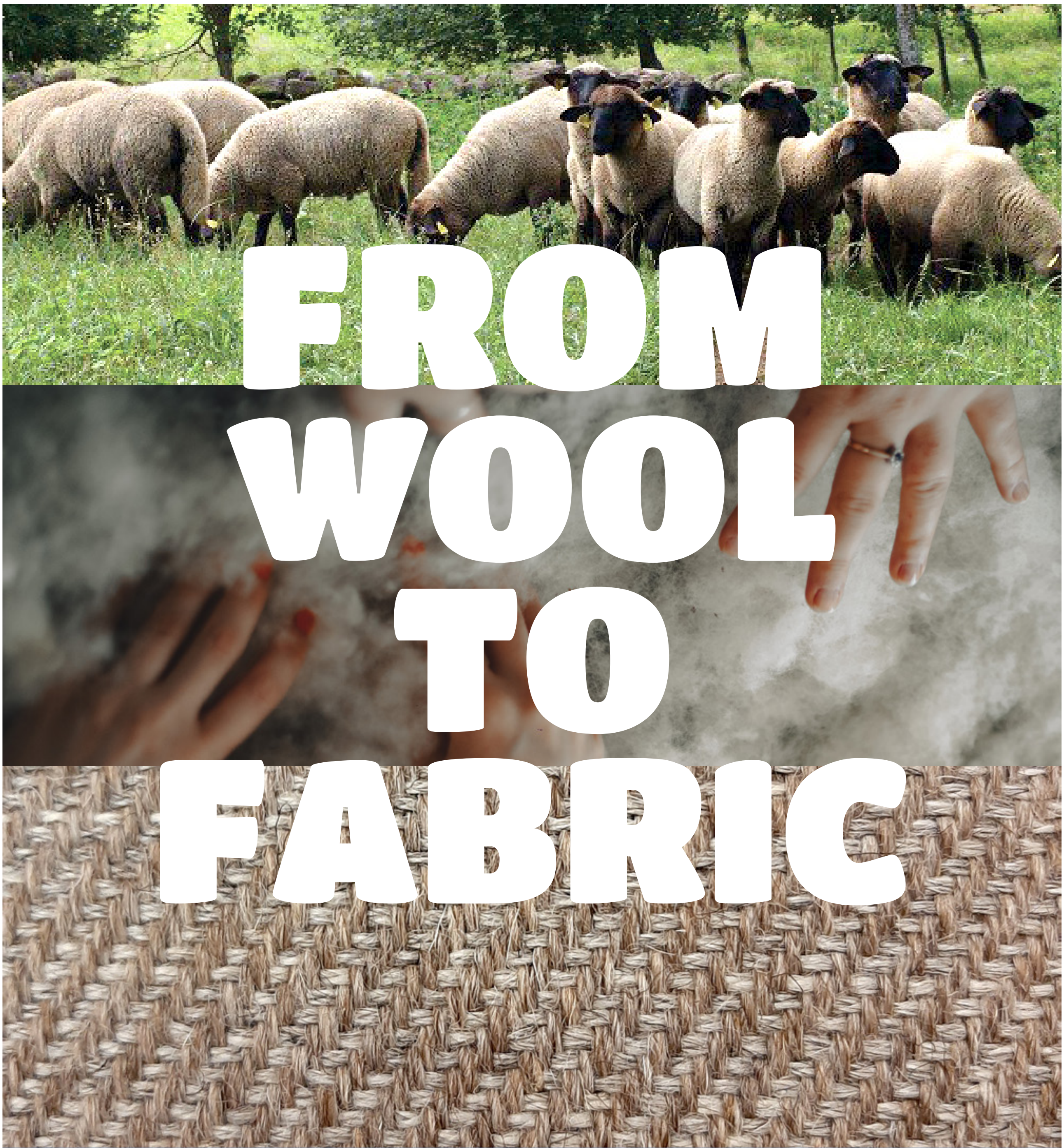
FROM WOOL TO FABRIC



Estonian and Norwegian sheep's wool as a textile material. Production, properties and possibilities of use on the example of the wool of six sheep breeds

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Introduction

In the cold Nordic climate, sheep's wool is the oldest and most valuable source of textile material. The first signs of sheep breeding in Estonia come from 5,000 years ago (Rannamäe, 2016), and in Norway, 6,000 years ago. Historically, sheep have been kept primarily for wool. Today, the extent of the use of wool varies greatly from country to country and depends on the supporting systems and existing value chain. An excellent national wool collecting and grading system has been developed in Norway, because of the importance and wide usage of local wool. In Estonia, on the other hand, meat has become a more important sheep product, next to which wool has regressed to the status of an annoying by-product. No attention is paid to improving the quality of wool, and there are also many prejudices about it. Therefore, most of the wool is destroyed and does not become a useful commodity. This educational material has been created with the support of the Estonian-Norway joint project, in order to increase the valorization of local wool. The purpose of this material is to introduce the excellent properties of wool and to encourage craftsmen and designers to use domestic wool more than before.

Historically, wool has been mainly used in the production of clothing and interior textiles, but today, coarser fibre and uneven or soiled wool is increasingly used in the production of technical textiles. THERE IS NO GOOD OR BAD WOOL: THERE IS A SUITABLE APPLICATION FOR EVERY TYPE OF WOOL! The target group of this study material is primarily students of textile majors, and thus, mainly focuses on finer and more uniform wool suitable for textile production.

One of the goals of studying textiles is for students to acquire knowledge about and experience with materials, tools, and textile techniques, in order to render and produce their own textiles. Knowledge about the characteristics of the wool material's interaction with woven and knitted textile techniques is very much needed in this learning process. Working with the wool material involves the interplay between material and technique and the interaction between body and tool; the maker being an extension of the tool itself. This is important in the process of working with handicrafts. As more experience is gained, it is possible to have greater control over the result. However, in the process from thread to finished fabric, there are still many variables that, through embodied making, are only possible to control to a certain extent. In this study material, the authors aim to provide insight into the varied attributes of wool from different sheep breeds, different yarn qualities, and its interaction with different weaving and knitting techniques.

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PART 1

SHEEP WOOL AS TEXTILE MATERIAL

1.1 WOOL PRODUCTION

Introduction of sheep farming

Sheep have been domesticated alongside humans for about 12,000 years. The first evidence of the use of sheep for wool dates back to 6000 BC; the oldest traces of woolen textiles are a few millennia later. What was once an important source of fibre has now become mainly a meat animal. There are more than 1000 different breeds of sheep in the world.

As of 2021, there are 1.266 billion sheep in the world, producing a total of 1,950,237 tons of unwashed wool. The production of pure wool in the same year is 1,033,927 tons (iwto.org). While in the second half of the last century the main sheep breeders were Australia and the USSR, in the last two decades, China has become the largest breeder, ahead of India and Australia. Despite having fewer sheep, Australia is ahead of China in wool production. Regardless of the number of sheep, sheep's wool makes up only 0.9 percent of the world's textile industry, significantly below the production of artificial fibres.

In a simplified way, wool can be divided into three groups: fine merino wool, medium coarse but uniform single coat wool (one layer fleece), and double coated wool (two-layer fleece) from native sheep breeds. While merino and finer single-coated wools find use more easily, it is problematic to find use for coarser single and double-coated wools.

Although the wool production of Norway is approximately 2% of the world's wool production and in Estonia, much less, it is still important to value this distinctive fibre at a local level more than in its current state.

SHEEP BREED	AMOUNT
Estonian Whitehead	9289
Estonian Blackhead	7373
Kihnu native sheep	2614
Dorper	2216
Lleyn	1902
Texel	1638
Gotland sheep	1602
Icelandic sheep	523
Estonian native sheep	438
Suffolk	424
Dorset	272
Meriino d`Arles	220
Swifter	174
Swedish finewool (finull)	150
Lacaune sheep	131
East Friesian sheep	107
Norwegian white sheep	100
Ouessant	88
North Country Cheviot	65
Dala	62
Zwartbles	52
Romanov	37
Blue Texel	26
Åland sheep	22
Belgian sheep	21
Oxford Down	21
German Blackheaded Mutton	21
Valais Blacknose	11
Finnsheep	7
Latvian Darkhead	7
Île De France	5
Cheviot sheep	4
Shropshire Sheep	1
Crossbreed sheep	30728
breed unspecified	5307
TOTAL	**65658**

Table 1. Sheep breeds grown in Estonia and their number as of 31.12.2021 (pria.ee)

Breeds and number of sheep in Estonia

As of 31.12.2021, there are a total of 65,658 sheep in Estonia (including 31,466 ewes, 26,304 ewe lambs and 7,888 rams). A total of 31 breeds are registered in the PRIA register (Table 1), but many of them are very small in number. There are over a thousand sheep in only seven breeds: the most common of them are the Estonian Whitehead and Estonian Blackhead sheep. They are followed by the Kihnu native sheep: the oldest local native breed, only recently officially recognized. The other most common breeds are Dorper, Lleyn and Texel, which have been introduced during the last decades and are mainly raised for meat, and the Gotland sheep, whose best value is their beautiful pelts. However, the largest amount of sheep in Estonia are different crossbreeds (30728). Dividing sheep according to their wool, the only breeds with double-layered wool are the Kihnu native sheep and Estonian native sheep.

As of the beginning of 2022, the calculated amount of wool in Estonia is 130 tons. About 90% of it does not find enough valorization. There are about 1700 sheep farmers, and the average herd size is about 50 sheep. Sheep flocks cover Estonia relatively evenly, and only in some regions are there bigger concentrations of smaller flocks. (Matsin et al 2022, 208-209)

Breeds and number of sheep in Norway

In Norway there is 15 times more sheep than in Estonia. A total of 1 million breeding females are kept during the winter (Norges Sau og Geitalslag, The Norwegian Sheep Breeder's Organization, Norwegian Genetic resource center, Animalia)

SHEEP BREED	NUMBER OF SHEEP (APROXIMATELY)	CONSERVATION STATUS
Blæset sheep	2600	Threatened
Dalasau	760	Threatened
Fuglestadbrokete sheep	1650	Threatened
Old Norwegian spæl sheep	14 800	Not threatened
Old Norse Sheep (wild sheep)	17 000	Not Threatened
Grå trøndersau	1600	Threatened
Merino	200	Not recognized as a Norwegian breed
Norwegian White Sheep (NKS)	690 000	Not threatened
Norwegian pelt sheep	8 000	Not threatened
Rygjasau	1900	Threatened
Spælsau (both white and pigmented)	13 000	Not threatened
Steigar sheep	400	Threatened

Table 2. Numbers of some Norwegian sheep breeds which are part of the conservation program.

There are 3 types of short-tailed sheep (Table 2): the Gammel Norsk Spælsau (Old Norwegian Spæl sheep), the Gammel Norsk sau (Old Norse sheep) and the two variants of Spælsau, white and pigmented. The other sheep breeds are long-tailed, and in Norway, they are defined as crossbred sheep. This is because their origin is a crossbreeding between local sheep and imported sheep, mostly in the late 1800's. The wool of these sheep is uniform. The Norwegian Cheviot sheep was recognized as a Norwegian sheep breed in 2020 but is not included in the statistics. It is not endangered.

Norway produces an estimated 3500 tons of wool per year. The wool that is delivered directly to the spinning mills will not be counted in the wool statistics, and this must be kept in mind when looking at the numbers in wool production. Currently, a few tons of wool are distributed outside the wool station system in Norway, and if the production of the mini mills increases, more wool will avoid the statistics, and there will be a need for a report from the smaller spinning mills on their production.

Wool production and processing value chain

The complete chain of wool production encompasses the journey of wool from shearing to finished products. Figure 1 shows the stages of wool processing in a simplified way. Although all the processes are the same, the roadmaps of the wool at different sizes of production are slightly different: while in large-scale production many steps are carried out in different industries in different counties and the wool moves long distances from one place to another, the small-scale production chain is much more localized and many of the processes are carried out within the same company.

In order to find the maximum use for wool, it is important that all parts of the complete wool processing chain work, cooperate and have equal throughput. In Norway, with the help of state subsidies and the cooperation of farmers, it has been possible to build a wool purchasing and sorting system that supports all other parts of the value chain.

Estonian Wool System

In Estonia, there is no centrally organized complete chain of wool processing. Wool is bought by various small companies for their own production. Older woolen wool mills buy home-scoured wool. Newer semi-worsted wool mills buy mainly unscoured wool, because they have higher expectations for the quality of wool scouring than can be achieved by washing at home. In addition, wool is bought by the WOOLA brand, which produces packaging, and the MÄÄ brand, which produces horticultural wool pellets.

Norwegian Wool System

A good system for collecting, sorting and distribution of wool is essential for businesses working with this unique material. In Norway, there is a solid system that allows sheep owners to deliver the wool to a wool station after shearing. The wool station sorts the wool and assesses the quality. The farmer gets paid according to the amount and quality of the wool.

Most sheep in Norway are sheared twice a year. In the spring, the sheep get a new haircut before going to the summer grazing grounds. The spring wool is often quite dirty and full of plant remnants, as the sheep have been indoors eating hay or hay silage all winter. The next shearing is in the autumn, when the sheep come back from the summer grazing grounds. Then, the wool is usually cleaner, after being washed by the rain and blown by the wind. The amount of dirt and plant parts in the autumn wool varies according to where the sheep has spent the summer. After shearing, the wool is packed in paper bags and sent to the wool station. The wool station grades the wool based on amount of dirt, kemp and length and fibre diameter. As Norway has no industrial wool scouring facilities, most of the Norwegian wool is sent to Bradford, England for scouring. After scouring, the wool is ready for sale on the international wool market. Approximately 20-25% of the Norwegian wool is sent back to Norway and used by the Norwegian industry.

During the last 15 years, a parallel value chain has evolved, and small wool processing plants, such as Selbu spinneri, have been established. These mini mills either buy wool directly from the farmer or from the wool station and wash and process the wool in small batches. This makes it possible to keep the whole value chain in Norway, including wool scouring. The advent of small-scale wool processing also brings producer and consumer closer together, as the farmers can sell yarn made from their own wool spun at a local spinning mill.

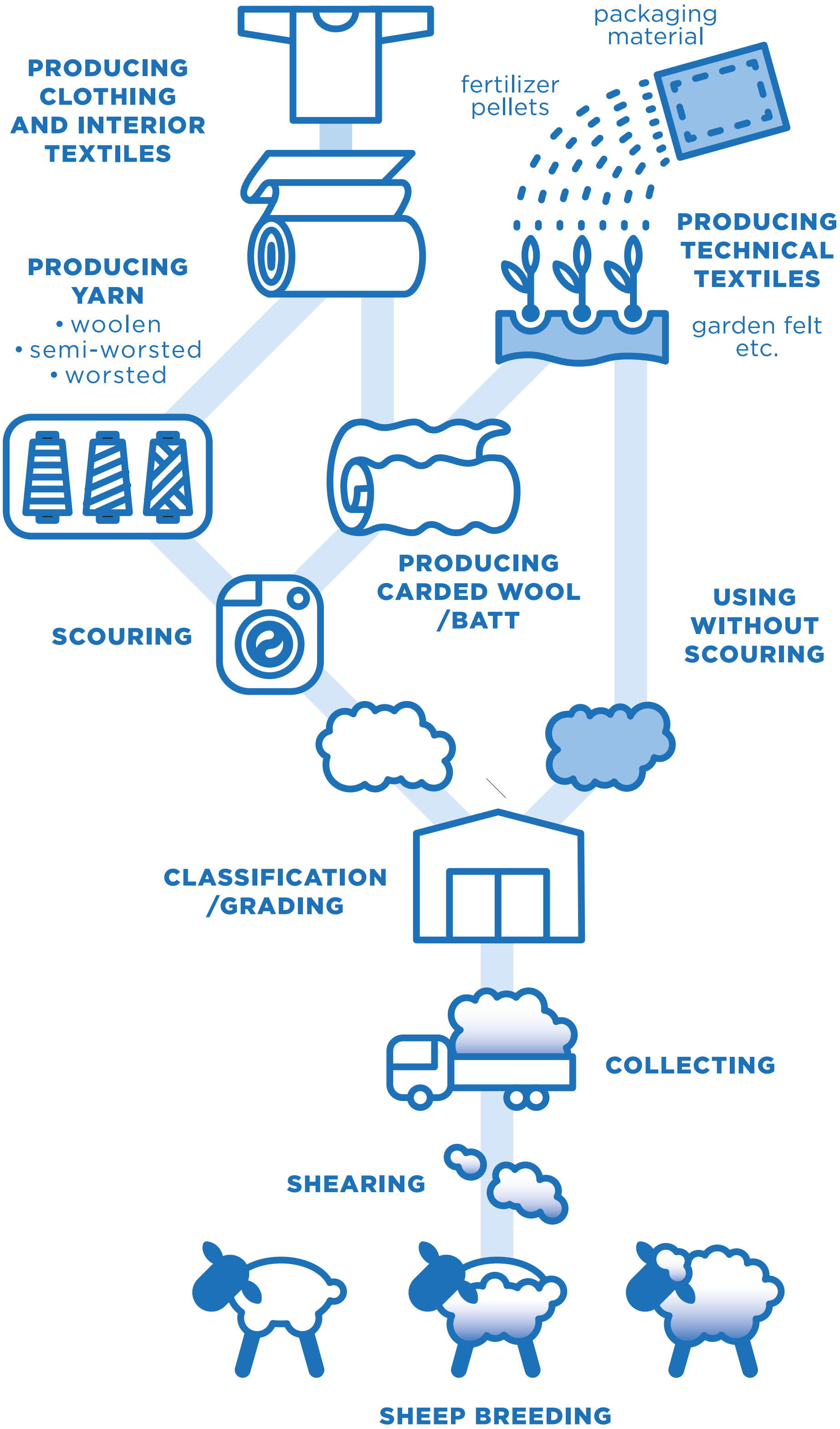


Figure 1. The stages of wool processing

Properties of wool fibre

As an animal fiber, wool consists mainly of protein, which makes it chemically very distinct from plant fibers, which consists mainly of cellulose. There are three types of wool fiber: wool, guard hairs and kemp hairs.

Wool hairs are soft hairs that form the undercoat of the double-coated wool fleeces. In the single-coated wool fleeces, the wool hairs make up the entire fleece. The fiber diameter of wool can be from 14-25 microns (fine fibers – soft wool) to 25-45 microns (coarser fibers – strong wool).

Guard hairs are long, thick and smooth hairs that cover the wool fleece of the double-coated sheep. These hairs provide protection against rain and snow. Guard hairs are normally between 45 and 140 microns.

Kemp or medulla hairs are hollow with an air space inside. The air space can run through the whole hair length or just parts of it (broken kemp). The kemp hairs are brittle and break easily. They do not take dye from plant dyeing or acid dyeing, and a high kemp content will make the yarn weak, as the kemp hairs are not flexible and break easily.

An important property of the wool fibre is the crimp, which makes wool spinning easier and adds volume to the fabric, which makes the wool material very warm. The number of crimps indicates the quality of the wool: in some cases, fine sheep wool has more crimp, and this is one possible way to recognize thinner fibres. Wool has “memory”, which means that a garment made of wool will keep the same shape for many years, also after washing. This is due to the crimp.

Wool fibre has the unique ability to felt. The reason for this is the scales on the surface of the wool fibre, which bind the fibres tightly together under the influence of fluctuating temperature and humidity. This is a feature that is used often in the finishing of woolen fabrics.

Wool fibre is highly absorbent: it can bind almost a third of its weight without feeling wet. It is also more fire resistant than many other fibres: wool does not catch fire easily, burns very badly and needs a direct contact with open fire in order to burn. This is also the property that helps to determine the material: if you put wool into a flame it will stop burning as soon as you remove wool from the direct flame. Known as the “flame test” for wool, this is how to separate pure wool from mixed products.

Even more: wool contains ingredients that, together with wool’s moisture-binding properties, make it an excellent raw material for fertilizer and various horticultural textiles.

General factors affecting wool quality

Wool quality depends on the planned use for the wool. The best wool quality for a soft garment for children will not be suitable for making rugs to keep on the floor of the living room. The finer wool will be best suited for close-to-body garments, while the coarse wool is best suited for jackets and sweaters, and for use in furniture textiles and for rugs.

Wool quality is influenced by several factors, the most important are listed below:

- The wool quality of each sheep breed and wool type, including individual variation in the sheep breed populations
- The living conditions, the feeding, and the age of the sheep
- The shearing, the shearing environment and the timing of the shearing

The wool on the body of the sheep is of uneven fineness. This is due to the difference in the thickness and properties of the skin on different parts of the body. The finest wool grows on the sides. The wool on the head, rump and legs is coarser. On the lower part of the hind legs, it is normal to find kemp or medulla hairs. The fineness of the wool also depends on the age of the sheep: lambs have finer wool than adults. The variation in fineness can also differ between sheep breeds, as some breeds have larger variation on the body than others.

The quality of the yarn obtained during wool processing is based on the quality of the wool. In order to obtain good quality wool suitable for spinning, a lot have to be done before shearing. The wool quality is dependent on the sheep's living conditions. Sheep that live outdoors all year will develop a different wool quality compared to sheep that are kept indoors for some part of the year. The health of the sheep must be carefully monitored and feed and minerals must be chosen according to the breed, life stage and lamb production. Sheep that can feed naturally in varied landscapes will develop the best wool, as they will choose the plants that they need for the development of a functional wool fleece and for healthy growth, milk for the lambs etc. It is also very important to choose a suitable method of keeping the sheep so that there is no felting of the wool, soiling, contamination with hay crumbs and changes in the wool fibre as a result of the health of the sheep. If the sheep grazes in forested areas, the wool fleece can be damaged by needles from coniferous trees. The needles will fall out during handling of the wool – washing, picking and carding.

1.2. WOOL PROCESSING

Sheep shearing

Sheep need to be sheared at least once a year for their health and well-being. Some more woolly breeds need to be done twice a year. Most Estonian sheep are sheared once a year. Only native sheep breeds are sheared twice a year. The time of shearing depends on the breed and the preferences of the farmer, but the main shearing season is spring or summer, because then the sheep have time to grow enough fleece for the winter.

In Norway it is customary to shear sheep twice a year, although in some areas along the Norwegian coast there is a tradition to keep the sheep outdoors all year. In these areas, the sheep are sheared only once a year, during spring/early summer. The Old Norse Sheep or Gammel Norsk sau (often called villsau or wild sheep) is the best suited sheep for living outdoors all year round along the Norwegian coast.

In general, wool sheared in the autumn is considered to be of higher quality, because during the summer, the sheep have the opportunity to be outside more, which is why the wool is cleaner. Thanks to the fresh feed, the wool fibers are also healthier and more uniform. At the same time, this is not a definitive rule, because depending on the conditions of keeping and other circumstances, wool sheared in the spring is not necessarily worse.

Shearing customs and standards are quite similar all over the world. Professional sheep shearers travel around the world to shear, and the shearer can come to Norway from New Zealand, Australia, or Scotland during the shearing season. There are several experienced local shearers in Estonia who have learned shearing from local or international experienced shearers and offer their service all over Estonia (Photo 1). However, there is a shortage of shearers during the shearing season. Many farmers also learn how to shear, and in some areas, there are local shearers.

Photo 1. Estonian shearer Mats Meriste shearing the sheep. 2021. Photo by T. Uibo.

In Norway, shearing courses are arranged by the Norwegian sheep owners' association (NSG, Norsk Sau og Geit) in order to recruit local shearers, as there is a lack of shearers during season. During the course, the shearer learns how to handle both the sheep and the wool. It is important that the sheep is well-handled, to avoid stress or injury for both the shearer and the sheep.

When shearing, you should make sure that the fleece is dry. It is important to prepare a clean area for the shearing. The shearer must have enough space and animals moving to the shearing site should not bring hay/straw in on their hooves. The shearing area should have a clean floor or, if outdoors, it is possible to use a tarpaulin or canvas as flooring. Shearing should be done on a base that can be wiped clean after each animal is sheared to prevent contamination of the next fleece with debris, short fibres, or dirty pieces of wool that have fallen from the previous fleece. A professional shearer knows how to consider the individuality of each sheep in order to avoid spoiling the wool on his part.

During or right after shearing, the wool must be sorted into three qualities. This should normally be done by an assistant or by the sheep owner, because the shearer must concentrate on the work at hand. In Norway, they handle the wool during the shearing as follows:

- The first type to be sorted is wool with a lot of dirt, which should not be collected, but thrown into the compost on the farm.
- The second type is wool that is too short/dirty/old wool from the hindlegs, belly edges, around the tail and from the neck. This wool should be sorted in a separate bag. During shearing, a person shall assist the shearer to sort the wool effectively.

