moisture regain \%} = ((W_m - W_d)/W_d) \times 100 \quad (1)$$

where W_d is the mass of the dry specimen and W_m is the weight of the conditioned specimen. The drying temperature during testing was set to 103 °C.

3.4. Vegetable Matter (VM) Test

The amount of vegetable matter was determined using the testing method stated in IWTO-19, "Determination of the wool base and vegetable matter base of core samples of raw wool". Test specimens of the dried scoured subsamples were weighed and dissolved in hot 10% caustic soda

solution. Once the wool was dissolved, the alkali-insoluble impurities were then rinsed dried and weighed. This total weight of alkali-insoluble impurities was then expressed as a percentage. The percentage of hard heads and twigs was obtained after the combing process. The ash residue expressed as a percentage was determined from the dried scoured subsamples incinerated for two hours at a temperature of 750 °C. The percentage of grease residue was evaluated by an alcohol extractable matter test on a Soxhlet extractor.

3.5. Testing of Carbonized Vegetable Matter

The preconditioned subsamples of raw wool, scoured with nonionic detergent, were weighed and mass recorded. A liquor ratio of 1:25 was used and the carbonizing solution was prepared by adding 5–7% sulfuric acid and 1–2 g/L of nonionic detergent. The wool samples were then soaked for 2 to 3 h at 20–30 °C and then rinsed and drained. Samples were then dried at 60 °C to a low regain, followed by sample baking at 100 °C to carbonize the vegetable matter. The samples were then passed through heavy rollers to crush them and then shaken to remove the embrittled vegetable matter. The samples were finally passed through a neutralizing solution containing sodium carbonate, rinsed with a small addition of detergent and left to dry at room temperature. The samples were finally kept in a conditioning room at a standard temperature of 20 ± 2 °C and humidity of $65 \pm 2\%$ for 24 h, the weight of the samples was recorded.

3.6. The Wool Yield (Y) Test

The wool yield (Y) was determined by assessing the amount of usable clean wool that could be obtained from greasy wool after the removal of impurities. Commercial yields were calculated using the wool base (WB), vegetable matter base (VMB) and hard heads base (HH). All calculated yields include standard allowances for moisture content and for the small amounts of residual ash (dust) and alcohol extractable matter (grease) left after processing. The following formulae were used to calculate different commercial yields. The general formula applied for commercial yield calculation is as given below:

$$\text{Wool yield} = (\text{WB} \times (100 + \text{Regain\%})) / (100 - \text{Ash residue and alcohol extractives}) \quad (2)$$

where WB is the wool base.

Besides this, several other well-established yield methods i.e., IWTO Schlumberger dry top and Noil yield (1% TFM), IWTO clean wool content (IWTO CWC), IWTO scoured yield at R% regain (SCD, 16 and SCD, 17), Japanese clean scoured yield (JCSY) and ASTM clean wool fiber present (ASTM CWFP) were also followed to measure the wool yield.

4. Results and Discussion

4.1. Sheep Average Fleece Weight

The sheep average fleece weight was determined from the individual sheep fleece weights taken during shearing. The results showed that the mean fleece weight was 2.04 ± 0.06 kg with 37% coefficient of variance (CV). This is less than 4.5 kg, the international mean yield of wool per animal per year. However, the fleece weight ranged from 0.7–3.3 kg, indicating the genetic capacity of Kenyan sheep for wool production. Table 1 shows the fleece weight by the sex of the sheep, that is, male and female

Table 1. The average weight of greasy wool per sheep.

Sheep	Number	Mean Fleece Weight (kg)	CV (%)
Male	23	2.06 ± 0.06	28
Female	72	2.02 ± 0.08	33
All	95	2.04 ± 0.06	37

The well-adapted genotypes of the local breeds of sheep are well-suited to the tough climatic conditions. Some breeds preferred by farmers are those that are resistant to the local sheep parasites and diseases [10]. Most of the sheep breeds in Kenya have semi-fine wool and most sheep breeds are as well-developed from local ewes. Improving the local sheep to a fine wool sheep model may need about four or more generations of crossing with a designated pure breed [11]. Fine wool breeds require greater attention in terms of animal health, growth rates, and longevity in order to survive [12]. The climatic conditions in places where pastoralism is most commonly practiced are relatively extreme. The dry season in some regions poses a challenge for quality pasture and water. This can contribute to the low quality and yield of wool fibers.