- The third type is the wool from the rest of the sheep. It is examined to ensure that there are no areas with many pieces of hay (mostly from the neck and withers area) or skewing. The edges of the wool are then folded in the middle, the wool is rolled up in a wool ball and put into a paper bag. Before the next wool fleece is put into the bag, the shearing assistant puts a paper sheet on top of the last fleece. In this way, it will be easy to separate each fleece for later grading/classification.

Watch the shearing video here: *https://uttv.ee/naita?id=34448*

Wool sorting and grading

In Estonia, there are no wool stations for gathering and grading fibres. The small wool mills do their own sorting according to their knowledge, needs, and spinning equipment capabilities. Mainly fibres of a different nature are sorted from each other (thinner-fuzzier, longer-stiffer, etc.) and if necessary, the dirt and excessive vegetable parts are removed.

In Norway, after the wool is put into paper bags, the farmer will keep the wool for at least two weeks. During this time, the wool bags are left open, to ventilate out humidity from the wool. Then it will be transported to a collection site, each bag marked with the name and the production number of the farm. Later, a truck will collect the wool and transport it to the wool station, which is located at a regional slaughter (there are 11 wool stations in Norway today).

The wool is classified/graded by professional wool classifiers at the wool stations. These are people that often work as slaughters most of the year, but have additional education as wool graders, and work with the wool part-time. It takes approximately 4 years to become an educated wool grader. The wool grader must pass an exam, and to keep the wool grader certificate he/she needs to pass this exam at regular time intervals. Animalia, a non-profit organization in Norway that works on research and development within meat, wool and egg production, arranges courses for the wool graders.

The wool of slaughtered sheep is also graded at the wool stations. This wool goes directly into the wool station from the slaughter at the same site. In most cases, the sheep is first euthanized, and then sheared before the rest of the slaughtering procedure. This is very effective and better for the animals.

The grading of the wool is fast, the classifier checks each fleece and grades it according to the Norwegian wool standard (*https://www.animalia.no/contentassets/d91150be325e4d72b5b814f83b92b2f8/202961-animalia-ullstandard-engelsk-04.pdf* 05.02.2023) during a short time span of a few seconds. Each fleece is graded separately, and the wool class is noted in a database in order to both pay the farmer for the right wool quality, and also for using the results in national statistics.

Regarding the use of wool in the mini mills, this chain of work might look a little different. Some wool might be delivered directly from the farm to the spinning mill and sorted for use there.

Watch the Norwegian wool sorting video here: *https://uttv.ee/naita?id=34489*
Watch the Estonian wool sorting video here: *https://uttv.ee/naita?id=34490*

Learn more about Norwegian wool shearing and sorting here (only in Norwegian!): *https://www.animalia.no/no/Dyr/ull-og-ullklassifisering/saueklipping-og-ullhandtering-video/*

More information about the assessment of wool quality is shown here (only in Norwegian!): *https://www.animalia.no/no/Dyr/ull-og-ullklassifisering/spalull---vurdering-av-kvalitet-video/*

Wool scouring

The largest amount of European wool is scoured in big scouring plants in Poland, Belgium, and the UK (Bradford, Photo 1). The advantage of large-scale scouring is that the fibres are mixed very evenly which makes it usable for big textile industries. In a large scouring plant, it is also possible to remove lanolin during the process, which is a highly valued raw material for the cosmetics industry. Processing larger quantities of wool at the same time also helps to keep prices very low. The disadvantages of using larger-scale scouring facilities are long transport distances and the inability to wash small quantities of fibres of different colours and qualities. Also, farmers do not have the opportunity to get back the wool of their herd.

The older Estonian woolen yarn mills offer the service of making yarn from already washed wool. Many farmers of small flocks of sheep wash small amounts of wool themselves. Small wool mills very often do their own scouring. In order for the quality of wool scouring to be as good as the larger-scale facilities and even as possible, it is necessary to separate the wool fibres more loosely. If the wool fibres are placed too tightly, when washing with detergent, the water does not move properly between each wool fibre and the wool may remain too lanolin-rich or dirty. The finer the fibre and the more lanolinic the wool, the more carefully the wool needs to be loosened before washing.

Photo 2. Scouring line in Bradford, UK in 2017. Photo by A. Matsin

In Norway, the smaller spinning mills have their own wool washing system. Selbu spinneri washes wool in larger (8 and 12 kg capacity) Electrolux washing machines (Photo 3). They are filled with 3-8 kg of wool and washed with a special wool program that was adapted by Selbu spinneri in 2011, together with an Electrolux agent. The wool is washed in warm water (85 degrees Celsius) and after centrifugation, dried in metal baskets at room temperature. A similar washing system is also used in the Vilma wool mill (Photo 5). The only difference is that the washing temperature is slightly lower (about 65 degrees Celsius).

After washing and rinsing, the wool must be dried. Drying cabinets can be used for this, but it is important that the air temperature is not too high. To dry smaller amounts of wool, it is good to use, for example, (metal) mesh baskets where the wool is spread in a thin layer to dry (Photos 4 and 6).

Photo 3. Washing of wool in Selbu spinneri.
Photo M. Espelien Blomli

Photo 4. Drying of wool in Selbu spinneri.
Photo M. Espelien Blomli

Wool processing before spinning

In order to start making yarn from wool fibres, several previous stages must be completed. There are two main technologies for making yarn: woolen and worsted techniques. The main difference between woolen and the worsted yarn is the arrangement of the fibres in the yarn: in worsted yarn, the direction of the fibres is more parallel, so the yarn is stronger and not as fluffy as that made with the woolen technique. Worsted and semi-worsted yarns differ from each other in that during the manufacturing process, short fibres are removed from the worsted sliver but not from the semi-worsted sliver. The beginning processes are the same for both techniques until carding; the carding machines used for the two techniques are very similar, but the size of the resulting sliver differs. The following working process description is based on the semi-worsted spinning techniques used in Vilma wool mill (Estonia) and Selbu Spinneri (Norway). The machinery they use are made by Ramella (Italy, *www.ramella.com*) and Belfast Mini Mills (Canada, *www.minimills.net*).

Photo 5. Washing of wool in Vilma wool mill.
Photo by A. Kaljus

Photo 6. Drying of wool outside in Vilma wool mill.
Photo by A. Kaljus

Fibre opening

The purpose of the picker's work is to loosen and fluff the wool fibres that become stuck together during washing and to separate most of the dirt (plant parts, soil, sand, etc.). To pick the wool, the wool must be washed (more or less) free of lanolin and must be dry, otherwise wool fibres may get stuck in the machine. The washed wool is placed evenly on the line in moderately sized amounts (Photos 7 and 9). The fibres then move through a picker, which is a machine with a roller with large metal pins that opens the fibre mass after scouring. In Estonia, the fleece is vacuumed into a separate large collection bag located in the collection cabinet next to the picker (Photo 10). In Norway, the picker is situated in front of a wool room (Photo 8), where the wool blows directly in due to the fast turning of the picker drum. The room is rather large, and this makes it easier to blend the wool.

Photo 7. Wool on the line of the picker in Selbu spinneri. Photo by M. Espelien Blomli

Photo 8. Wool room in Selbu spinneri. Photo by M. Espelien Blomli

Photo 9. Wool on the line of the picker in Vilma wool mill. Photo by A. Kaljus

Photo 10. Collection cabinet of wool in Vilma wool mill. Photo by A. Matsin

Photo 11. Carder in Selbu spinneri. Photo by M. Espelien Blomli

Photo 12. Carded and single-pindrafted roving in Selbu spinneri. Photo by M. Espelien Blomli

Carding

The fluffed wool in the picker goes on to carding. The carder works by passing the fibres between cylinders covered with card clothing that rotate in opposite directions (Photo 11). During carding, the wool fibres separate from each other and begin to lay in one direction. After carding, a roving (a long and narrow bundle of fibre) comes out of the machine (Photo 12). Similar to the work of the picker, the wool has to be spread on the line at the carding machine. It is important that the fluffy wool gets on the line with a very even distribution. For this purpose, weighing the wool with a scale is used. Since wool fibres have different capacities and weights, the weight of the amount of wool placed on the line also fluctuates. The more evenly the wool is spread on the line, the more evenly and without obstacles the roving will come out. During carding, a large part of the debris is also released (plant remains, dust particles, etc.). In both Norway and Estonia, spinning oil (a plant-based oil) is applied during carding to avoid static if necessary.

Pin-drafting or stretching through the draw frame

The wool roving obtained during carding moves to the next processing stage, which is stretching the fibres to make a more parallel and even sliver of wool. In the Ramella system, this is done with a pin-drafter (Photo 13 and 14). In the Belfast system, this is done by a simpler draw frame. Using these machines, the rovings are stretched together into a much more even and smooth sliver (Photo 15). Two to six rovings are fed into the comber machine together. When passing

Photo 13. Pin-drafter in work in Vilma wool mill. Photo by A. Kaljus

Photo 14. Pin-drafter in work in Vilma wool mill. Photo by A. Kaljus

Photo 15. Sliver of the Kihnu native sheep wool in Vilma Wool mill. Photo by A. Kaljus

through the device, the wool fibres are aligned with each other by setting them as even and parallel as possible with combs with metal bristles in the Ramella pin-drafter, and with a metal worker with small spikes in the Belfast machine. During the stretching, the slivers are adjusted to the required thickness. The process might be repeated several times before it is sent to the spinning frame. The number of combing times depends on the specific wool type and the desired yarn parameters.

Yarn spinning and plying

On the spinning machine, the prepared sliver is spun into a single yarn (Photo 16). A comb-type spinning device (ring spinner) stretches the wool sliver thinner, so that the desired yarn thickness is achieved.

On the spinning frame, stretching takes place in two stages: the first stretch is smaller, and the second stretching range is larger. To achieve the best result, it is good to use different parameters according to the fibre length, fineness, and crimp of each specific type of wool being spun.

In parallel with setting the thickness, the appropriate twist direction and twist strength are also selected. When choosing the twist strength, it must be taken into account how many times the yarn will be multiplied later, as well as the future usage of the yarn.

When spinning is started, the thin strip of wool coming out from under the rollers is guided onto the spinning tube by means of an auxiliary thread (Photo 17 and 18). During the spinning process, the operation of the machine is monitored and, if necessary, the accumulated debris is removed from the roller cleaning brushes, and the short fibres and broken yarns are continued.

It is good to leave the finished single yarns to "calm down" for a few days to avoid double twists while plying (Photo 19). For multiplication, tubes with single yarns are placed on the multiplication frame. From there, they are fed to the spinning machine through tensioners in the required amount for multiplication (double, triple, etc.). The necessary multiplication strength and direction are set. The Ramella Spinning machine has corresponding holders/separators for multiplication, which keep the single yarns parallel to the yarn advance roller, after which the yarn is twisted. This ensures that the twists of the yarn are distributed evenly. In the Belfast system, the yarn is spun on the ring spinner and then plied on the plyer, which is a separate machine (Photo 20 and 21).

A conditioning process can also be used for finishing the yarn. The yarn is run through a steamer with boiling water and it dries in a hot tube. Afterwards, the yarn dries for a little longer on the cones to ensure the correct dryness and weight.

Photo 16. Slivers ready to spin in the back of the spinning frame in the Vilma wool mill. Photo by A. Kaljus

Photo 17. Yarn on the spinning tube in the Vilma wool mill. Photo by A. Kaljus

Photo 18. Spinning frame in Selbu spinneri. Photo by M. Espelien Blomli

Photo 19. Single yarn waiting for plying in Vilma wool mill. Photo by A. Kaljus

Photo 20. Plying frame in Selbu spinneri. Photo by M. Svorkmo Espelien

Photo 21. Plying process in the Selbu spinneri. Photo by M. Svorkmo Espelien

1.3. MAKING TEXTILES

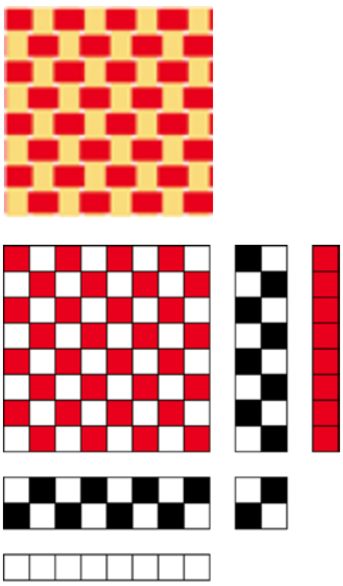
Weaving

The garments used in historical clothing throughout several centuries are mostly woven on looms from 2/2 twill fabric. The yarn used for the fabrics was single-spun. According to the function of the garment, the fabrics were also finished in different ways, for example, the long-coat, which was supposed to keep out the wind and rain, was very heavily waulked. Undoubtedly, woolen fabrics are irreplaceable providers of warmth in the northern climate. Due to the properties of the fibre, the woolen fabric also holds its shape well and is durable if treated carefully.

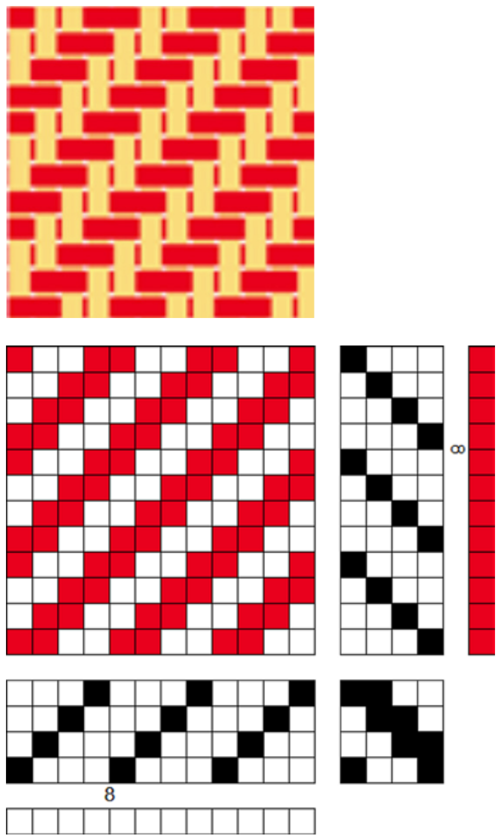
Wool is also widely used in the production of interior textiles, which are used in both domestic and public environments. Woolen fabric is very durable, so it is suitable for textiles such as furniture fabric. Woolen floor rugs help keep you warm in the winter. Since woolen fabric does not burn well, it is also suitable for furnishing public spaces, as it meets fire hazard requirements.

Weaving is a technique for manufacturing fabrics. Weaving is based on two tread systems, one vertical – the warp, and one horizontal – the weft. In a counter march loom the warp is dressed into the loom with shafts, heddles, lams and treadles. The warp-threads are threaded into the heddles in a defined system. Shafts with heddles are connected to the treadles in a system called draft. The warp and the weft can be interlaced together in different ways called bindings. To get a shed for weaving, one of the treadles is pressed. A shuttle with warp-yarn can then be thrown into the shed in the warp.

Figure 2 shows how to heddle/enter on 2 shafts for tabby and 4 shafts for twill. The vertical grids illustrate the shedding order. The square in the lower right corner shows the draft – how the shafts, and treadles are connected.



Tabby



Twill

Figure 2 Two of the basic bindings are Tabby and Twill. Drawing made by E. Wendelbo

Knitting

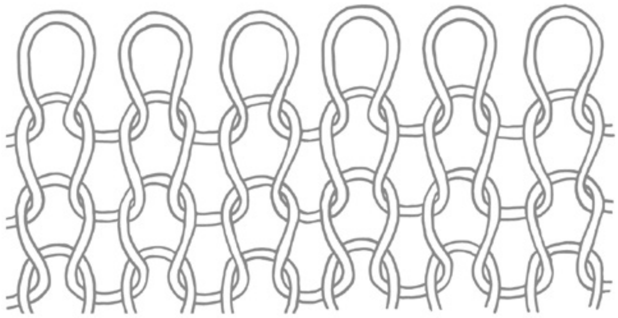


Figure 3 The structure of the simplest type of knitted fabric. Drawing made by A. Pink

Compared to weaving, knitting is a younger technique which gained considerable popularity in domestic textile production a few centuries ago and is still very popular today. Whether the knitted material is made by hand or by machine, it has similar properties. Thanks to the elasticity of the woolen yarn, the knitted item is also elastic and keeps its shape well. Knitted items of clothing are comfortable to wear and allow free movement, which is why they are indispensable both for physical work and sports. A Nordic person cannot imagine life in winter without woolen socks. Depending on the thickness of the yarn used, it is possible to make very different items: from light dresses and jackets to heavy and warm felt coats. Felting also makes the knitted material stronger and more durable.

Knitted fabric is a textile that is created by knitting, during which the yarn runs in a meandering fashion and forms loops in each row, which are connected to the loops of the previous and following rows (Figure 3). In comparison to woven fabric, the looped structure gives the textile more elasticity and flexibility and it can be easily formed into smaller items. Tools for knitting are knitting needles or a knitting machine. Knitting is a one-tread system, but different patterns and multiple colours can be used by manipulating the loops. Using the knitting technique, it is possible to make sweaters, socks and gloves without stitching the parts together, as the different components of the garment can be knitted together.

Fabric finishing process: stamping, waulking, fulling

In industrial production, it is possible to finish fabrics in different chemical ways, which ensure, for example, that the fabrics are moth-proof and won't felt. In this material, however, simpler artisanal finishing techniques will be discussed in more detail.

Before starting to weave the wool fabric, it is important to understand the textile's desired properties and end-use. For example, the felting properties can be useful for fabric for outdoor garments that are water and wind resistant. At the same time, it is necessary to be aware that the grade of felting or waulking will have an influence on the grade of pilling, the elongation and the elasticity of the fabric.

When there is a raw, finished woven or knitted fabric, it is processed so that it obtains the qualities desired for a specific purpose. The amount of felted/fulled fabric depends, of course, on what type of garment will be sewn.

- It could be that the material should be water repellent and windproof for outdoor use (wadmal). This requires 15–20% shrinkage or more.
- The fabric must be able to be cut without unraveling the edges.
- The material should be pliable so that it can be used to make clothing, this requires 5–10% shrinkage

Stamping/waulking/fulling are old techniques used to process wool material in order to make it warm, windproof, and water repellent. Wool can be felted with mechanical processing in combination with water. The wool fibres have scales that get stuck together when they are set in motion. If the water is lukewarm, the scales open more easily than if the water is cold, and the felting/fulling process is faster.

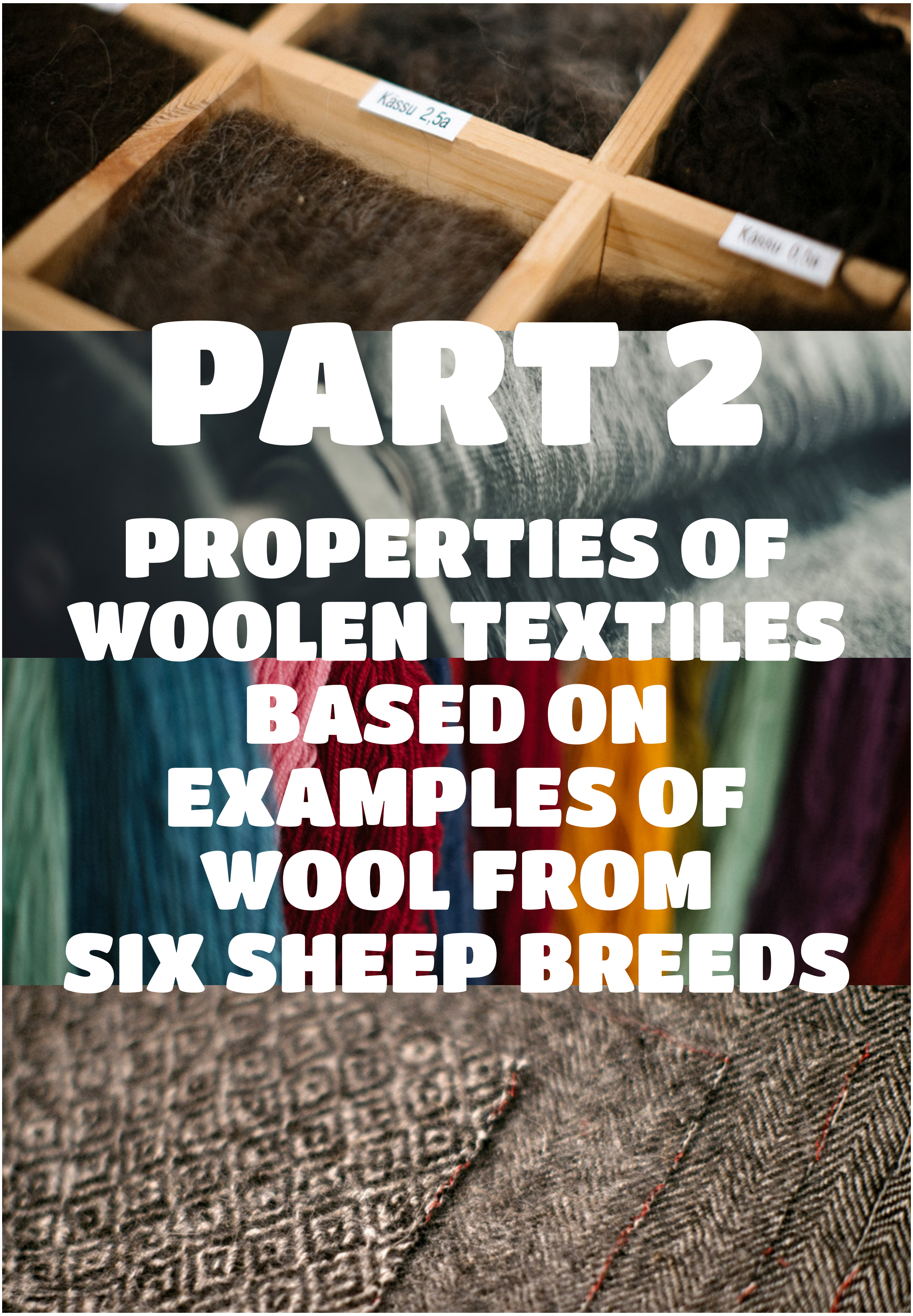
The felting process is controlled through certain mechanical movements, in order to achieve the desired outcome. There are different ways to process wool fabric to felt. In different traditions and areas, felting and fulling have been performed in different ways, based on geographical and topographical circumstances:

- The material is worked by several hands around a table, or on a rough board, and the material rotates between the workers in rhythmical movements. Women sing waulking songs (Shetland)
- Stamping with one's feet in a stamping tub or a container
- Fastening the material to a rock at the seashore and let the tide and the waves do the mechanical work (Shetland and Faroe Islands)
- Placing the material in a large basin near a waterfall and let the water set the material in motion (Romania, Transylvania)
- Mechanical stamping with heavy wood logs, such as at a wadmal stamping mill (Norway)
- Washing the wool fabric in a washing machine, but not on the gentle wool program.

There is a difference between wool material that is felted in a washing machine and wool material that is mechanically processed with wood logs (stamping or in between two rough boards). In the washing machine, the material becomes fluffy, and the fibres can wander out of the fabric. When it is stamped in a wadmal stamping mill, the material is pounded, and the fibres creep into the fabric. The fabric becomes firmer.

When the fabric is finished and still wet, it must be stretched to straighten out folds and unevenness. When there is moisture in the material, it is relatively malleable, which makes it easier to remove irregularities.

- The fabric is rolled around a circular log that has been wrapped with cotton or linen fabric. Next, a coarse stitching is sewn along the edge of the wool fabric to hold the fabric in place and to get a good stretch.
- Another way of stretching is to roll the fabric up around two semicircular logs. By driving wedges between the half logs, the material will be stretched. The fabric dries in a roll for three to four days but must be re-rolled once per day to get the moisture out.



PART 2

PROPERTIES OF WOOLEN TEXTILES BASED ON EXAMPLES OF WOOL FROM SIX SHEEP BREEDS

During the project, three Estonian and three Norwegian sheep breeds were selected, their wool was collected, and yarn and woven and knitted textiles were made from the wool. In all the different stages, the characteristics of the materials were measured and tested. The following chapter describes the stages of material selection and collection and provides an overview of the testing results.

It is important to note that although the collection and processing of materials was intended to be completed using the same principles and methods, there are aspects of the results that differ from country to country due to differences in local methodologies. These differences are mainly related to the gathering and processing of wool into yarn. For example, in Estonia's Vilma wool mill, wool was collected from specific sheep, but in Norway a larger amount of wool was collected from a larger number of non-specified sheep. In Norway's Selbu spinneri, two different colours of wool were used for the same breed, to be better able to keep the yarns apart, but the colours might have slightly different properties, so the conclusions drawn for one yarn cannot be exactly generalized for the whole breed. On the other hand, choosing only one colour would not be representative, and the mixing of colours to get a more general result would also be difficult. There are large differences in wool quality between sheep of different colours, due to the different colour genes.

There were also several differences in the yarn processing procedure. Although both wool factories use a similar semi-worsted technique, Viljandi Vilma spinning mill does not use a separator to remove coarse outer wool hairs nor finishes the yarn with a conditioner. The Vilma mill used a Ramella spinning system for the project, while Selbu spinneri used the Belfast spinning system. However, you can still effectively compare the properties of the wool from the sheep of one country with others.

2.1. GATHERING MATERIALS AND PRODUCING TEXTILES FOR THE TESTING

Estonian sheep breeds, shearing and collecting the wool

In this educational material, wool from three Estonian sheep breeds has been collected and analyzed, namely the Estonian Whitehead, Estonian Blackhead and the Kihnu native sheep (Photo 30, 1-3). The choice turned out to be in favor of these breeds, because whitehead and blackhead are historical Estonian sheep breeds.

When selecting the wool of Estonian Whitehead and Blackhead sheep, the sheep with the highest bloodline of the given breed were selected from the database kept on the breeding flocks. A list of Estonian sheep and their blood characteristics is given in appendix no 1. In the selection of Kihnu native sheep, the selection was based on sheep breeder Anneli Ärmpalu-Idvand's recommendations. In total, 48 fleeces were used for making yarn and 44 of them were tested separately.

Estonian Whitehead sheep (EV) breed is an early-maturing, well-formed meat sheep breed, with white, semi-fine, single coat wool (Photo 22). The breeding of the Estonian Whitehead sheep began in 1926 but it was recognized as an independent breed in 1958.

Photo 22. The Estonian Whitehead sheep. Photo by K. Tambet

Today, Texel and Dorset sheep are used to improve the meatiness of the Estonian Whitehead sheep, and Norwegian white sheep can be used to increase fertility and milk yield.

The wool from the Estonian Whitehead sheep breed comes from 17 different sheep from 3 different herds: Maatar OÜ (Viljandi county), Forest Haldus OÜ (Viljandi county) and Urmas Aava (Pärnu county). All of them shear the sheep once a year, mainly in early spring, but some of them in summer as well.

Estonian Blackhead sheep (ET) breed is an early-maturing, well-formed meat sheep breed that produces white, semi-fine wool (Photo 23). The Estonian blackhead sheep was recognized as an independent breed in 1958. Today, Suffolk and Oxford Down sheep are used to improve the meatiness of the Estonian Blackhead sheep breed, and Finnsheep have been used to increase fertility.

The wool from the Estonian Blackhead sheep breed comes from 21 different sheep from four different herds: Allika farm OÜ (Harju county), Alo Sinimäe (Pärnu county), Laire Käis (Põlva county) ja Sireli farm (Harju county). All of them shear the sheep once a year, mainly in summer, but one of them also in early spring.

Photo 23. The Estonian Blackhead sheep.
Photo by P. Veersalu

Kihnu native sheep (KM) is one of the sub-branches of the Estonian native sheep, a relatively recently recognized indigenous breed, whose history in Estonia goes back several centuries and which is therefore an important part of rural heritage (Photo 24). It is also important to note that the wool of the Kihnu native sheep differs from the other selected Estonian sheep breeds, as the wool mostly consists of a finer under wool and a coarser top wool (double coated wool), making it an interesting test material. The wool from the Kihnu native sheep breed comes from 10 different sheep from two different herds.

Read more about the Kihnu native sheep on the website (only in Estonian!): https://kihnu-lammas.ee/

Photo 24. The Kihnu native sheep.
Photo by T. Mägi.

Norwegian sheep breeds, shearing and collecting the wool

The Norwegian sheep breeds included in this project are Gammelnorsk Sau/Villsau (Old Norse Sheep/wild sheep), Blæset sau (Sheep with white stripe in the face), Grå Trøndersau (Grey Sheep from Trøndelag) and Gammelnorsk spælsau (Old Norwegian Short-tail Sheep) (Photo 30, 4-6). For this project, the wool of Norwegian sheep breeds is sorted by colour – two colours from each sheep breed. This makes it easier to separate the yarn types, and also makes it possible to compare the quality of the two colours.

Blæset sau (NB)

Blæset sau (Sheep with white face stripe) has its origin along the southern west coast of Norway, near Stavanger (Photo 25). The breeding history of this sheep breed is unclear. The name Blæset sau means sheep with a white stripe on its face. Blæset sau is a long-tailed sheep with a single-coat type fleece of medium-fine fibres. The lambs of the Blæset sau have dark brown, or almost black wool. When the animal gets older, the wool tends to become grey, but is still quite dark. Wool from Blæset sheep is dark brown or dark grey. Most of the colour variants of this sheep breed are not very light fast and will have sun bleached tips after a summer in the Norwegian mountains. The wool can be well suited for medium-soft mid-layer garments or tougher outer layers, depending on the quality and how it is spun. Grey and brownish black wool was collected from classified wool that was bought from the wool station in Malvik, close to Selbu spinneri in Trondheim.

Photo 25. Blæset sau.
Photo by M. Espelien

Old Norwegian Short-tail sheep (NS) (Gammelnorsk Spælsau) is an athletic and beautiful sheep (Photo 26). It was developed in the early 1900s through targeted breeding from the Old Norwegian Sheep and is considered to have national conservation value. These sheep are smaller than modern spælsau and give high quality wool. The wool is double coated with soft underwool and coarser guard hairs. All the colours: black, grey, blue, brown, light brown and coal grey, make the wool a perfect material for woven, knitted and felted fabrics. Such fabrics are excellent for home decoration pieces and outer layer garments. Beige and grey wool was collected from a farm in Kvikne, 200 km south of Trondheim.

Photo 26. Old Norwegian Short-tail sheep.
Photo by A. Espelien

Photo 27. Old Norse sheep. Photo by A. Espelien

Old Norse sheep (NV), or the "wild sheep" is an athletic sheep breed that usually stay close together in a family group (Photo 27). This is probably the oldest sheep breed in Norway. They are mostly kept in coastal areas and can often be seen on coastal islands, grazing on kelp and seaweed. The wool is double-coated wool and provides excellent weather protection, both for the sheep, and as manufactured garments for coastal outdoor activities. For this project, wool was collected from several different farms along the coast of Mid-Norway.

In the context of the following testing, it is important to note that three of the six sheep breeds included in the project have single coat wool (Estonian Whitehead sheep, Estonian Blackhead sheep, Blæset sau) and three have double coated wool (Kihnu native sheep, Old Norse sheep, Old Norwegian Short-tail sheep).

PRACTITIONERS' CORNER
Since different breeds have been used for crossing, the properties and quality of the wool can vary greatly within the same breed. There is also wool from young and old sheep, as well as ewes and rams, with different properties. The different colours of the wool also have different properties. Therefore, when buying wool, it cannot be assumed that sheep of the same breed will produce wool of the same quality!

Wool sorting and grading

Estonian wool was sorted at the Vilma wool mill (Photo 28 and 29). The length of the wool fibre suitable for machines producing semi-worsted yarn is 5-20 cm; in the best case, 7-15 cm. The lengths of the wool fibres for this project remained mostly within the range mentioned above. The wool fibre length of Estonian Whitehead and Blackhead sheep was more even. The wool of the Kihnu native sheep, which consists of two layers, had a more uneven fibre length. During wool sorting, fibres that were too short (shorter than 5 cm) and too long (longer than 20 cm) had to be manually removed. It was also necessary to sort out the wool tops stuck together with dirt. The biggest loss of Estonian Whitehead sheep and Estonian Blackhead sheep wool mass during sorting was from dirt (plant particles, organic debris and too dirty fibre tops). Of the Kihnu native sheep wool, the most loss was due to felted fleece. Estonian Whitehead sheep wool was pure white. Estonian Blackhead sheep wool had very few gray fibres. The colour of Kihnu native sheep wool varied from white, light gray to dark gray and dark brown.

In Norway, wool was partly sorted at a wool station and partly at Selbu spinneri. The wool of each sheep breed was sorted according to the routines at Selbu spinneri. The Old Norwegian spælsau wool came from autumn shearing. The undercoat wool was approximately 5-6 cm and the guard hairs were 12-18cm. The wool was sorted into two different colours for this project, brown and beige. The wool from the Old Norse sheep was from summer shearing. These sheep are sheared once a year and the undercoat wool was 5-8 cm and the guard hairs 10-15 cm. The wool was sorted into two different shades of grey. The Blæset sheep wool was 6-7 cm. The wool was sorted into brownish black and grey.

Wool scouring

The wool from the Estonian sheep breeds used in the project was washed with a semi-industrial washing machine, Electrolux S556, which has a capacity of 10 kg. Wool is lighter and bulkier than normal washing, so the washing machine can only be filled with 2-3 kg of wool, depending on the fineness of the wool and the proportion of lanolin and fat. The wool for the project was washed in batches of 2-2.5 kg. 250 ml of wool detergent was added to this amount. The wool washing program is specially adapted to the washing machine and washes the wool clean at a temperature of 65 degrees, with plenty of water and little agitation. The program consists of

Photo 28. The unsorted fleece of Estonian Whitehead sheep. Photo by A. Kaljus

Photo 29. The sorted fleece of Estonian Whitehead sheep. Photo by A. Kaljus

one soak, two washes and three rinses. The washing machine is connected to a hot water boiler, which enables warm water to flow into the machine immediately instead of heating the cold water like a normal washing machine. Otherwise, the wool would be felted too much. After washing, the wool is spread in a thin layer in air-permeable boxes and dried outdoors in the wind and sun, while occasionally turning the wool over.

In Norway, Electrolux machines are used, one 445 which can wash 8 kg and one larger which can wash 12 kg. With the smaller machine, the wool was washed in 2.5-4 kg batches and in 6-9 kg batches in the larger. The washing and rinsing water temperature was 80-85 degrees. The wool was rinsed and centrifuged after washing and left to dry in open metal racks in the production room.

Yarn producing

Estonian yarns were made in the Vilma wool mill and Norwegian yarns in Selbu Spinneri. Two different types of yarn were produced: a thicker yarn for weaving (two ply: 315 m/100 g) and thinner for knitting (two ply: 360 m/100 g). All yarns were made with medium high to high spin and plying twist to be strong enough to be suitable for weaving.

When making the yarn, it was important that the wool of different sheep from one breed was mixed as much as possible. Beginning at the picking stage, fibres of different shades of Kihnu native sheep were mixed together, with the majority mixed during combing. In the Vilma wool mill, the wool went through the following processing steps: picking, carding, pin-drafting (4x), spinning, plying and cone winding. In Norway, the wool was sent through the picker, a fibre separator, the carder, a draw frame, to the ring spinner and then the plyer. After plying, the yarn was conditioned and left to dry for at least one week.

The carding machine worked very well on mixed sheep wool from ET and EV. The carding tape ran evenly, which enabled even combing and finally, an even yarn. Kihnu native sheep roving came out more uneven due to the different wool fibre lengths. In Norway, the carding and the stretching/combing went well for all the sheep breeds.

If all the preliminary work has been successful (carding, pin-drafting) and the slivers are even (there are no thicker or thinner places), then the yarn will be even and nice when spun.

The yarn spun in Estonia was measured to spin at the correct coarseness. 63m or 72m of yarn had to weigh 10g. 10 different spun yarns were measured, and each weighed between 9.6-10.4 g. Several such tests were done previously as well. The variation in the thickness of the yarn may be due to the small amount of wool that was tested.

As the later fabric production showed, some of the yarns were of different thicknesses. Even if the yarn number is the same, the thickness of the yarn can differ because of the different weight/density, thickness of the fibres, and because some sheep breeds have more compact wool. This is mainly because the guard hairs are heavier and more compact.

PRACTITIONERS' CORNER
All stages of the production of yarn, from sorting and grading the wool to the finishing treatment, affect the end result of the yarn and the textile made of it. Production of high-quality yarn depends on skilled workers and is based on both written knowledge and tactile skills.

Photo 30-a. Samples of wool, sliver and yarn of six sheep breeds.
Photos by M. Anton

Wool from the back | **Wool from the side** | **Sliver**

Estonian Whitehead (EV)

Estonian Blackhead (ET)

Kihnu native sheep (KM)

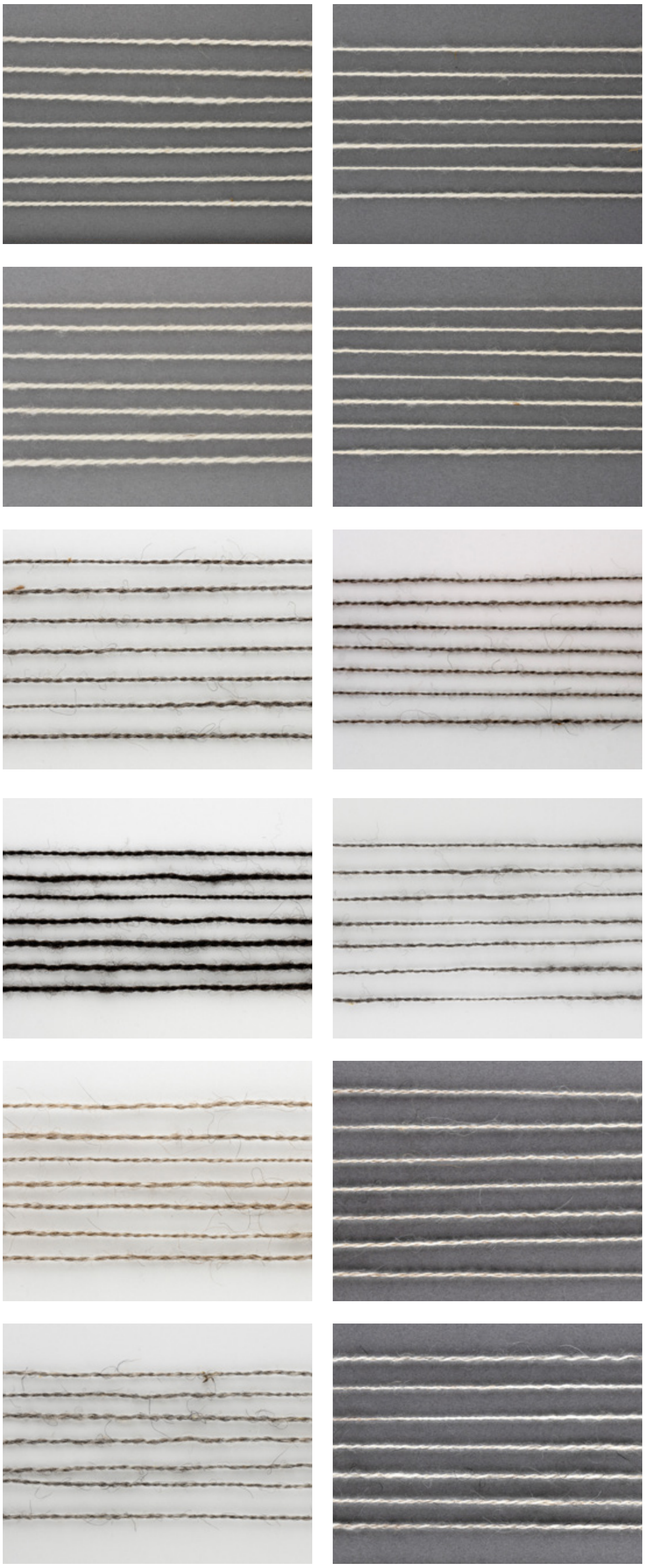
Norwegian Blæset (NB)

Old Norwegian Spælsau (NS)

Old Norse sheep (Norwegian Villsau) (NV)

Photo 30-b. Samples of wool, sliver and yarn of six sheep breeds.
Photos by M. Anton

Thicker yarn (315 m/ 100 gr) **Thinner yarn** (360 m/ 100 gr)



Estonian Whitehead (EV)

Estonian Blackhead (ET)

Kihnu native sheep (KM)

Norwegian Blæset (NB)

Old Norwegian Spælsau (NS)

Old Norse sheep (Norwegian Villsau) (NV)

Weaving fabrics

The fabrics (Photo 47) were woven in USN (Photo 31, 32, 33) and UT VCA (Photo 34). All fabrics were cut in half, one half of which was tested without finishing and the other with finishing.

The fabrics for testing were handwoven with 8 treads/cm in warp and weft. The choice of 8 treads per cm in warp and weft is based on experience from testing fabric woven in 5 treads/cm, 6 treads/cm and 8 treads/cm. The latter was chosen because of the firmness, softness, and considering that beginners were going to make similar fabric. Since the fabrics are woven by hand by different people, there may be a slight difference in the density and uniformity of the fabrics. In general, however, the fabrics are similar.

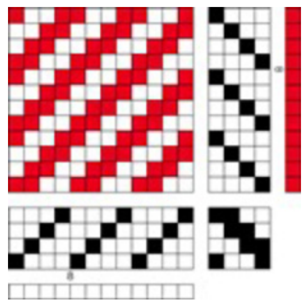
PROJECT ESTONIAN AND NORWEGIAN LOCAL SHEEP WOOL – RESEARCH AND STUDY MATERIALS FOR TEXTILE STUDENTS IN HIGHER EDUCATION.		**TEST SPRING/FALL 2022**
Warp:	315 m/100 grams, 2 plied	
Length of warp:	6.60 m	
Weight of warp:	0.750 kg	
Total thread:	432	
Reed:	40/10 (1/2)	
Threads per cm	8 per cm	
Weaving width in reed:	54 cm	
Weft:	same as Warp	
Weft /cm:	8 per cm	Draft: 2/2 plain twill

Table 3. Technical data of the woven fabric construction

The properties of all three yarns made from **Estonian sheep wool** made them very good for weaving on looms. The thread was strong and smooth and did not cause any problems when weaving, such as warp breakage. During the weaving process, the yarn of Kihnu native sheep seemed a little stiffer and less elastic than that of Estonian Whitehead and Estonian Blackhead. As when weaving any woolen fabric, it was necessary to ensure that the warp tension was uniform throughout the weaving, as well as the density of the weft thread. The latter was easier to observe in the case of Estonian Whitehead and Blackhead yarns.

All **Norwegian yarns** worked well for both warp and weft. Yarn made of Blæset wool had a soft quality that worked well during the weaving process. Norwegian Spælsau and Old Norse sheep contained cover hair and bottom wool and had a glossy surface. Even with the same width, length and roughly the same weight, Old Norse sheep and Spælsau fabrics felt heavier and had a different fall than fabrics woven with yarn from Blæset.

Photo 31. Warping of the warp.
Photo by E. Wendelbo

Photo 32. Heddling of the warp.
Photo by E. Wendelbo

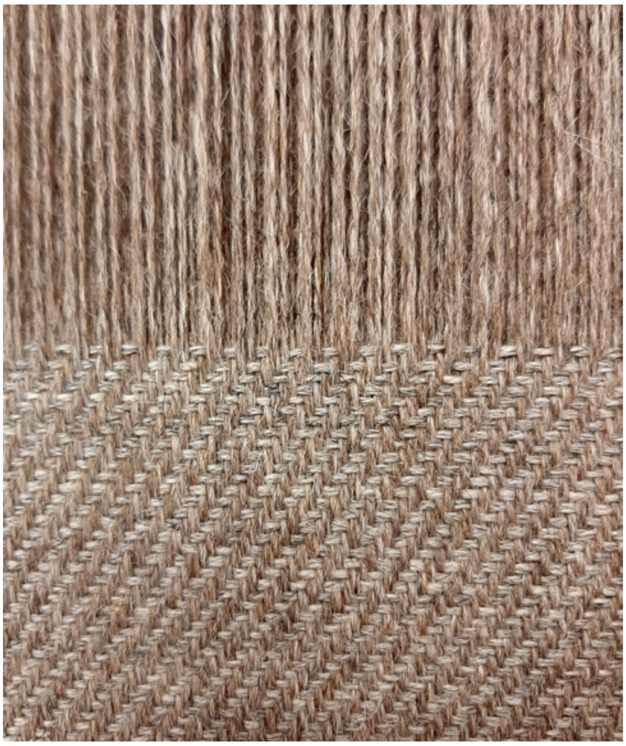


Photo 33. The weaving of the Norwegian Spælsau fabric.
Photo by E. Wendelbo

Photo 34. The weaving of the Estonian Blackhead fabric. Photo by A. Kaljus

PRACTITIONERS' CORNER

The fabric will contract about 5 – 7% in width and length when it is taken out of the loom. Different yarns contract differently.

Finishing of the woven textiles

All woven textiles were treated in exactly the same way in Norway. The woven fabrics went through a mechanical finishing process in a wet state with a shrinkage percentage of 7%. For an increased degree of water and wind repellency, 10 – 12% shrinkage is needed. The fabrics became softer and slightly denser after washing and light waulking, and might be suitable for upholstery, garments or blankets.

For this project, the Norwegian partners tested the waulking process in a homemade wooden box and placed the test fabrics between 2 rough boards (Photo 35, 36). Two people moved the upper board in rhythmical movements. The fabrics were wet, and during the process, soap and lukewarm water were added (Photo 37). Measuring the fabric after every 5 to 10 minutes was important for controlling the shrinkage. During each measuring pause, the fabric was stretched (Photo 38) and folded into a different shape (Photo 39). The time that it took for shrinkage was different for different fabrics; since the waulking was done by hand with a simple tool, it is not possible to compare the time used for this process. Waulking was stopped at a 9-12% shrinkage in the width of the fabric. The fabrics were stretched by rolling them around two semicircular logs. By driving wedges between the half logs, the material was stretched (Photo 40).

Photo 35. Homemade wooden box for waulking.
Photo by E. Wendelbo

Photo 36. Detail of waulking board.
Photo by E. Wendelbo

Photo 37. Soaking of the fabric.
Photo by E. Wendelbo

Photo 38. Stretching of the fabric.
Photo by E. Wendelbo

Photo 39. Folded fabric on the waulking board.
Photo by E. Wendelbo

Photo 40. Final stretching of the fabric with the help of the wedges. Photo by E. Wendelbo

BREED	WEIGHT	LENGTH BEFORE FINISHING	LENGTH AFTER FINISHING	% OF SHRINKAGE	WIDTH BEFORE FINISHING	WIDTH AFTER FINISHING	% OF SHRINKAGE
EV	730 g	252 cm	229 cm	**9%**	51 cm	46 cm	**10%**
ET	706 g	252 cm	222 cm	**12%**	51 cm	45 cm	**12%**
KM	655 g	252 cm	225 cm	**11%**	52 cm	46 cm	**12%**
NB	676 g	252 cm	224 cm	**11%**	51 cm	45 cm	**12%**
NS	746 g	252 cm	225 cm	**11%**	51 cm	46 cm	**10%**
NV	745 g	252 cm	224 cm	**11%**	51 cm	46 cm	**10%**

Table 4. Technical data of woven fabrics before and after waulking

Waulking posed some challenges for controlling the shrinking process. The length and width of the fabrics prior to waulking were the same, but the weight of the fabrics were different. The weight of the fabrics might have influenced the results, although generally the final numbers were quite even.

PRACTITIONERS' CORNER
Different finishing techniques give different results on different wool. Woven textiles made from the native sheep breeds need more time to get the same shrinkage result than woven textiles from single-coated wool. This might be caused by the coarse guard hairs in the native sheep breeds, as they will restrain from felting, and lengthen the felting process.

Knitting textiles

All knitted textiles were produced at the UT VCA (Photo 47). The yarn used for the textiles was two-ply: 360 m/100 g. All samples were knitted on a Brother hand knitting machine, density 6 (Photo 41, 42, 43, 44). It could also have been knitted with density 5, but with a slightly thinner texture, the machine knitted the yarn more easily. For some yarns, density 5 would have been too tight. However, the goal was to knit all the yarns with the same density. Two fabrics were knitted from each yarn, the shorter (1000 rows) went into testing without felting and the longer one (1200 rows) was felted before testing. The width of the textile was 198 loops.

The knitter generally rated the yarn as very suitable for machine knitting. Her favorites were Estonian Whitehead and all Norwegian yarns. There was no clear difference in the suitability of crossbred and native sheep yarn. The yarn count was the same for all yarns, but the Norwegian yarns seemed visually finer.