4.2. Scoured Wool Yields

Scouring removes most of the grease, wax, suint, and dirt from wool fibers, but not vegetable matter (see Section 4.6 for wool yields when all impurities have been removed). The wool yield percentages after scouring are shown in Figure 5.

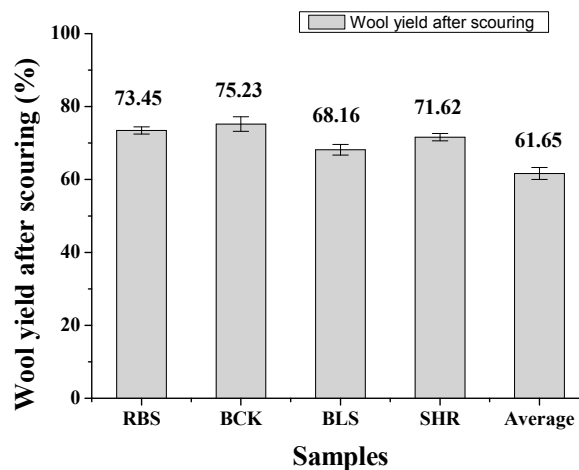


Figure 5. Wool yield percentages after scouring.

It can be seen that the wool shorn from the back area (BCK) had the highest mean yield of more than 75%. The results show that BLS, which was wool shorn from belly and legs, had the lowest mean yield, 68.16%; and thus the highest percentage of waste, 31.84%. The average waste percentage for all the samples was 38.35%.

4.3. Vegetable Matter (VM) and Vegetable Matter Base (VMB%)

The animals need grasslands or feed supplies with sufficient nutritious pasture to encourage the growth of good quality wool. Proper shedding is required to replace the shelters that compromise the quality and cleanliness of wool, as well as hygiene for animal well-being [11]. Sheep farming is more preferable due to its low cost of feed, fewer diseases and less labor required, as compared to larger stock.

Vegetable matter refers to the burrs (including hard heads), twigs, seeds, leaves, and grasses present in wool. Some different types of vegetable matter are shown in Figure 6. Vegetable matter base (VMB%) is the oven-dry mass of ash-free, ethanol-extractive-free burrs (including hard heads), twigs, seeds, leaves, and grasses present, expressed as a percentage of the mass of the sample. Wool base (WB%) is the oven-dry mass of wool fiber free of all impurities, i.e., free from ethanol extractives and all vegetable matter and other alkali-insoluble impurities expressed as a percentage of the mass of the sample. The percentages of the different types of vegetable matter presented in the samples are shown in Figure 7.

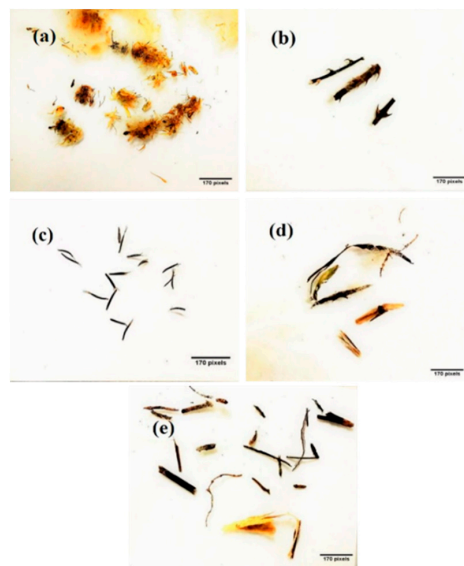


Figure 6. Different types of vegetable matter (a) Setaria grass; (b) Thistles; (c) Bidens Pilosa; (d) Pasture grass; (e) Small sticks.