Photo 41. Creating loops on the knitting machine. Photo by L. Reinula

Photo 42. Knitting machine Brother.
Photo by L. Reinula

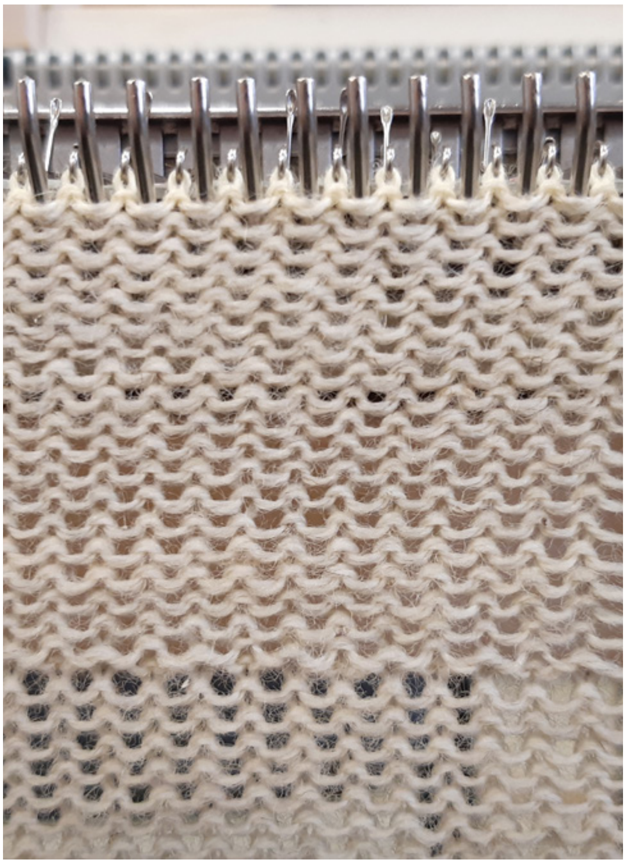


Photo 43. Detail of the knitted fabric on the machine.
Photo by L. Reinula

Photo 44. Finished rolls of finished fabrics. Photo by L. Reinula

Photo 45. Sewing the edges of woven fabrics. Photo by A. Kaljus

Photo 46. All test fabrics are ready for finishing. Photo by A. Kaljus

Finishing of the knitted textiles

All of the knitted textiles were finished together in a washing machine at the UT VCA. The purpose of finishing was to felt the fabrics for a sweater or a light scarf. Since the edges of the machine-knitted fabric start to roll when being washed, before felting, the fabrics were sewn from the edges into a tube so that their right sides remained inside (Photo 45,46). This preliminary work was necessary so that the fabrics felted evenly. Otherwise, rolled edges will shrink differently. The fabrics were felted with a semi-industrial washing machine, Electrolux S556 model, which has a capacity of 10 kg. In total, the fabrics weighed 4.1 kg. Approximately 2/3 of the machine was filled with this weight. Normal wash was selected for the washing machine program: Normal Colour 40°C, which lasts 42 minutes. ProFit Wool detergent was used in 0.25 ml amounts.

BREED	WEIGHT	WIDTH BEFORE FINISHING	WIDTH AFTER FINISHING	% OF SHRINKAGE	LENGTH BEFORE FINISHING	LENGTH FINISHING AFTER	% OF SHRINKAGE
EV	750 g	60 cm	54 cm	**10%**	261 cm	237 cm	**9%**
ET	655 g	62 cm	55 cm	**11%**	251 cm	235 cm	**6%**
KM	735 g	62 cm	52 cm	**16%**	261 cm	250 cm	**4%**
NB	675 g	65 cm	55 cm	**15%**	270 cm	244 cm	**10%**
NS	655 g	66 cm	55 cm	**17%**	266 cm	255 cm	**4%**
NV	635 g	68 cm	52 cm	**24%**	261 cm	259 cm	**1%**

Table 5. Technical data of knitted fabrics before and after finishing

The table shows how different fibres act differently in textiles. The differences present in the fabric before finishing (Table 5) are due to the variation in the fibres and yarns. Fabric made with yarn from double-coated fibres shrunk less in length but more in width. Fabric made from yarn from single-coated fibres shrunk more evenly. The results show great variability in different sheep breeds and wool types. The shape of the loop allows for greater contraction across the width of the fabric. The yarns that are not as elastic shrink more.

PRACTITIONERS' CORNER

The shrinkage percentage is affected by many factors, including the capacity, size, and filling percentage of the washing machine. Additionally, different yarn and fabric structures act differently with different programs. The choice of soap is also important. A soap with a pH of around 7 (neutral) will not induce much felting. A soap with a higher pH (like green soap) will induce stronger and faster felting. It is important to wash out this kind of soap to stop the felting when the textile is finished.

Photo 47-a. Samples of unfinished and finished woven and knitted fabrics. Photos by Maritta Anton

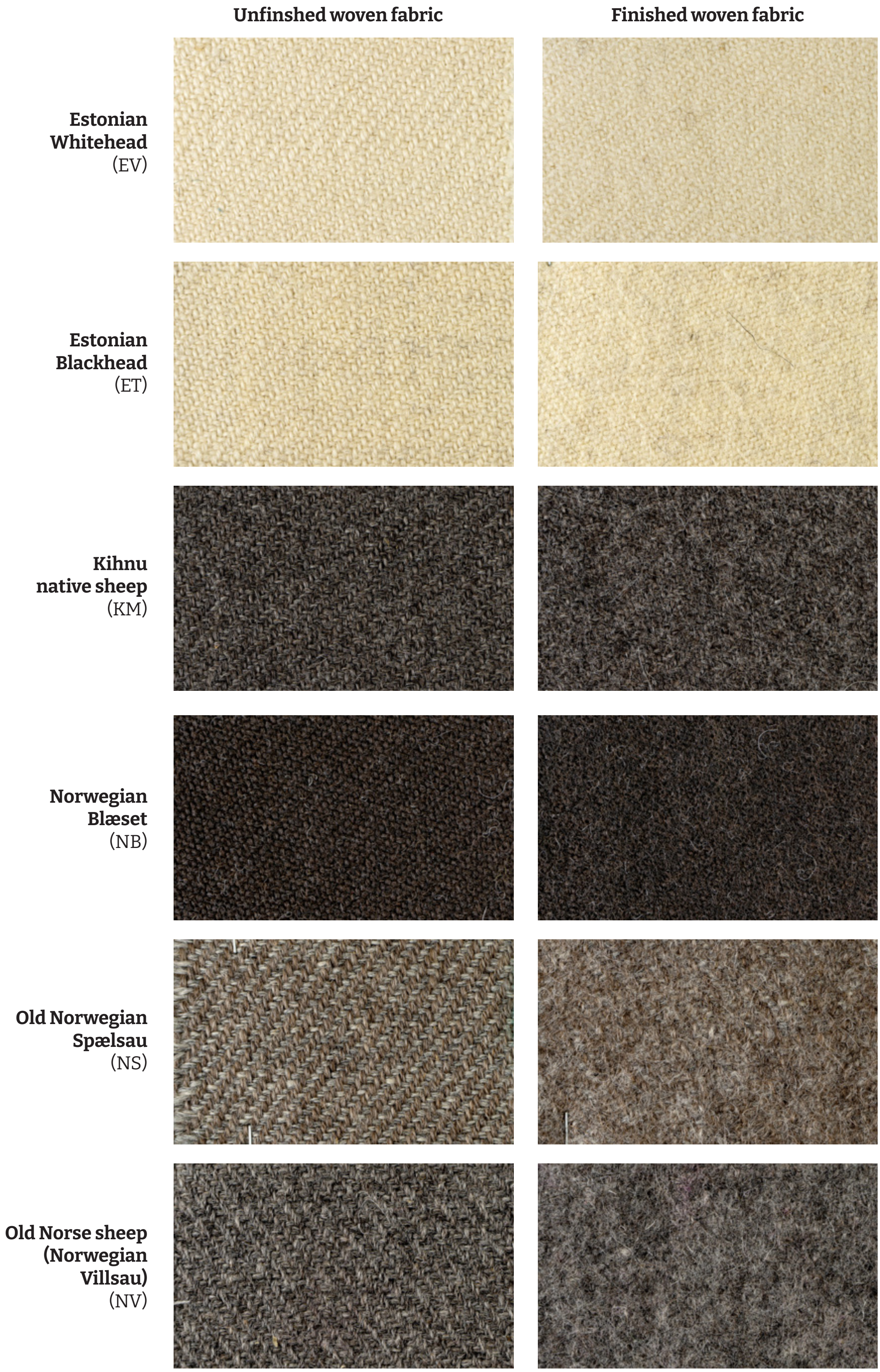


Photo 47-b. Samples of unfinished and finished woven and knitted fabrics. Photos by Maritta Anton

Unfinished knitted fabric | **Finished knitted fabric**

Estonian Whitehead (EV)

Estonian Blackhead (ET)

Kihnu native sheep (KM)

Norwegian Blæset (NB)

Old Norwegian Spælsau (NS)

Old Norse sheep (Norwegian Villsau) (NV)

2.2. ANALYSIS OF THE TEXTILE MATERIAL

General introduction about research of wool fibres and textiles

In order for test results to be internationally comparable, tests must be performed according to standards. There are different levels of standards:

1. International level – for example, ISO standards (basic standards in textile testing) are standards of an international organization.
2. Regional level – for example EURO standards (EN ISO) – developed based on ISO.
3. National level – these are national standards. Each country has its own standards that have been adopted from ISO standards or are independently created.

The tests carried out within the framework of the project have mostly been carried out in accordance with international standards. For each different type of test, the type of standard used for guiding the testing procedure is described.

In order for the results of the tests to be comparable, the conditions for performing the tests are very important. This is especially important for textile materials whose properties depend on the humidity and temperature of the surrounding environment. The properties of many textile materials (especially hygroscopic ones) depend on their moisture content, which in turn, depends on the humidity of the surrounding environment. In order for test results in different laboratories to be comparable, standard testing conditions have been agreed upon *(ISO 139 Textile materials: Standard conditions for conditioning and testing)*. The normal testing conditions are:

- Relative humidity 65±4%
- Temperature 20±2°C

It is also defined that the textile material must achieve the humidity corresponding to normal conditions by absorbing moisture, not by giving it up. For this purpose, the "dry" textile sample is dried for one hour at 50°C in a drying oven or climate cabinet. This results in a lower moisture content. The sample is then stored under normal conditions. Under normal conditions, the sample must be kept until it reaches the conditional humidity, i.e. its weight increase is less than 0.1% per hour. Textile products with different structure and density require different times for this:

- Fibres, yarns, light and medium density clothes: 12 – 24 hours
- Heavy clothes: 24 – 72 hours

As part of the project, all tests were performed in the textile testing laboratory of TTK University of Applied Sciences, where the testing conditions were on average the following: temperature 26±2°C and relative humidity 44±4%. The conditions are somewhat different from normal conditions, but the probability that this would affect the test results to an appreciable extent is very small. In the case of wool, it is a hygroscopic textile material. The higher the moisture content of wool, the stretchier and weaker it is. Since the humidity, which can affect the strength and stretch properties of wool, differs from normal conditions by only a few percent, and all tested materials were kept under the same conditions, the test results of all tests of the same type are comparable.

The method of sampling is also very important *(Standard: EVS-EN 12751:2000 Textiles. Sampling of fibre, yarn and fabric materials for testing)*. The prerequisite for obtaining the correct result is the exact correspondence of the sample or samples to the structure and properties of the object under investigation. Usually, textile materials do not have uniform properties and therefore sampling from one place is not sufficient. The sample is formed from samples taken from several locations. It is not possible to provide completely satisfactory instructions for taking samples, precisely because of the very different forms of textile materials. For example, in theory, it would be correct to take fabric samples from a certain distance along the length of the fabric roll. In practice, this rule is not applicable for economic reasons. The number of samples depends on the special requirements and the sampling procedure is agreed upon between the interested parties. Test pieces of the same type, intended for determining the mechanical and physical properties of the fabric, must not contain the same warp and weft yarns. **The number of tests** performed on a sample taken from textile materials depends primarily on the unevenness of the material, the distribution of indicators, and the requested probability. In continuous quality monitoring, it is possible to mathematically determine how often tests must be performed if the distribution of the indicators is known, and if the changes in the indicators that are to be highlighted during the monitoring have been agreed upon. Standards and methodologies always state how sampling is done and the number of tests.

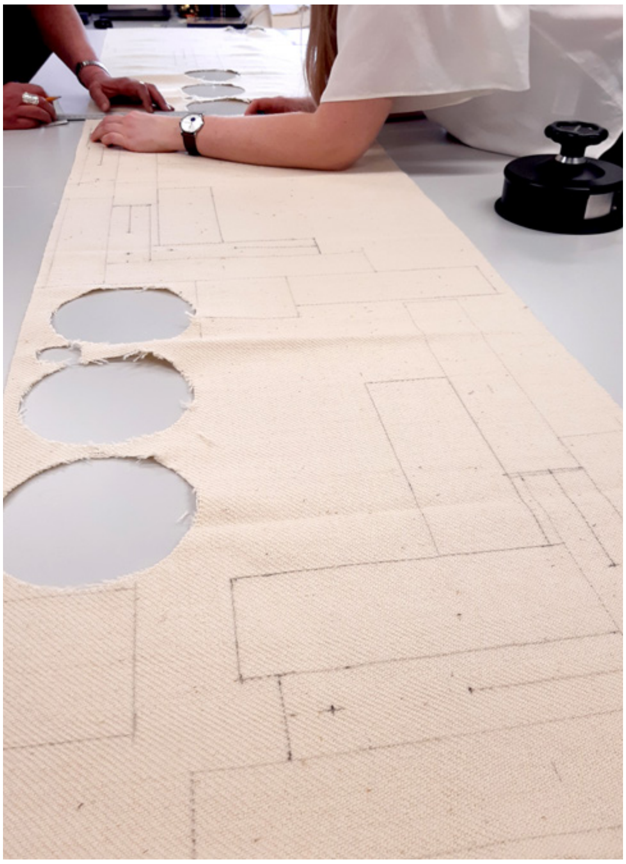


Photo 48. Measuring and cutting the test specimens. Photo by D. Tuulik

The method of sampling and the number of tests carried out within the project are also based primarily on the relevant standard (Photo 48). Deviations from the standard are mainly due to the limited amount of test material. The deviations that occurred in this project are presented in the descriptions of the corresponding tests.

The accuracy of **recording the test** results is also determined by the standards. If not, the usual rules apply:

1. The readings are recorded with the value of the smallest division of the measuring scale of the device 2. If a very different result from the others is obtained during the experiments, it is still recorded in order to later check its specificity and decide whether to consider the given result or not.

List of tests performed in the project:

- **LINEAR DENSITY OF FIBERS**
- **FABRIC WEIGHT**
- **TENSILE STRENGTH** (yarns, fabrics)
- **TEARING STRENGTH**
- **ABRASION RESISTANCE**
- **PILLING**
- **AIR PERMEABILITY**
- **ELONGATION, ELASTICITY**

Wool and yarn

Tests were performed with unscoured wool from six different sheep breeds. Wool samples were collected from the side and back of the sheep fleece and marked separately (Photo 30). Fibre tests were also performed with slivers after pin-drafting according to the sheep breed. All test results have been analyzed and compared with each other.

The wool of Estonian sheep breeds was tested from different herds and different sheep.

There were 44 Estonian sheep in total:

- Estonian Whitehead (EV) – 2 herds, 13 sheep
- Estonian Blackhead (ET) – 4 herds, 21 sheep
- Kihnu native sheep (KM) – 2 herds, 10 sheep

There were 6 Norwegian sheep fibre samples, 2 colours from every sheep breed:

- Norwegian Blæset (NB) – grey and brownish black
- Old Norwegian Spælsau (NS) – brown and beige
- Old Norse sheep (Norwegian Villsau) (NV) – grey and light grey

Linear density of wool fibres

Linear density is the measure of fibres' mass per unit length or length per unit mass. Commonly seen units of linear density include denier (D), decitex (dtex), cotton count (cc or Ne), and metric count (Nm). A yarn or fibre's fineness cannot be expressed in terms of diameter because its diameter is not stable and uniform along its length, and its cross-sectional shape may not be circular. As the definitions of linear density and yarn count are fairly straightforward, their measurements are also easy to understand. Generally, a fixed length of fibre or yarn's mass is measured, then the linear density or yarn count can be determined. Higher value means thicker (or heavier) yarn for the same material.

The linear density of the fibre has been measured using a Vibroskop 400 device according to the user manual instructions of the device, the measurement unit is decitex (dtex). Decitex (dtex) is a metric unit defined as the mass in gram per 10,000 m.

The vibroscopic method measures fibre's linear density by subjecting an individual fibre of a given length to vibration at a resonance frequency under specified tension, and calculating the linear density using Mersenne's law as shown in the following equation:

$$f = \frac{1}{L}\sqrt{\frac{T}{\mu}}$$

Where f is the resonance frequency of vibration in Hz, L is the length of the vibrating fibre in km, T is the tension applied to the string in N, and μ is the linear density of the fibre in tex (g/km).

ISO1973 also describes the vibroscopic method. The vibroscopic method is considered more accurate for single short fibre linear density measurement.

It is also possible determine the diameter of a fiber in microns if known its denier and density.

Linear density of wool fibres testing

For the Estonian sheep breeds, a total of 44 x 2 fibre samples were tested. 15 fibres were tested from each sample, for a total of 1320 single tests.

For the Norwegian sheep breeds, a total of 6 x 2 fibre samples were tested. 15 fibres were tested from each sample, for a total 180 single tests.

Additionally, fibre tests after pin-drafting were done with three samples of each Estonian sheep breed and six samples of each colour of three Norwegian sheep breeds. 15 fibres were tested from each sample, for a total of 270 single tests.

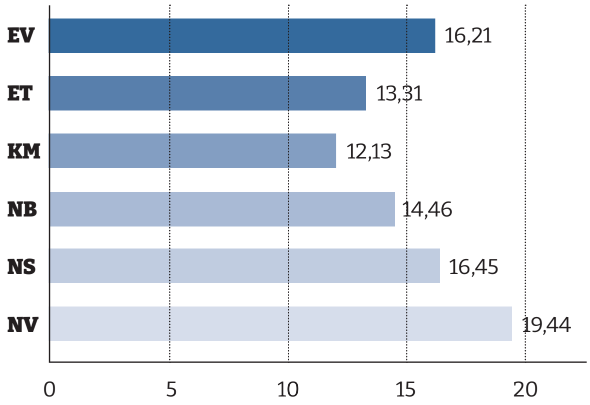


Figure 4. Linear density (dtex) of fibres

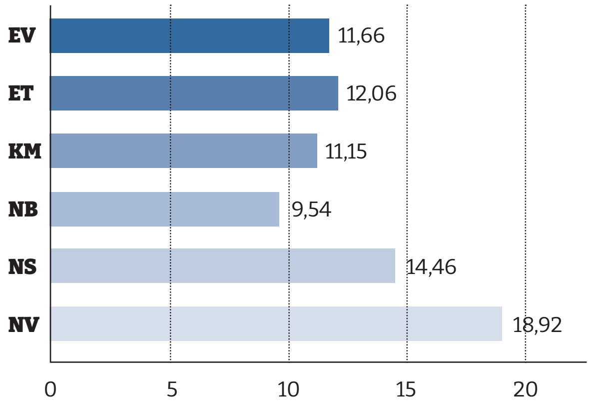


Figure 5. Fibres' linear density (dtex) after pindrafting

Figure 4 shows the arithmetic mean result of wool fibre tests for all sheep breeds and Figure 5 shows the mean result of mixed wool fibre tests after pindrafting.

As can be seen in the case of these samples, the average fineness of the raw wool fibres of Estonian sheep breeds is lower than that of the wool fibres of Norwegian sheep breeds. However, after mixing the wool fibres of the same breeds, the fineness of the wool fibres in all breeds is somewhat lower than that of the raw wool before sorting and mixing. The fineness of the wool fibres of Estonian sheep breeds is more uniform. The fineness of the Norwegian *Blæset* breed's wool fibres has been significantly reduced compared to the raw wool. The reason for that can be the usage of a fibre separator which enables to the separation of the coarser fibres.

Wool fibres (fibres' linear density) analysis

If the test results are analyzed, then it should also be mentioned that the back wool is generally a bit thicker than the side wool in all breeds. Estonian sheep breeds have smaller differences in back and side wool than Norwegian sheep breeds.

The Norwegian sheep breed *Old Norse sheep* has the biggest difference between back and side wool thickness (22.2 dtex and 16.6 dtex, respectively). Different colours of Norwegian sheep breeds *Blæset* (brown 13.2 dtex and blackish-brown 15.7 dtex) and *Old Norse sheep* (gray 25.3 dtex and light gray 13.9 dtex) also have noticeably different thicknesses within the breed.

Regarding Estonian sheep breeds, it can be observed that the thickness of the wool fibre also varies from herd to herd. For example, the average thickness of the Estonian Whitehead sheep breed with the coarsest wool fibre is 17.1 dtex and 11.6 dtex for the finest wool fibre; the average thickness of the Estonian Blackhead sheep breed with the coarsest wool fibre is 16.8 dtex and 12.3 dtex for the finest wool fibre.

Yarn tensile strength

Yarns of two different thicknesses spun from the wool of each sheep breed have been tested: for weaving (two-ply 316m/100g) and for knitting (two-ply 360m/100g) – a total of 12 yarns.

Tensile strength is the most important mechanical-physical property used to characterize the quality and strength of a yarn, which is why it is usually the most tested property. Tensile strength expresses the strength of a yarn under tension and is expressed by means of force. Tensile strength mostly refers to the behavior of fibres. The terms "breaking force" or "breaking strength" refer to the force needed to break the yarn.

Photo 49. Measuring tensile strength of yarn. Photo by M. Beilmann

Yarn testing

All yarns were tested for tensile strength according to the standard EN ISO 2062:2009 (Photo 49). A James Heal tensile tester was used for testing. The length of the test piece was based on the standard and was 500mm plus extra for fixing. The distance between jaws (grips) was 500mm and the rate of extension was 500mm/min. 20 tests were performed with each yarn. Figure 6 shows the average result of yarns (coarser and finer) spun from wool fibres of each sheep breed. The maximum force (N) was measured at the moment of breaking.

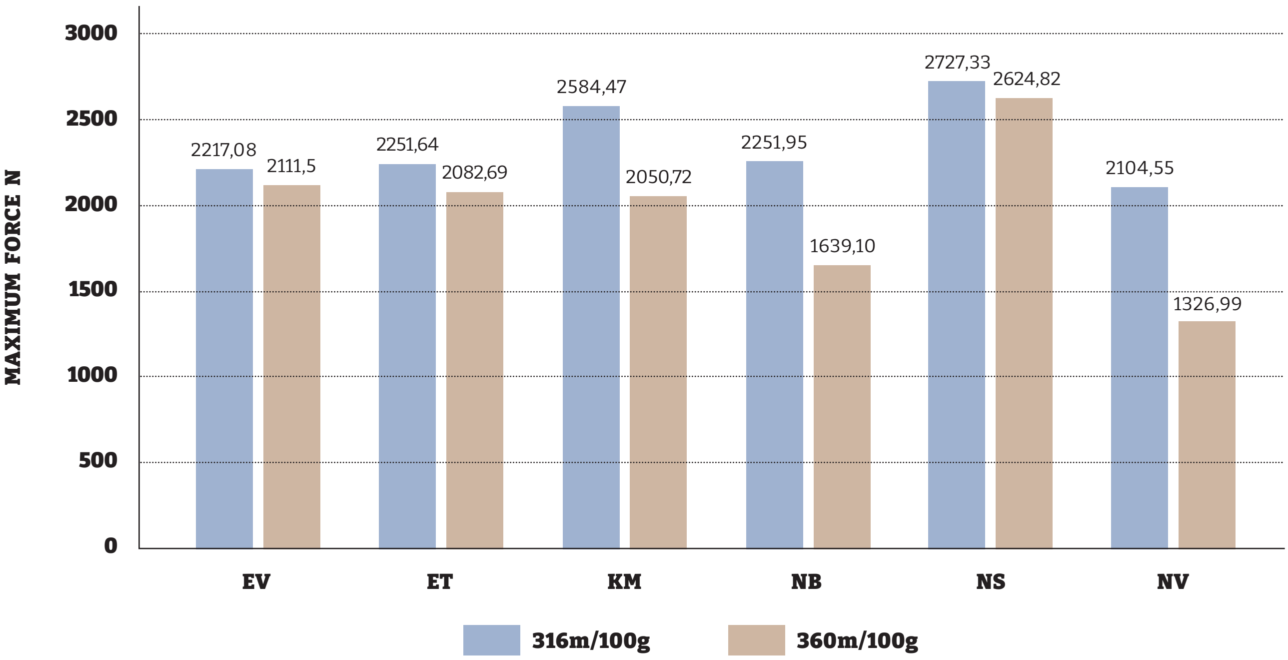


Figure 6. Tensile strength of yarns

While measuring the tensile strength, the maximum extension (%) of the yarns before breaking was also tested (Figure 7). Breaking elongation or extension refers to the elongation of the yarn corresponding to the tensile force. It describes the elongation of a yarn sample to the point of breaking and is usually expressed as a percentage.

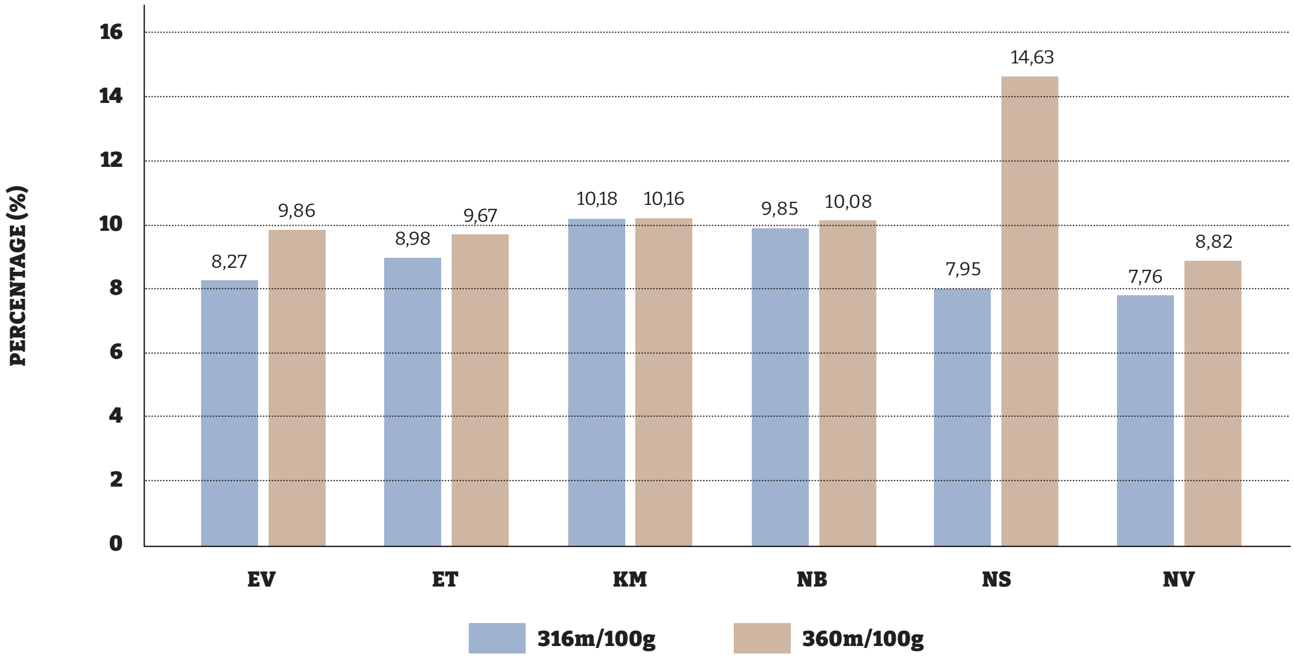


Figure 7. Yarn extension

Yarns (tensile strength) analysis

As can be seen in Table 3, the strongest yarns for both weaving and knitting were the Norwegian *Spælsau* sheep breed.

The biggest difference in tensile strength was found in yarns made from the wool of the Norwegian *Old Norse* sheep breed. The yarn for knitting was almost twice as weak as the coarser yarn. There is a very big difference in the tensile strength of the finer yarn in the Old Norse sheep and *Spælsau* sheep breeds, where yarn of same number spun from the wool of the *Old Norse* sheep breed is twice as weak as the yarn spun from the wool of the *Spælsau* sheep breed.

Both yarns of the Estonian Whitehead and Blackhead sheep breeds were relatively uniform in strength.

The elongation of the yarns before breaking was relatively similar for all yarns: stretching 8-10%. The finer yarn for knitted products spun from the wool of the *Spælsau* sheep breed was completely different, stretching over 14% before breaking.

Fabric testing

Fabrics are produced for very different purposes, with their own specific quality requirements. The chemical composition and physical structure of textiles determines whether they are suitable for a specific purpose. As consumers in modern society become more and more aware of and demanding regarding the properties of textile products, it also increases the necessity of testing textile materials. Determining fabric properties using measurable units, and analyzing the conditions affecting the properties, helps to more consciously manufacture fabrics that are well-suited for a specific purpose and meet the consumer's expectations.

Developments in textile technology, together with the increasing awareness of consumers, have made it necessary for the properties of materials to be unambiguous and for products to be consumed over a long period of time. Understanding the principles of testing procedures and competent interpretation of the obtained results continue to be very important.

Fabric testing plays an important role in ensuring product quality, ensuring compliance with standards and evaluating the appearance of textile materials. It provides information about the physical and functional properties of the fabric. Physical properties are those that characterize the physical structure of the fabric, such as density (thickness), width, weight, line density, etc. Functional properties are those that express the fabric's resistance to force, processing, or use: attributes such as strength, abrasion resistance, pilling and colour fastness, etc. Functional properties are often influenced by the physical properties of the fabric. While functional properties are often paramount in product development, aesthetic properties such as fabric touch and drape are just as important in the design process. In some cases, there is a compromise between functional and aesthetic properties, with decisions made based on aesthetic factors that can increase the functionality of the product at the same time.

It is very important to predict the functionality of the fabric through testing. Knowledge of fabric testing and functional analysis helps to solve consumer problems related to textile products and develop a product with properties that are the most suitable for consumers' needs.

Within the framework of the project, several different tests were carried out to determine the physical properties of fabrics. There were 24 fabrics to be tested from 6 different sheep breeds: 6 woven and 6 knitted (one from each breed), and felted versions of each of the different fabrics (12 in total).

Weight of Fabrics

The density of the fabrics was measured according to the standard EVS-EN 12127:2000. 10 x 10 cm size test pieces were cut out of the fabric samples, weighed and the arithmetic mean was calculated. Figure 8 shows the results of weighing both unfelted and felted fabrics. The unit of measurement is the weight of a square meter (g/m2).

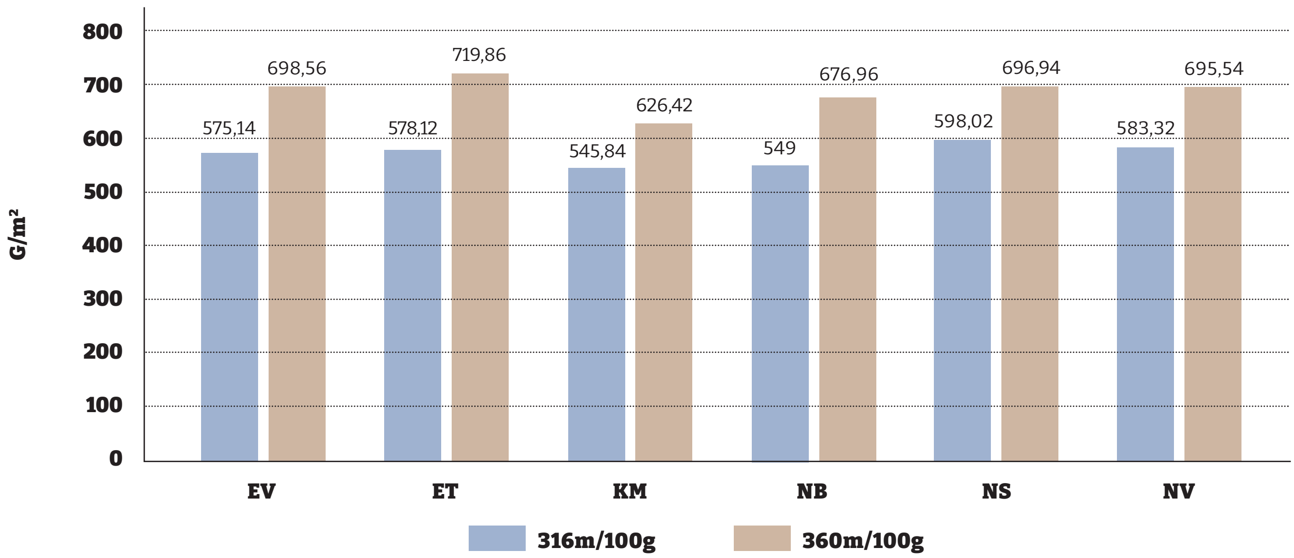


Figure 8. Mass per square meter of woven fabrics

The weight of the woven fabrics is relatively similar to the wool of the sheep breed used. This is quite expected, because yarns made with the same spinning technology and fabrics with the same weaving technology were used in the production. Felting made fabrics denser and heavier in a relatively similar way.

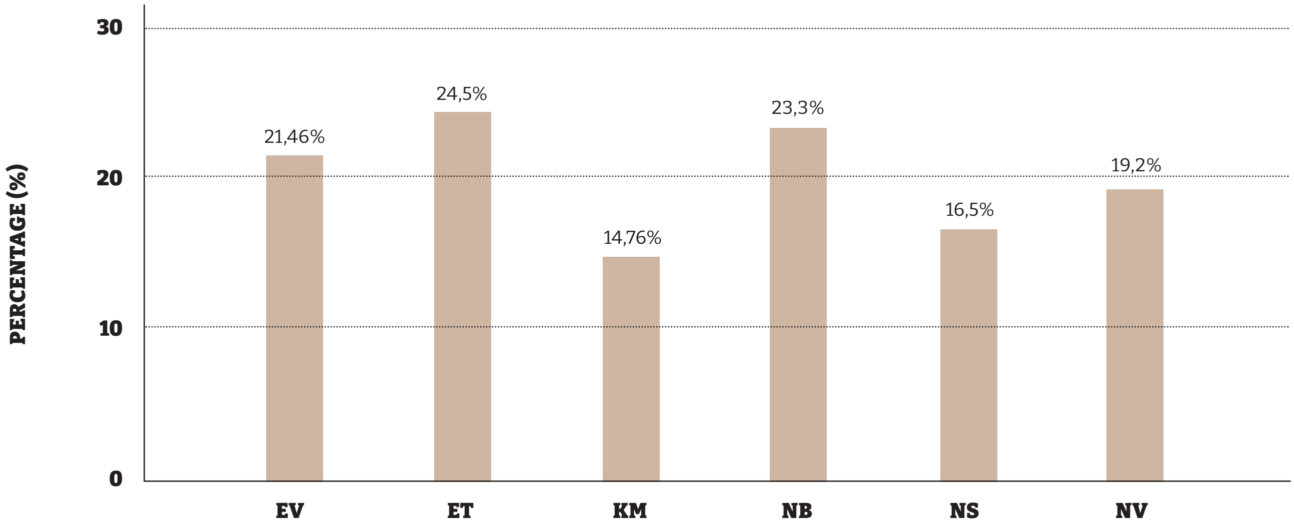


Figure 9. Increase in fabric weight after waulking

Figure 9 shows the percentage of felting of the woven fabrics of different sheep breeds, which ranges from 15-24% – the woven fabric of the Estonian Blackhead sheep breed is the most felted and the woven fabric of the Kihnu country sheep is the least felted.

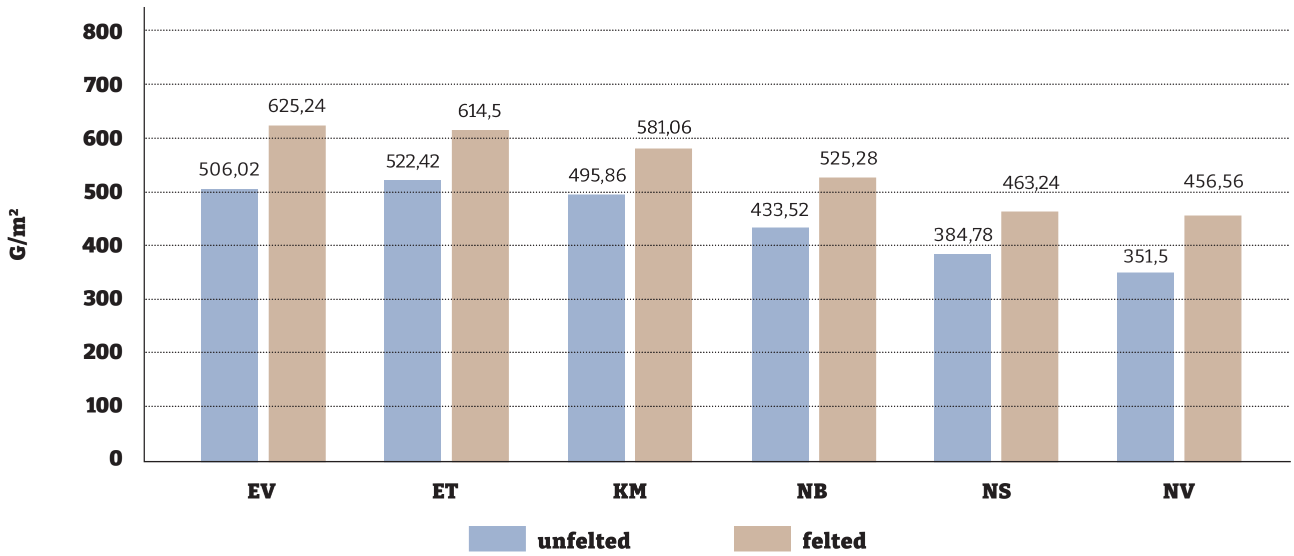


Figure 10. Mass per square meter of knitted fabrics

Figure 10 shows that the weights of different knitted fabrics vary significantly more. Fabrics made from the wool of Norwegian sheep breeds are lighter than fabrics made from the wool of Estonian sheep breeds.

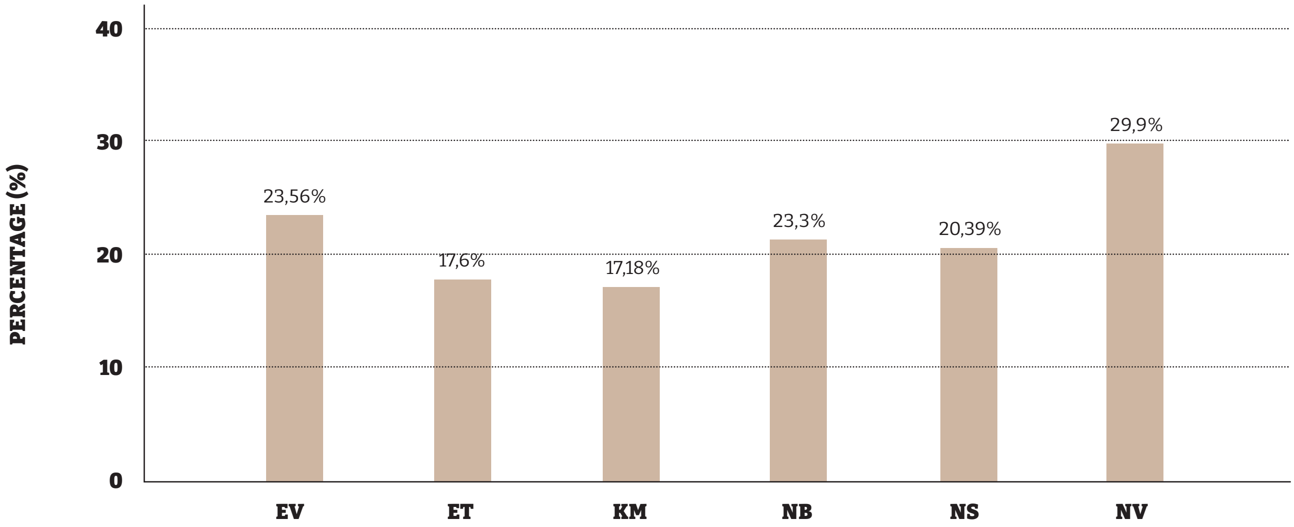


Figure 11. Increase of fabric weight after felting

The felting of the knitted fabrics is more or less equivalent to that of the woven fabrics (Figure 11), with all being in the 17-30% range. The Norwegian sheep breed *Old Norse sheep* felted best among the knitted fabrics, while the Estonian Blackhead woolen fabric skewed the most from the woven fabrics, and the least from the knitted fabrics.

Fabric breathability

Air permeability is understood as the moving amount of air flow passing perpendicularly through the fabric under specific conditions (size of the tested surface, air flow, pressure and time). The principle of the test is to measure the air flow at a certain pressure passing through the fabric perpendicularly in a specified area for a specified period of time. Air permeability has often been used in textiles and clothing to evaluate and compare the 'breathability' of these fabrics. Air permeability is not the same as wind resistance. Wind resistance affects the behavior of a material exposed to dynamically fast-moving air (wind) conditions. Air permeability describes the behavior of a material when exposed to slow-moving air.

Air permeability is expressed as the amount of air that moves (m^3/min) through a conditioned fabric attached in a fixed position at a specified pressure per unit area of the fabric (cm^2) when the air pressure is different on one side of the fabric than the other.

The air permeability of the fabric is most affected by the structure and finish of the fabric, as the length of the air flow path through the fabric is influenced by these variables. Air permeability is affected by several properties at the same time, such as the fineness of the fibres, the coarseness and twist of the yarn, the density of the yarns in the fabric, the finish and the thickness of the fabric.

In the case of woven fabrics, the air permeability is significantly affected by the twist of the yarn. As the twist increases, the density of the yarn also increases and the diameter of the yarn decreases. This, in turn, reduces the coverage of the yarn, which increases breathability. The nature of the yarn and the knitting technology used affect the shape and form of the yarn, as well as the area between the yarn, allowing the yarn to move within the fabric structure. This mobility of the yarn can create air holes in the fabric, so the air permeability increases again. At the same time, yarns with a high twist can be knitted very close together, which reduces air permeability.

Air permeability testing

Air permeability was measured based on the standard EVS-EN ISO 9237:2000 (Photo 50). According to this method, it is possible to test woven and non-woven fabrics, airbag fabrics, blankets, furred and non-furred fabrics, knitted fabrics, and multi-layered fabrics. Fabrics may be raw, heavy, coated with polymers, laminated or otherwise treated.

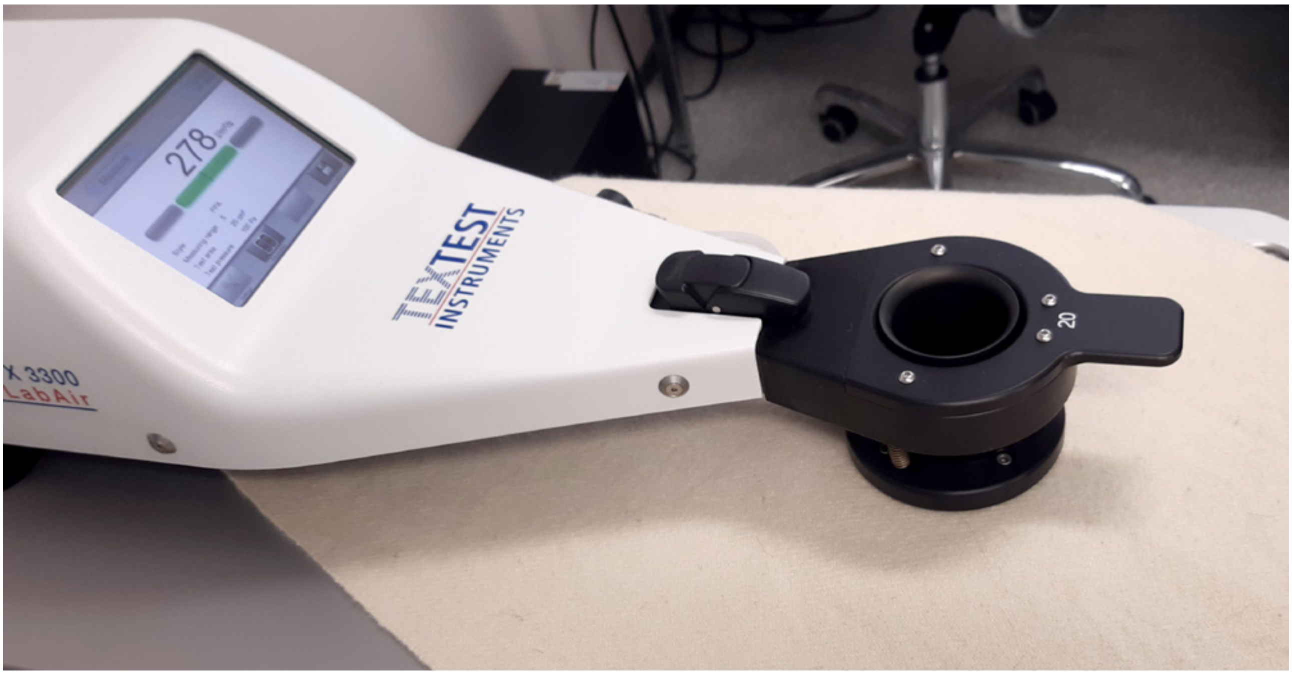


Photo 50. Measuring air permeability of woven fabrics. Photo by D. Tuulik

Individual specimens were not cut for testing, but all available material was used before specimens were cut out for other tests. Measurements were made from the available material in as many different places as possible, across the entire width and length of the fabric. In total, the air permeability of each fabric was measured at ten places, and the average value of the air permeability of each fabric was calculated.

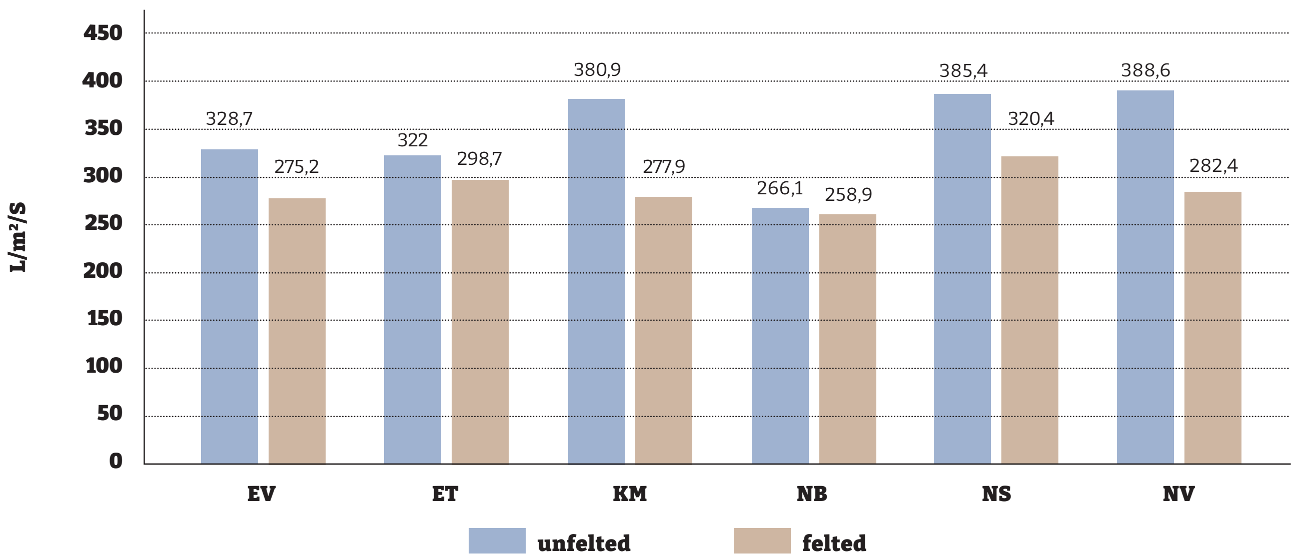


Figure 12. Air permeability of woven fabrics

Figure 12 shows the results of non-felted and felted fabrics. Woven fabrics made from the wool of the *Kihnu native sheep, Spælsau* and *Old Norse* sheep breeds let more air through. When comparing fabrics to each other, felting made the breathability more uniform.