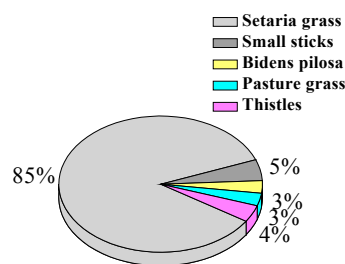


Figure 7. Percentages of different types of vegetable matter (%).

A bale of greasy wool can comprise anything from about 30–50% non-wool components, such as grease, suint, dirt, VM, and moisture [13]. The percentage of hard heads and twigs (HH%) is obtained after combing and given separately from VMB%. Thistles with sharp hooks along their length were also found, though not to the same extent as the other vegetable matter. They were quite hard to break, but not hard to remove compared to Setaria grass [14]. Thus, it is also important to determine which type of impurity is more common, so that possible remedies may be practiced later.

The Setarian grass is a type of grass with seeds that cluster together and have many hooks at the edge, thus it is also known as foxtail [14]. They are quite difficult to remove from the fleece. Bidens Pilosa has black elongated seeds with hooks on one side and they also cluster [15]. The pasture grass was dry and the exact type could not be easily identified, but it was easily removed. This was the same case with the small sticks, which were dry and easy to get rid of. It is, therefore, necessary to weed grazing fields [16]. The HH% was the largest impurity, while fatty residue was the lowest, for all types of wool shorn, as presented in Table 2.

Table 2. Vegetable matter analysis of the samples.

Samples	BCK	RBS	BLS	SHR
HH%	2.3 ± 0.30	3.1 ± 0.25	1.1 ± 0.50	3.4 ± 0.65
VMB%	1.0 ± 0.15	2.5 ± 0.35	0.2 ± 0.05	2.5 ± 0.45
Ash Residue%	0.8 ± 0.20	1.1 ± 0.25	0.4 ± 0.10	1.2 ± 0.25
Fatty Residue%	0.2 ± 0.05	0.4 ± 0.05	0.2 ± 0.05	0.5 ± 0.05

4.4. Moisture Regain of the Scoured Wool

Moisture regain is the ability of a dry fiber to absorb moisture under set conditions of humidity [17]. Wool fibers are known to be hydrophilic and the way fibers respond to moisture is an important property since it has a major influence on other properties [18]. Fibers swell when they absorb moisture and thus their weight, size and shape are changed [19]. Moisture absorption also affects the stiffness, mechanical, frictional and electrical properties of the fibers. For instance, the electrical conductivity of wool fibers improves when moisture is absorbed, since water is an excellent conductor of electricity [20]. The rate of absorption and desorption affects properties such as drying. The moisture regains of the scoured wool are shown in Figure 8. The results showed that the moisture regains of the samples were 14.70%, 13.68%, 13.63% and 14.15% for BCK, BLS, SHR, and RBS, respectively. Thus, the moisture should also be considered when discussing the yield of the wool.

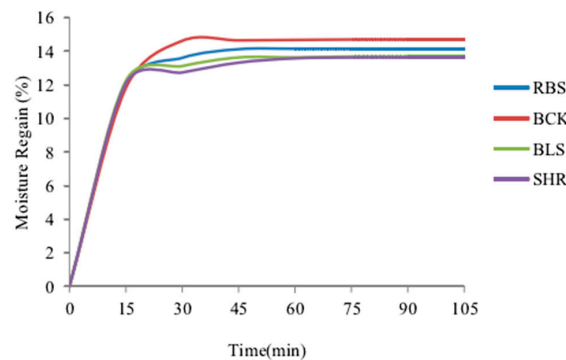


Figure 8. Moisture regain of the scoured wool.

4.5. Carbonized Wool and Carbonized Vegetable Matter

The percentages of the carbonized wool and carbonized vegetable matter were used to obtain carbonizing yields and are shown in Figure 9. This yield reveals the expected processing losses during carbonizing and is added to the wool base during the calculation of some commercial yields. The results indicated that RBS, the wool shorn from the flank, had the highest percentage, 10.2%, of the vegetable matter. The average percentage of vegetable matter in all the types of carbonized wool samples was 6.62%.