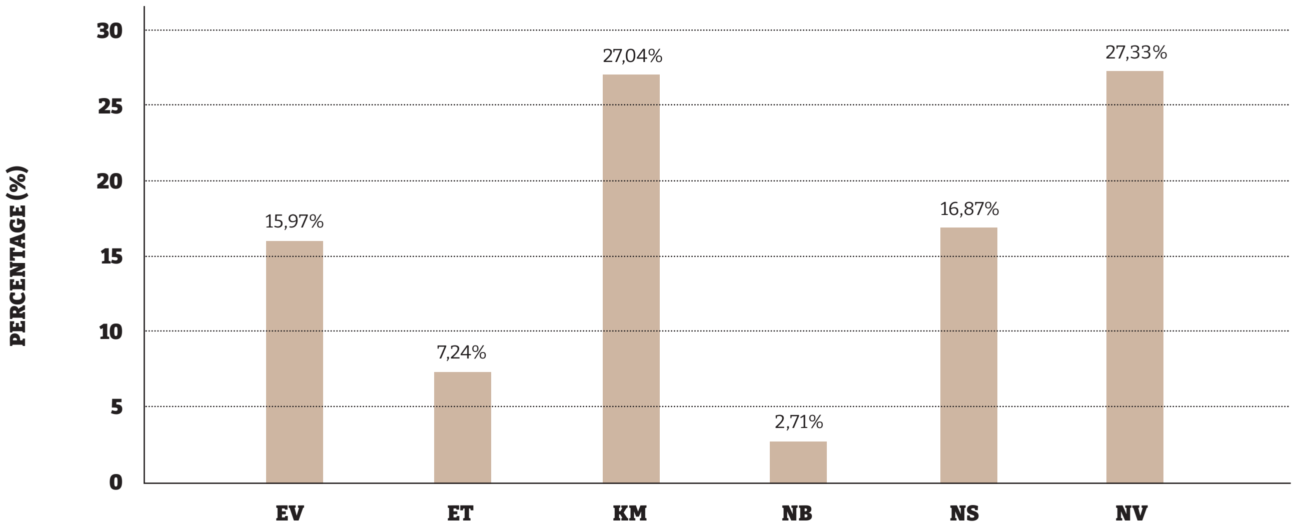


Figure 13. Reduction of air permeability of woven fabrics as a result of waulking

Figure 13 illustrates that felting has the most effect on the air permeability of woven fabrics made from the wool of the *Kihnu native sheep* and *Old Norse* sheep breeds, which is interesting since the weight change when comparing felted and unfelted fabric was rather small for these breeds. The fabric structure of double-coated fleece is much tighter after waulking.

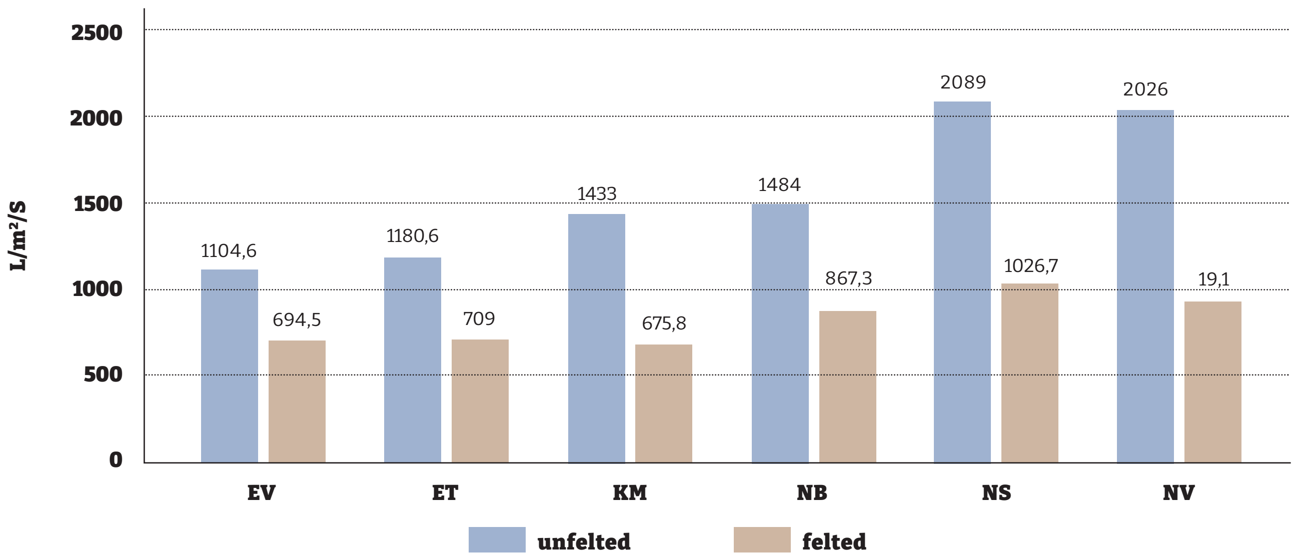


Figure 14. Air permeability of knitted fabrics

Figure 14 shows the results of non-felted and felted fabrics. Air permeability of knitted fabrics is higher in fabrics made from the wool of Norwegian sheep breeds. This is understandable, because the weight and density of these fabrics are lower than in fabrics made from the wool of Estonian sheep breeds.

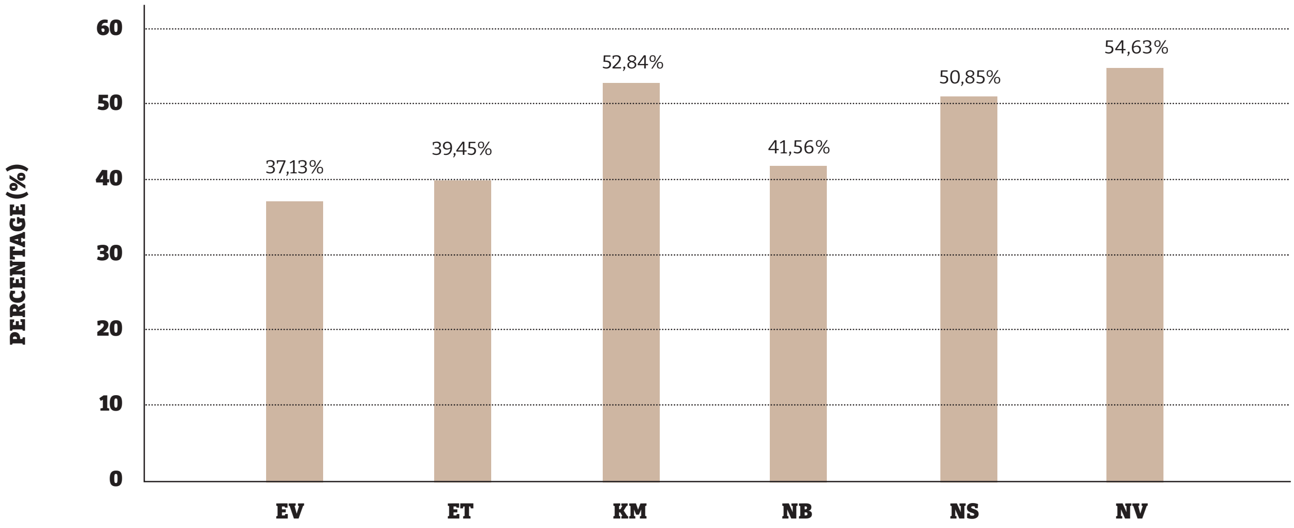


Figure 15. Reduction of air permeability of knitted fabrics as a result of felting

For knitted fabrics, felting significantly affected air permeability more than for woven fabrics. Felting knit fabrics made from the wool of the *Kihnu native sheep*, *Spælsau* and *Old Norse* sheep breeds reduced air permeability by more than half (Figure 15).

The behavior of fabrics made from the wool of the *Kihnu native sheep* is worth noting – neither the woven nor the knitted fabric felted well, while for both structures, the change (decrease) in air permeability was one of the largest.

Abrasion resistance

The durability of textile materials is understood as their ability to withstand the effects of several damaging factors during use, washing, cleaning, production, processing, transportation and storage. Factors affecting the wear of textile materials can be divided into mechanical: abrasion, repeated bending, stretching, compression, etc., physical-chemical: UV radiation from the sun, temperature, chemical reagents, etc. and biological: deterioration processes, etc. Wear is a multifactorial process where one or more factors may predominate. For most types of clothing, the main cause of wear is abrasion.

When two surfaces come into contact with each other, they move relative to each other, either in the form of sliding or abrasion. Abrasion describes the resistance to relative motion of two different surfaces in physical contact. It also takes less energy to rub smooth materials together. Since rougher surfaces have more surfaces that rub against each other than smooth surfaces, it is therefore necessary to apply more force to move them against each other. In other words, the abrasion is stronger and the wear resistance of the materials is lower when dealing with rough surfaces.

Abrasion strength characterizes the durability of the fabric, which in turn, is a contributing factor to the product's longevity. Although abrasion resistance is only one part of determining the quality and durability of a fabric, abrasion can manifest itself in many ways, making it difficult to relate the abrasion conditions of a fabric being worn or otherwise used to laboratory testing. Therefore, there are many different types of abrasion testing equipment, procedures, methods of evaluating wear resistance, and interpretations of test results.

Abrasion resistance is the ability of a material to resist surface wear as a result of rubbing against another material.

The abrasion resistance of fabrics depends on many factors, such as the type of fibre, the mechanical properties characteristic of certain fibres, the dimensions of the fibres, the structure of the weft and warp yarns, the construction and thickness of the fabric, and the finishing agents added to the fibres, yarns, or the entire fabric.

In general, there are two main approaches to evaluating abrasion resistance:

- Abrasion of the test fabric until a predetermined end point is reached, for example in the form of thread breakage or hole formation, while counting and recording the time or abrasion cycles required for this.
- Abrasion of the test fabric for a specified number of cycles, and subsequent evaluation of the change in appearance, loss of fabric mass, loss of strength, change in thickness or any other significant properties.

Abrasion resistance testing

During the abrasion resistance test, two different methods were used. The breakage of the yarns and the change in the measured weight have been observed. Consequently, the testing is based on three standards:

EVS-EN ISO 12947-1:2001
EVS-EN ISO 12947-2:2016
EVS-EN ISO 12947-3:2001

To perform the abrasion resistance test, three round test pieces were cut from each test material and placed on the upper test heads of the Martindale test rig. Three test pieces were cut from different places of the fabric. A woolen friction fabric was used on the lower test heads, which meets the parameters of the standard.

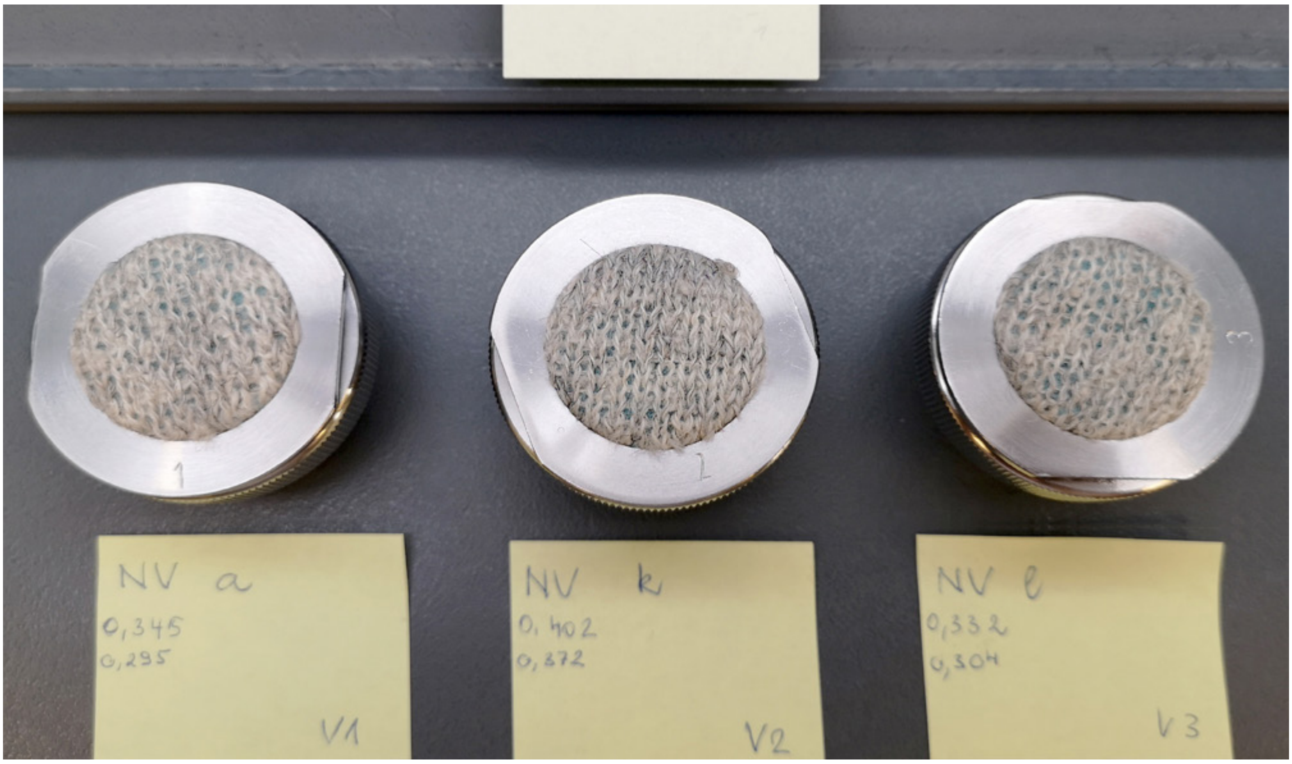


Photo 51. Visual assessment of abrasion resistance test specimens. Photo by M. Beilmann

When testing all fabrics, a weight of 595±7g (9 kPa) was used on the test heads, which according to the standard, is suitable for testing clothing fabrics.

The test specimens were checked for breakage of yarns every 5000 circles (Photo 51). The weight of the test pieces was fixed at the following circles: 0, 5,000, 20,000, 30,000, 40,000. If the test piece was resistant to more circles than 40,000, the test pieces were checked only for yarn breakage, and no weighing took place, because the resistance of the test pieces at higher circles would have been affected by removing them from the test head for weighing.

WOVEN	1	2	3	AVERAGE	BY BREED
EV	20 000	28 000	25 000	24 333	
EV felted	19 000	25 000	25 000	23 000	23 667
ET	25 000	25 000	25 000	25 000	
ET felted	28 000	25 000	25 000	26 000	25 500
KM	50 000	50 000	35 000	45 000	
KM felted	50 000 +	50 000 +	50 000 +	50 000	47 500
NB	50 000 +	30 000	25 000	35 000	
NB felted	15 000	23 000	50 000	29 333	32 167
NV	50 000 +	40 000	30 000	40 000	
NV felted	50 000 +	50 000 +	50 000 +	50 000	45 000
NS	35 000	30 000	40 000	35 000	
NS felted	24 900	20 000	21 800	22 233	28 617

Table 6. Abrasion test results of woven fabrics

The most resistant to abrasion were woven fabrics made from the wool of the *Kihnu native sheep (Table 6)*. Fabrics made from the wool of the Old Norse sheep breed were also very durable. Felted fabrics spun from the wool of both sheep breeds did not break even after 50,000 circles. A "+"-sign after the number means that testing could have continued because the test fabric had not yet broken. Fabrics made from the wool of the Estonian Whitehead sheep breed were the least resistant. Non-felted and felted fabric from the same breed of sheep resisted abrasion similarly.

The values of the abrasion resistance tests performed during this study are high. As a result, there may be a desire to compare test results with furniture fabrics, but this would not give a correct comparison. For this study, the materials were tested with a suitable weight for clothing fabrics (9kPa), for testing the furniture fabrics, a higher weight is used (12kPa). In order to assess the suitability of materials as furniture fabric, the research should be continued, and tests should be carried out. After that, it is possible to assess whether the abrasion resistance of the tested woolen fabrics is suitable for general domestic use (15,000 – 25,000), heavy-duty use/everyday use (25,000 – 30,000), or would be suitable for use in public spaces, where the furniture's abrasion resistance indicators must be higher.

The most resistant to abrasion were knitted fabrics made from the wool of the *Estonian Whitehead (Table 7)*. Fabrics made from the wool of the *Kihnu native sheep* breed were also very durable. Some samples of felted fabrics spun from the wool of both sheep breeds did not break even after 80,000 circles. Fabrics made from the wool of the *Norwegian Blæset* sheep breed were the least resistant. The Norwegian yarns were made with a slightly different technology and were slightly finer, which is why the strength of Estonian and Norwegian knitted fabrics

KNITTED	1	2	3	AVERAGE	BY BREED
EV	80 000 +	80 000 +	75 000	78 333	
EV felted	50 000	80 000 +	80 000 +	70 000	74 167
ET	80 000	80 000 +	80 000	80 000	
ET felted	48 400	40 000	35 000	41 133	60 567
KM	70 000	80 000 +	30 000	60 000	
KM felted	75 000	80 000	40 000	65 000	62 500
NB	55 000	35 000	65 000	51 667	
NB felted	25 000	45 000	36 500	35 500	43 583
NV	40 000	45 000	25 000	36 667	
NV felted	50 000	55 000	50 000	51 667	44 167
NS	50 000	40 000	50 000	46 667	
NS felted	55 000	50 000	50 000	51 667	49 167

Table 7. Abrasion test results of knitted fabrics

were slightly different as well. Non-felted and felted fabric from the same breed of sheep resisted abrasion quite similarly, except samples made from the Estonian Blackhead wool, where unfelted samples were much stronger than felted samples. The big differences in the results of different samples point to unevenness in both yarn and textile structure. In this case, the unevenness was greater in knitted textiles. This can be affected by the textile structure: while in woven textiles the fabric structure compensates for the unevenness of yarns, in knitted fabrics, the uneven yarn affects the strength of the fabric much more. Yarn made from double-coated wool consists of long fibers which better hold the yarn and fabric structure together (Photo 52).

Again, it is interesting to note that fabrics woven from the wool of the *Estonian Whitehead* sheep breed were the weakest among the woven fabrics, and at the same time, the knitted fabrics were the strongest among the knitted fabrics.

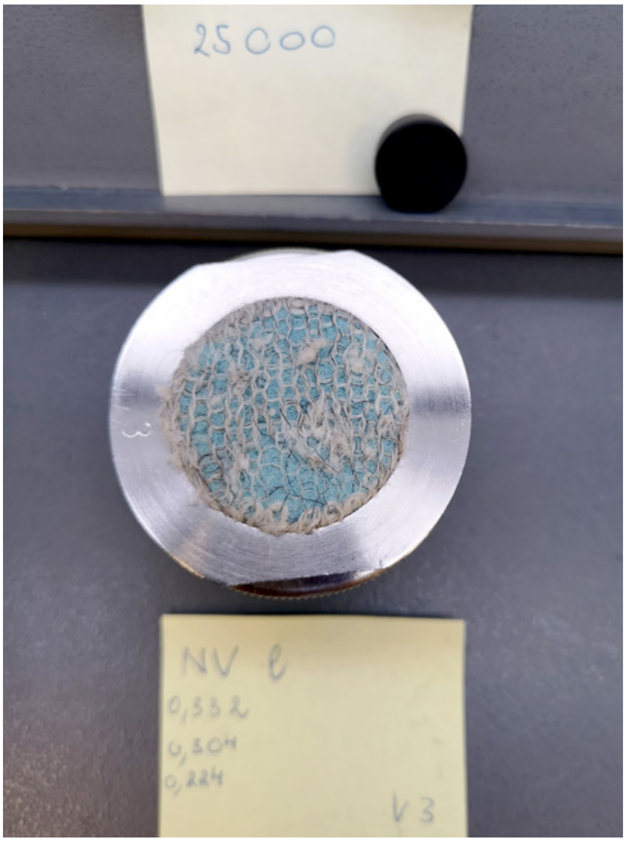


Photo 52. Visual assessment of Old Norse sheep (Norwegian Villsau NV) knitted fabric after 25,000 circles. Photo by M. Beilmann

Pilling resistance

In the initial abrasion stage of textile materials, when there has not yet been a large fibre loss, a phenomenon called pilling occurs, which is when the surface of the material becomes lumpy.

Pilling resistance measures the pilling of the surface of the fabric. Friction occurs when fibre ends or broken ends of fibres become loose from the surface of the fabric, but still get stuck to fibres that are trapped in the material.

Pilling occurs when the fibre ends remain on the surface of the fabric, become frayed, break, and intertwine with other fibres. Eventually the tops break or fall off the surface of the fabric. Unfortunately, if one top breaks, new ones form at the same time, so the appearance of the fabric does not improve when worn. Measuring pilling resistance has a different meaning than measuring fabric abrasion resistance.

In addition to the formation of tops as a result of abrasion, unacceptable changes may occur, such as fading and lint on the surface of the fabric. The test methods also investigate such changes in the surface of fabric.

More than twenty different test methods have been developed to test the pilling resistance of the material. Determination of pilling resistance is generally done in two steps: pilling with laboratory test equipment and pilling evaluation. The formation of tops or similar changes in fabric is usually tested in a laboratory using equipment that simulates wear and tear. The test method used has a big effect on the appearance of the fabric when it becomes patchy. Different devices may produce different results because wear is simulated with different materials.

When the fabric goes through the selected method, a subjective or objective assessment of the fabric's surface quality is given. In the subjective assessment, the tested samples are compared visually with a given standard, which can be a fabric sample or photos of the fabric that show the degree of pilling. Pilling is evaluated on an arbitrary scale from 1 (severe pilling) to 5 (no change).

In some procedures, a different material is used to encourage the formation of tops, so pilling is more visible than with the regular method. The description of the pill is provided as a minimum.

Pilling resistance testing

The pilling resistance test is based on the EVS-EN ISO 12945-2:2020 standard. Each fabric was tested with two different abradants. In the first case, a bottom test head covered with the same material was used opposite the tested material, and in the second case, a wool abradant cloth was used on the bottom test head (the wool abradant fabric corresponds to the parameters of the standard ISO 12947-1 is used). One type of test was performed with 3 specimens (Photo 53).

Photo 53. Pilling resistance testing. Photo by D. Tuulik

To perform the pilling resistance test, nine round test pieces and three woolen friction fabric test pieces were cut from each tested material.

When testing all woven fabrics, a weight of 415±2g was used on the test heads and a weight of 155±1g was used on the knitted fabrics. Changes in test specimens were checked and evaluated at the following circles: 125, 500, 1000, 2000, 5000, 7000. A suitable standard scale was used to evaluate the test results, based on the yarns and structure of the fabric. The results were evaluated on a 5-point scale from 1 to 5, where 5 means that no changes have occurred and 1 means that pills of varying sizes and densities cover the whole of the specimen surface.

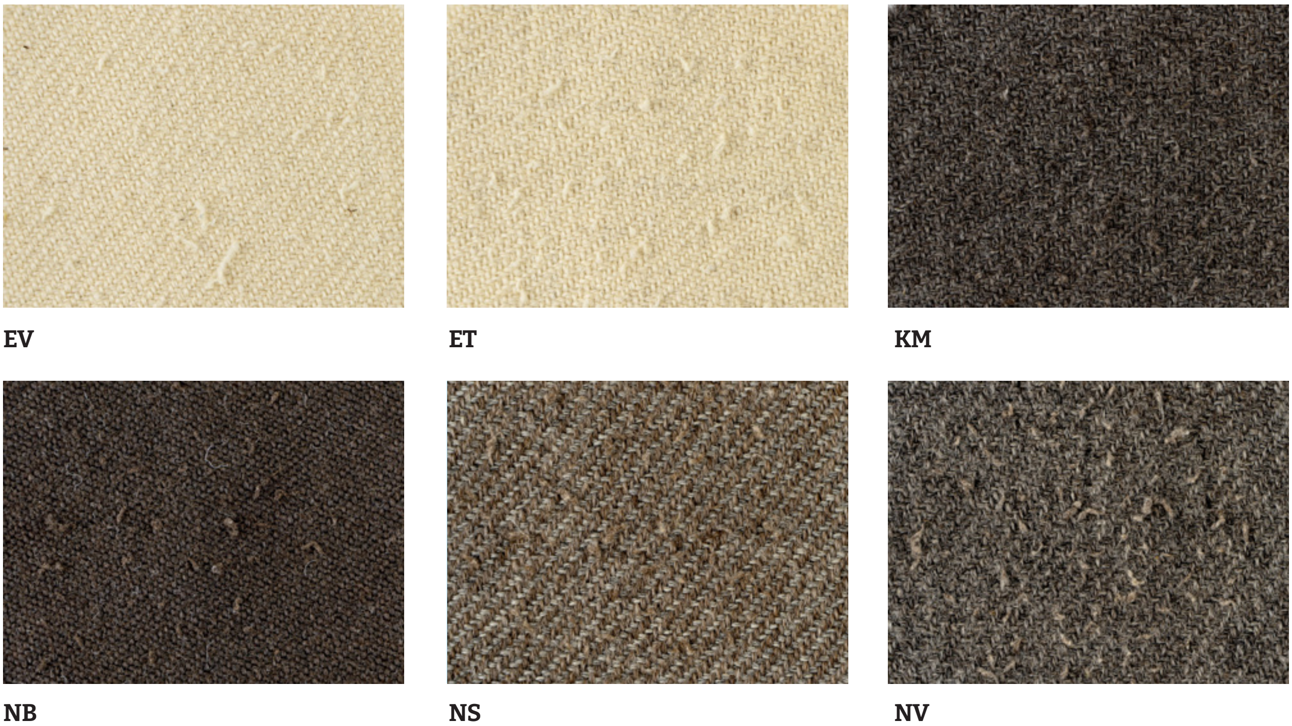


Photo 54. Pilling after 7000 circles (woven fabrics). Photos by M. Anton

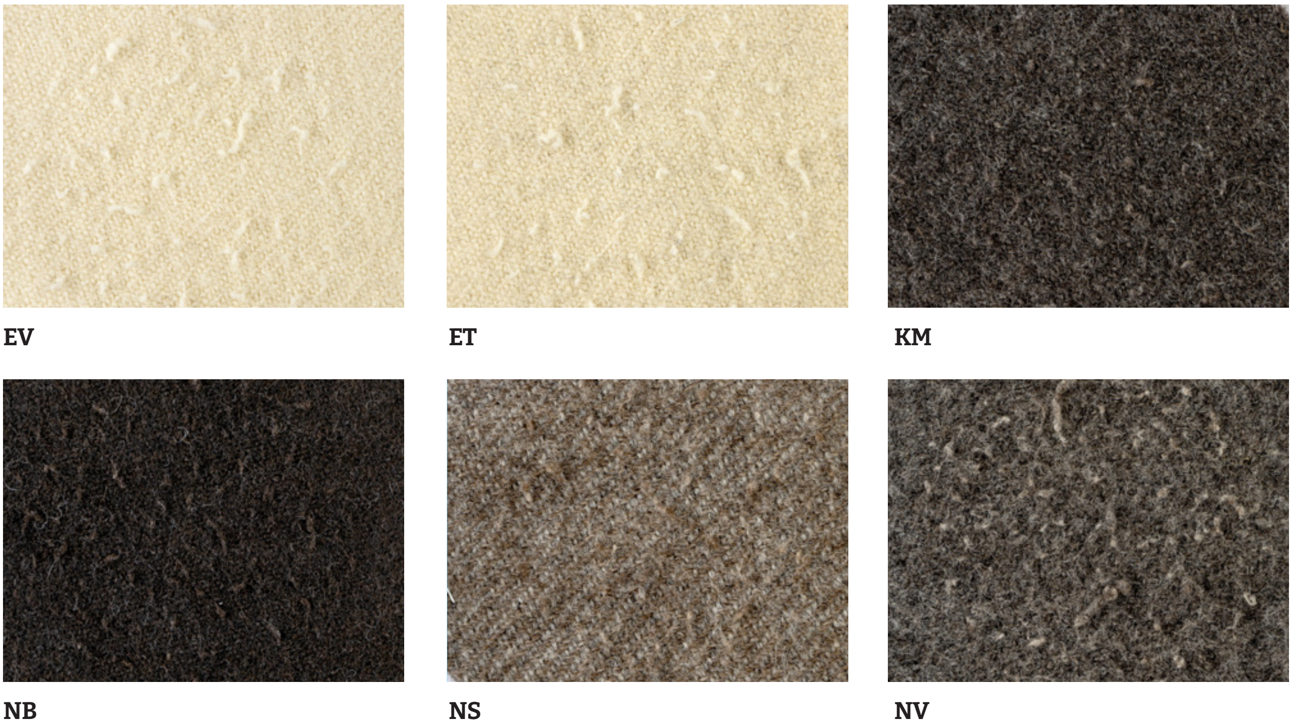


Photo 55. Pilling after 7000 circles (woven felted fabrics). Photos by M. Anton

All test specimens became covered with pills relatively quickly, some faster, some slower. For example, felted woven fabric made from the wool of the *Kihnu native sheep* became stuffed more slowly (Photo 55 KM). The most stuffed fabric was the one woven from the *Estonian Blackhead* sheep breed. The pilling was the least on the woven fabric of the *Norwegian Blæset* sheep breed, where the abrasion occurred against the special abrasion fabric. The change in the appearance of these test specimens is characterized by the fact that after a certain number of circles, the pilling began to decrease. That is, the pills appeared but started to fall off as the rpm increased.

Evaluating the fabrics by breed, the final result was the best on the woven fabrics of the *Norwegian Old Norse* sheep breed.

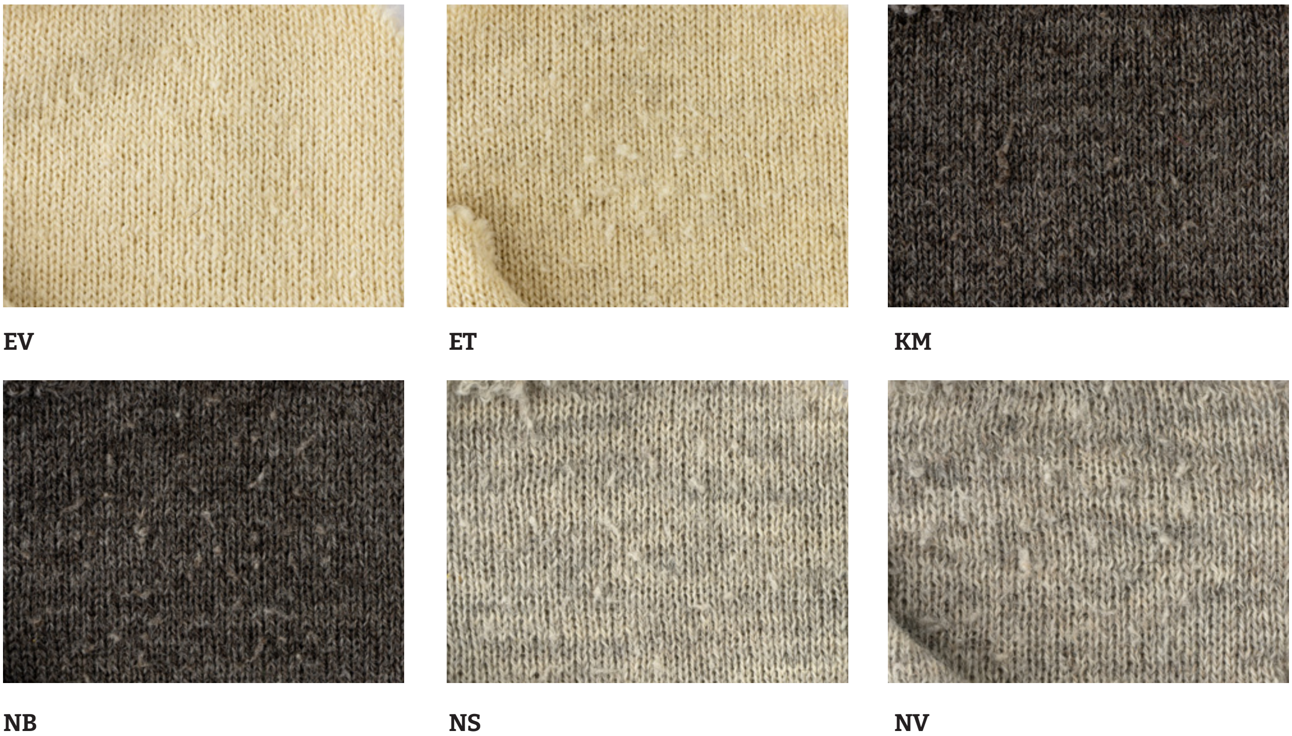


Photo 56. Pilling after 7000 circles (knitted fabrics). Photos by M. Anton

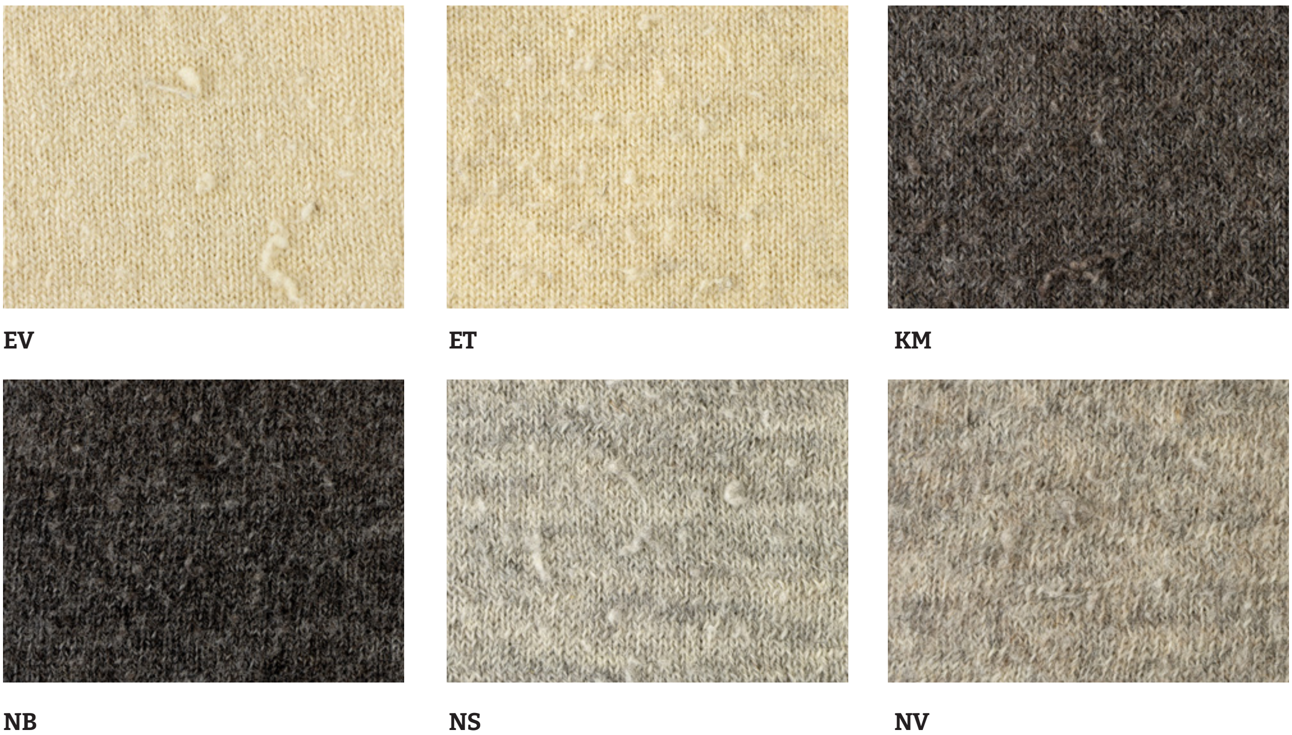


Photo 57. Pilling after 7000 circles (knitted felted fabrics). Photos by M. Anton

In general, knitted fabrics became less stuffy than woven fabrics *(Photo 56, Photo 57).* The less pilling were shown by fabrics woven from the *Estonian Whitehead* sheep breed, especially the unfelted fabrics (Photo 54 EV). The most pilling were felted fabrics from the wool of the *Kihnu native sheep* breed and the *Norwegian Blæset* sheep breed. While on woven fabrics, felted fabrics resisted pilling more poorly, on knitted fabrics it was the opposite – felted fabrics had less pilling than unfelted fabrics.

The pilling of both felted knit and woven fabrics was higher than unfelted fabrics.

When comparing the two cases – abrasion between the test fabrics themselves or the abrasion of the test fabric against the abrasion fabric – in the first case, the tops were larger and sparser and in the second case, smaller and denser. Therefore, when the tested fabrics rubbed against each other, tops were formed, which visually stood out more distinctly.

Fabric tensile strength

Tensile strength is the most important mechanical-physical property used to characterize the quality and strength of a fabric, which is why it is also the most tested property.

It is necessary to define the pulling force until the material breaks in two areas related to the properties of the materials: durability and safety. In other areas, such as maintainability, comfort and change in appearance, the procedures more closely mimic consumer use and do not test materials to failure, as normal use is rarely one that causes textiles to fail.

Tensile strength expresses the strength of a material under stress and is expressed by means of force. Tensile strength mostly refers to the behavior of fibres. Breaking force is the force required to tear the fabric. Elongation at break refers to the elongation of the fabric corresponding to the tensile force. It describes the elongation of a fabric sample to the point of failure and is usually expressed as a percentage.

The force applied to the fabric is equal to the energy required to break the fabric. Force is measured as the amount of mass required to make something happen. The tensile strength test is performed separately in the warp and weft direction of the fabric. At the same time as the tensile strength, the extension of the fabric, i.e., the elongation at break, is also determined.

Elongation is the change in length of a material when stretched. If the fabric with initial length l0 is stretched along the axis, it will lengthen by a certain length dl. In this case, the stretch of the fabric is dl/ l0, i.e., the length of the stretched fabric in relation to the original length. This is also called fabric stretch. The result is expressed as a percentage of the original length of the fabric sample or in millimeters.

The location of fabric sampling is very important. It is impossible to find two yarns and fabrics with exactly the same properties, so it is important to have a diverse range of fabric samples. Due to the way the fabric is manufactured and finished, the fabric properties may differ at the edges of the fabric and in the middle of the fabric. When testing tensile strength, it is necessary to exclude taking samples from the edge of the fabric, because this area often has slightly different properties than the rest of the fabric. This condition is sometimes referred to as the 10% rule: 10% of the width of the fabric is added to each side of the edge of the fabric – no samples are cut from this area; it is limited to the middle part of the fabric roll. In addition, the samples should not be cut directly next to each other. All the mentioned rules are very important in durability tests, because the results of the tests are affected by the construction of the yarn, the weave of the fabric, the density of the fabric and the finish.

When taking samples, it must be done in a way where each sample contains as many different yarns as possible. To do this, the pieces should be cut so that they do not contain the same yarns in either the weft or warp direction, depending on whether the test is performed for a weft or warp result.

Fabric tensile strength testing

The tensile strength testing is based on the standard EVS-EN ISO 13934-1:2013. To perform the test, five sets of test specimens were cut from each test material. One set of test specimens consists of two test pieces, the longer side of one of the test pieces is in the direction of the warp and the longer side of the other is in the direction of the weft.

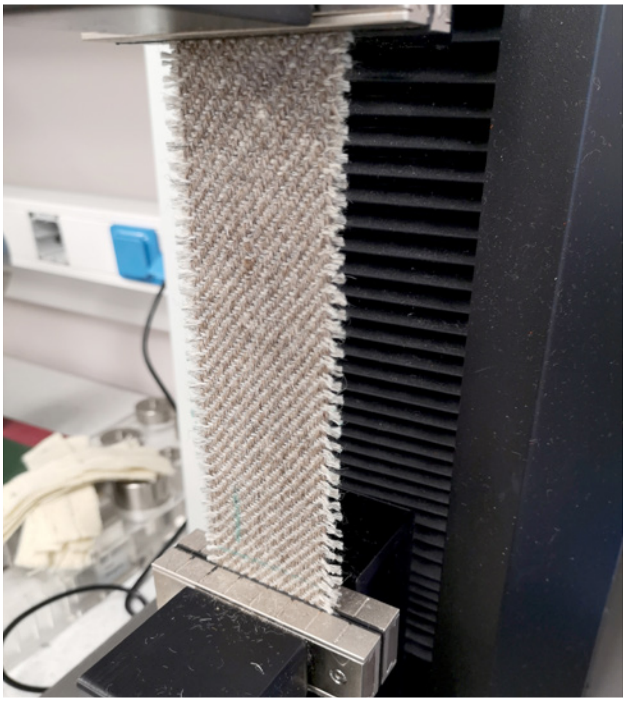


Photo 58. Testing tensile strength of woven fabric. Photo by M. Beilmann

When cutting the test pieces, the sets were placed as differently as possible so that the overlap of the warp and weft yarns was minimal, considering the dimensions of the material. The longer sides of the woven fabrics were fringed on both sides by 0.5 cm and the test pieces of the knitted fabrics were cut 1 cm narrower. Additionally, the lengths of the test pieces of woven fabrics and knitted fabrics differed based on the elongation of the material. The test piece for woven fabrics was cut with dimensions of 30x6 cm, and the test piece for knitted fabrics was cut to 20x5 cm.

During the test, one end of the test object was fixed between the upper and the lower gripper (Photo 58). Next, the device was started and began measuring the tensile strength. The test results were automatically saved in the program and the average values of tensile strength and elongation in both warp and weft directions are displayed below.

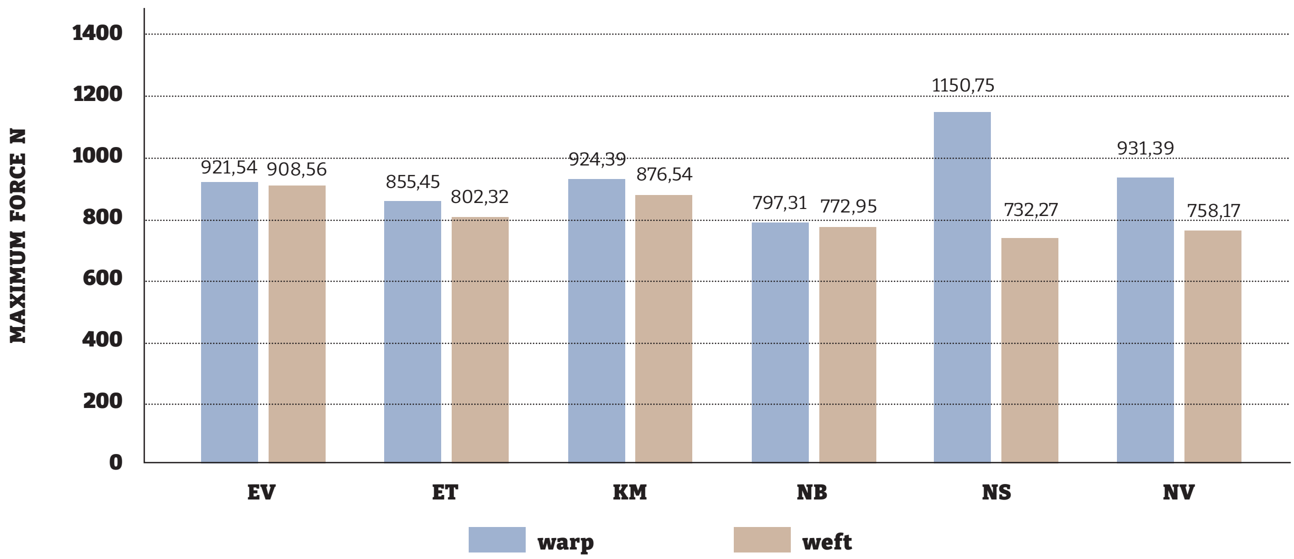


Figure 16. Tensile strength of unfelted woven fabrics

The tensile strength was relatively equal for all fabrics (Figure 16), with a slightly higher strength in the warp direction than in the weft direction. The exception was fabrics from the *Norwegian Spælsau* sheep breed, which were significantly stronger in the direction of the warp than other fabrics.

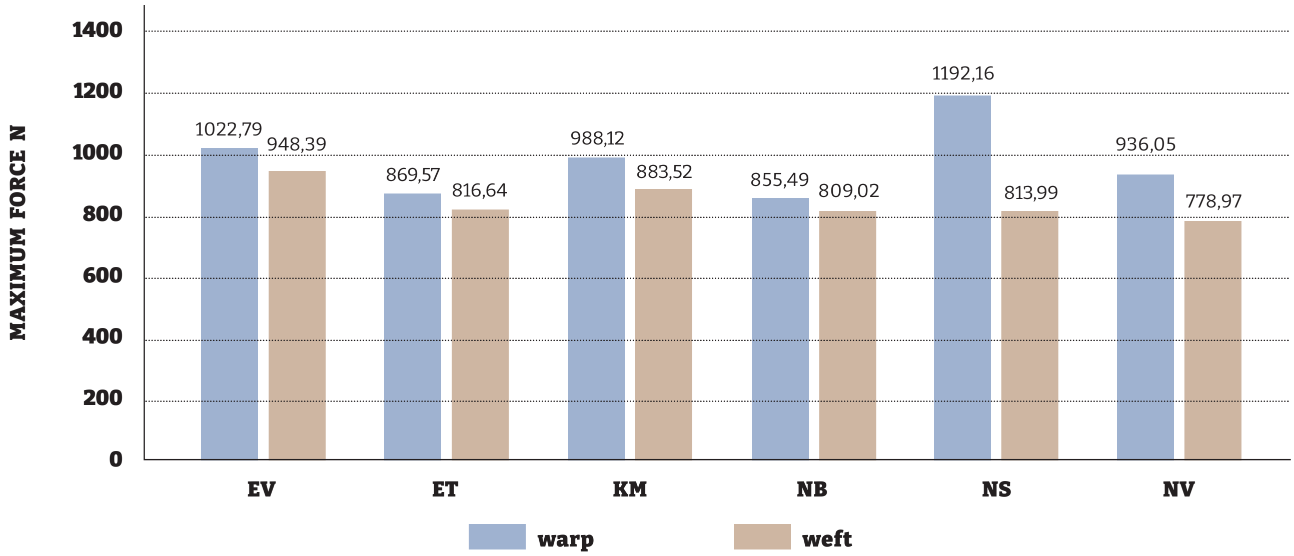


Figure 17. Tensile strength of felted woven fabrics

Felting did not significantly affect the tensile strength of woven fabrics, they remained proportionally the same (Figure 17).

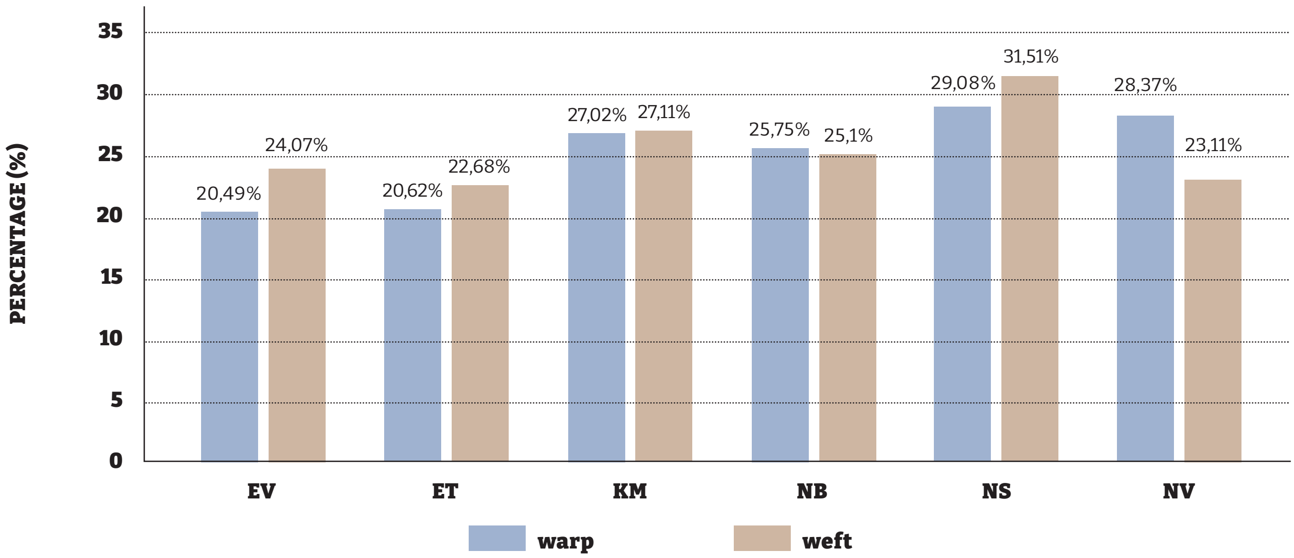


Figure 18. Elongation at rapture of unfelted woven fabrics

The elongation of the fabrics at the moment of breakage was between 20-30% for unfelted fabrics (Figure 18), proportionally matching the tensile strength results. The fabrics that stretched a little more than the others were also slightly stronger.

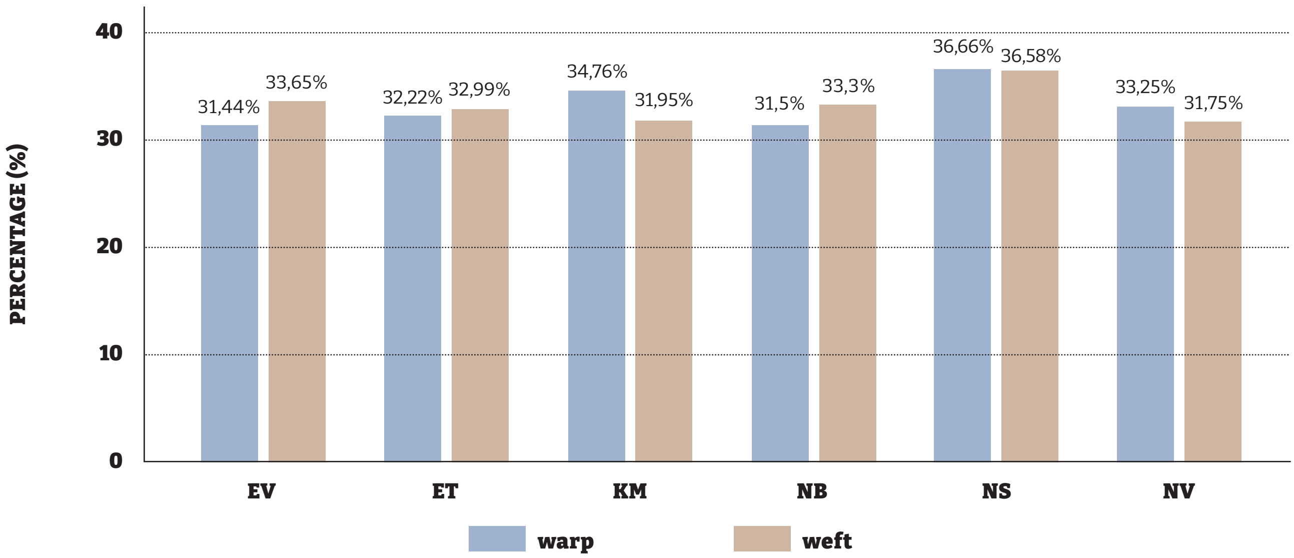


Figure 19. Elongation at rapture of felted woven fabrics

Felting made the elongation of the woven fabrics more uniform (Figure 19), increasing the elongation at breakage for all fabrics, ranging from 31-36%. Thus, the increase in elongation with felting was uneven – the elongation of fabrics from the *Estonian Whitehead and Blackhead* sheep breeds increased the most, and the elongation of fabrics from the *Norwegian Spælsau* breed increased the least.