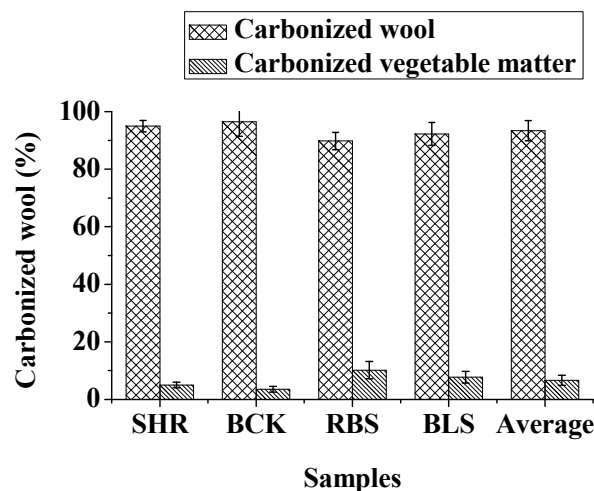


Figure 9. Percentages of carbonized wool and carbonized vegetable matter after carbonization.

The carbonized matter that was shaken off with some few short fibers from the wool samples is as shown in Figure 10, and turned black after processing.



Figure 10. Carbonized (a) vegetable matter (b) wool.

4.6. Wool Yield (Y)

The wool yield is the amount of clean fiber that is expected to be produced when a delivery of raw wool is processed. The yield may be expressed both as a clean mass and/or as a percentage of the mass of raw wool prior to processing. In this study, the yield has been expressed as a percentage of the raw wool. The wool base (WB%) for each sample is the percentage of clean wool after the removal of all impurities. The various calculated commercial yields are as given in Table 3. These wool yields are comparable with the wool yields reported previously. For instance, Harizi et al. [21] reported wool yields ranging from 50–70% for a Tunisian sheep breed, likewise, Ansari-Renani et al. [22] also reported $69.3 \pm 0.7\%$ at most for the Iranian sheep breeds. Larger wool yields gain the attention of worldwide wool textile industries, and thus help a country to boost its economy.

Table 3. Various calculated commercial wool yields.

Samples	BCK	RBS	BLS	SHR
Wool Base (WB%)	53 ± 2.8	54 ± 3.9	52 ± 2.7	50 ± 3.2
IWTO Schlumberger Dry Top and Noil Yield (1% TFM)	63 ± 3.1	63 ± 2.5	61 ± 2.2	59 ± 2.4
IWTO Clean Wool Content (IWTO CWC)	65 ± 2.4	63 ± 3.6	62 ± 3.9	60 ± 2.9
IWTO Scoured Yield at R% Regain (SCD, 16)	67 ± 1.5	64 ± 2.4	62 ± 1.5	63 ± 1.2
IWTO Scoured Yield at R% Regain (SCD, 17)	68 ± 3.7	65 ± 1.5	63 ± 2.8	63 ± 3.6
Japanese Clean Scoured Yield (JCSY)	64 ± 2.8	62 ± 3.6	61 ± 2.5	59 ± 2.5
ASTM Clean Wool Fiber Present	63 ± 1.2	62 ± 2.4	61 ± 3.5	59 ± 1.5

5. Conclusions

This article addressed an important area of research that is required to facilitate the improvement of the Kenyan wool industry. Future studies would be enhanced by sampling a larger number of animals and including a greater number of measurements, and the comparison of various Kenyan sheep breeds can be further studied. The values of the measured parameters resulting from the study suggest a potential for genetic improvement and thus improvement of economic qualities, to foster economic and industrial development. In addition, this study can also offer solutions to problems regarding wool production and the innovation of wool products for application in various economic sectors, such as for use as an agro-industry insulation material for horticultural greenhouses. This study found that even after a very high level of cleaning, more than 60% of the wool yield remains. Finally, the participation in and/or membership of international organizations to attract the attention of wool importing bodies throughout the world would make Kenyan wool more marketable in world markets, to avoid creating a branch of agriculture that may end up being sinister or creating a deficit and thus needing a subsidy from the government

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