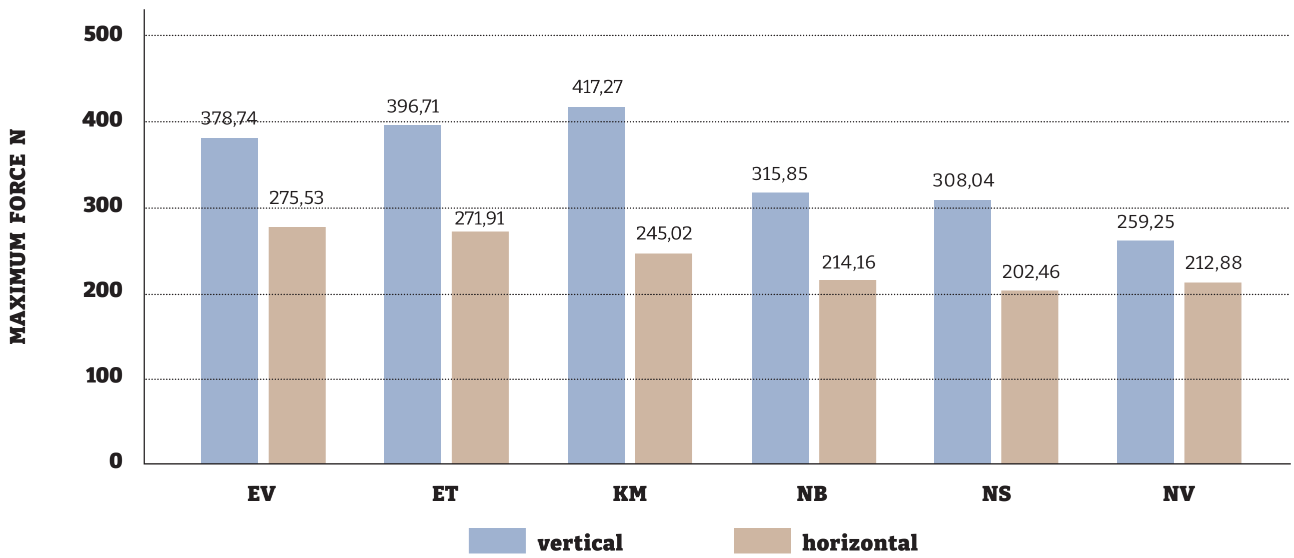


Figure 20. Tensile strength of unfelted knitted fabrics

The tensile strength of the knitted fabrics in the vertical direction was higher than in the horizontal direction for all fabrics (Figure 20). The tensile strength of knitted fabrics of Estonian sheep breeds was higher than that of Norwegian sheep breeds. The tensile strength varies more in the vertical direction than in the horizontal direction (Photo 59).

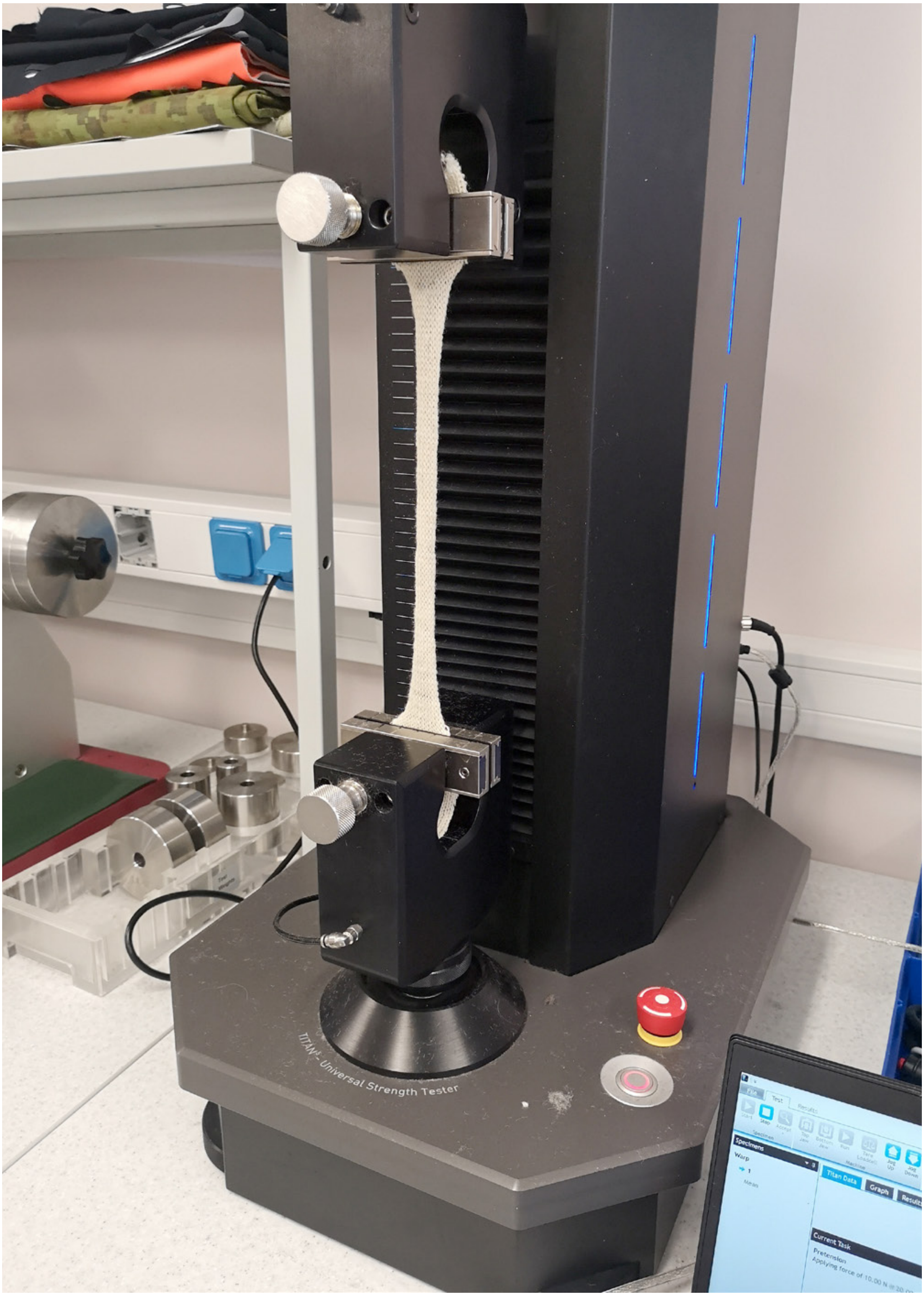


Photo 59. Testing tensile strength of knitted fabric in the vertical direction. Photo by Merje Beilmann

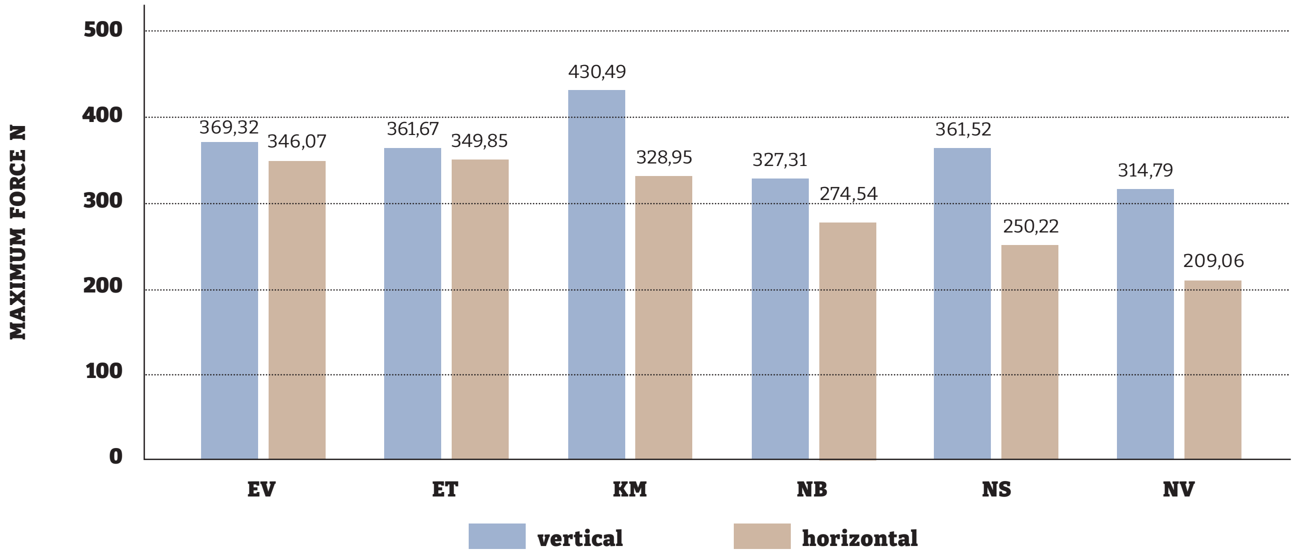


Figure 21. Tensile strength of felted knitted fabrics

Felting made the tensile strength of the knitted fabrics more uniform (Figure 21). The tensile strength of all fabrics increased more in the horizontal direction and remained relatively the same in the vertical direction compared to unfelted fabrics.

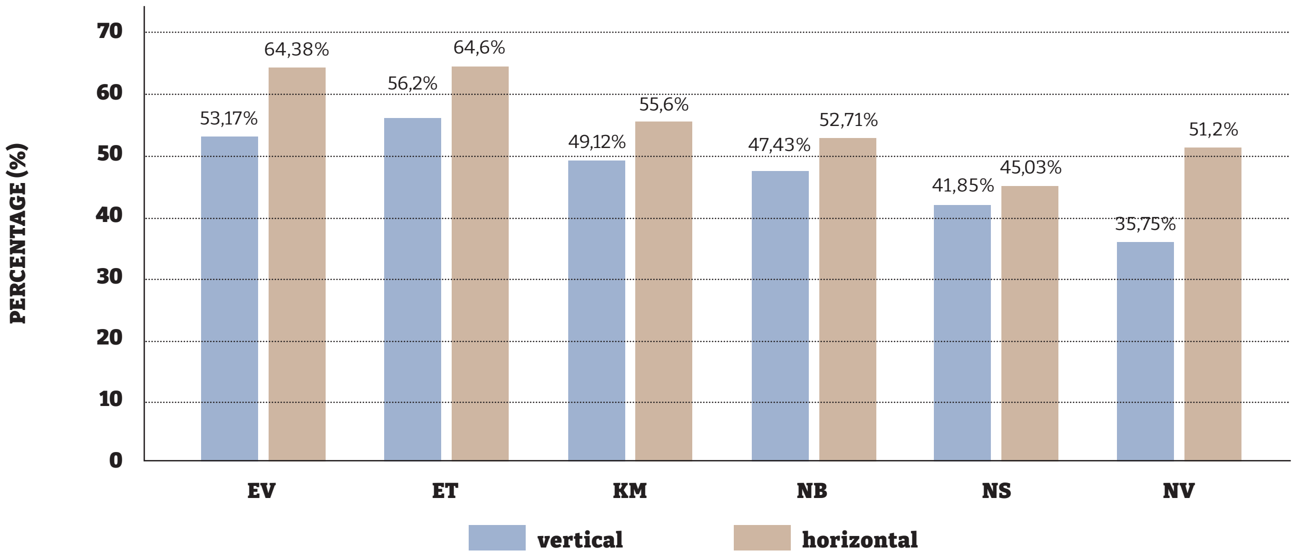


Figure 22. Elongation at rapture of not felted knitted fabrics

In the case of knitted and woven fabrics, the unfelted fabrics were stronger, elongated more when broken, and elongated more in the horizontal direction than in the vertical direction (Figure 22).

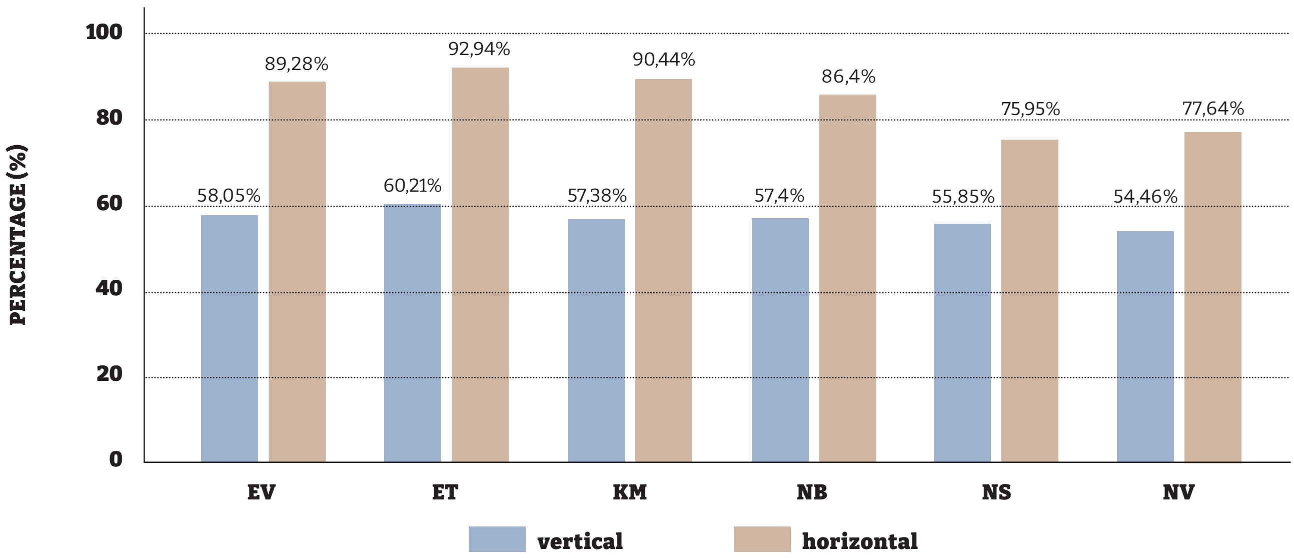


Figure 23. Elongation at rapture of felted knitted fabrics

Felting made the knitted fabrics more uniformly stretchable in the vertical direction, with all being close to 60% elongation at breakage (Figure 23). In the direction of the horizontal, the elongation became significantly higher, although the tensile strength became only slightly higher in these fabrics.

Tear strength

Tear strength is the force required to tear a fabric under certain conditions. Tear strength is especially important for fabrics that are used to make textile products that require durability. There are several different methods for determining tear strength.

The Elmendorf method is used to determine the average force required to produce a single tear starting from an incision in the woven fabric. The energy of the falling pendulum causes a tear (or other deformation) in the test fabric. Its extent is estimated by the loss of energy compared to the energy of the falling pendulum without the use of the test fabric. Depending on the type of fabric used and the standard, a weight attached to the pendulum can be selected.

The tear test can also be performed with a conventional tensile device. The force used to tear the test fabric is calculated from the average tensile force. In a conventional tensile test, the force applied to tear an undamaged test fabric is measured. In the tear strength test, the force is not applied uniformly, but is concentrated in the direction of a deliberately created incision.

The force recorded in the tear test is irregular. The result indicates the force required to initiate tearing and subsequently to continue tearing. For woven fabrics, the results are calculated separately for the warp and weft direction.

The main influences on tear strength are yarn properties and fabric structure. The nature of fabric tearing is different from linear pulling and depends on the ability of individual yarns to displace. Therefore, fabrics with a sparser structure, where the yarns can shift and pile up under force, promote greater tear strength. By increasing the density of the yarns in the woven fabric, the tear strength is reduced because the yarns break individually since they are close together and there is no possibility of displacement.

A tightly woven fabric tears more easily than a loosely woven fabric because the tearing force is spread from yarn to yarn as a linear force with one yarn restricting the freedom of movement of another yarn.

Tear strength testing

Tear strength was tested only on woven fabrics, as the structure of knitted fabrics does not allow for the use of the same method and equipment.

Tear strength testing is based on the standard EVS-EN ISO 13937-2:2000. To perform the test, five sets of test pieces were cut from each test material. One set of test specimens consists of two test pieces, the longer side of one of the test pieces was in the direction of the warp and the longer side of the other was in the direction of the weft.

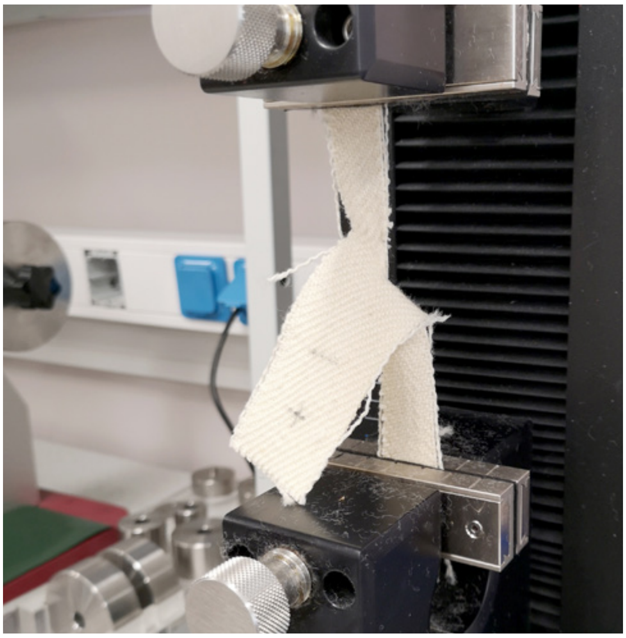


Photo 60. Testing tearing strength of woven fabric. Photo by M. Beilmann

When cutting the test specimens, the sets were placed as differently as possible so that the overlap of the warp and weft yarns was minimal, considering the dimensions of the material. The test specimens were marked with a point up to which the tearing of the device must occur.

During the test, one side of the test object was fixed between the upper and the lower gripper (Photo 60). Next, the device was started and the test was stopped when the tear had reached the marked point.

The test results were automatically saved in the program and the average values of the tear strength in both warp and weft directions are displayed below.

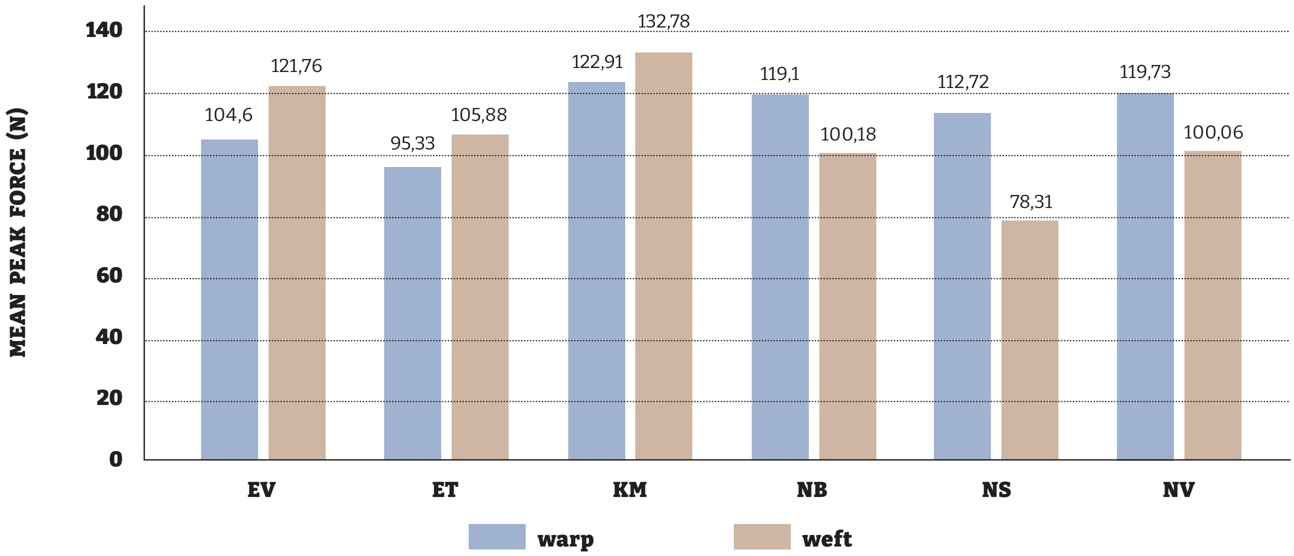


Figure 24. Tearing strength of woven fabrics

The tear strength of unfelted fabrics was unevenly distributed – the results were more uniform in the direction of the warp than in the direction of the weft. The most force was needed to tear in both warp and weft directions for fabrics woven from *Kihnu native sheep* wool (Figure 24). It is worth noting the fact that Estonian sheep wool fabrics had a higher tearing strength in the weft direction than in the warp direction, whereas for all Norwegian sheep wool fabrics, the results were completely opposite – the fabrics were stronger in the warp direction than in the weft direction.

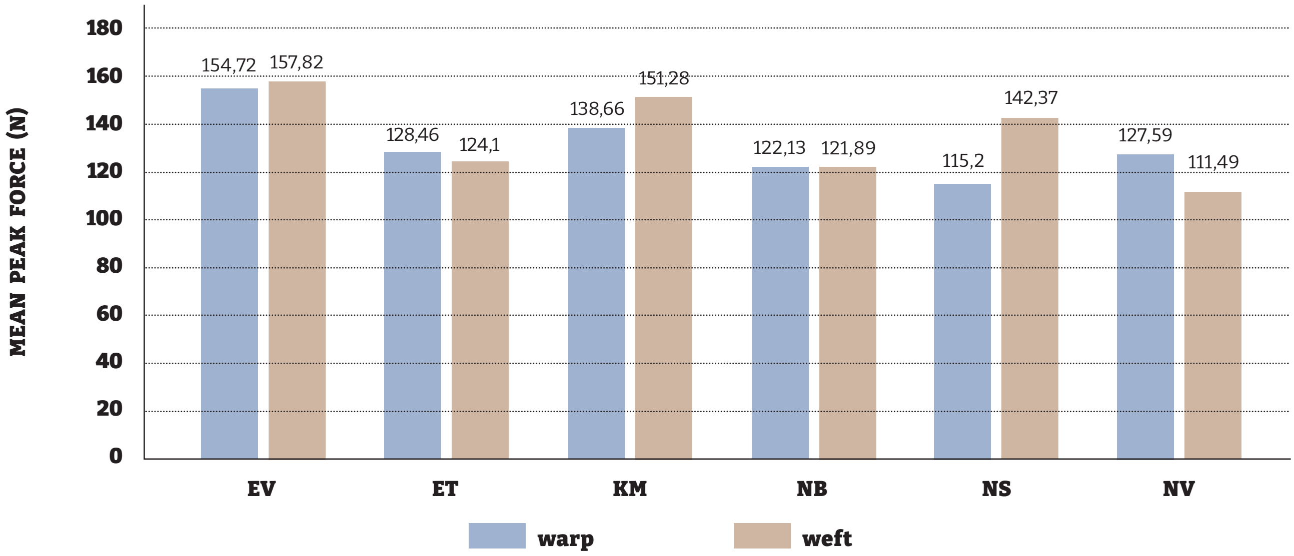


Figure 25. Tearing strength of felted woven fabrics

Felting made the tearing strength of the fabrics more uniform in the warp and weft direction (Figure 25). All fabrics became more or less strong as a result of felting. The strength increased more in the weft direction, while in the warp direction the strength of Norwegian sheep wool fabrics remained the same compared to unfelted fabrics.

Stretch and elasticity

Fabric stretches under any force applied to it. In tensile strength testing, force is applied to the material until the fabric tears, and the force and elongation at the moment of tearing are recorded. Tensile elongation is one indicator of durability. The fabric's ability to stretch under the influence of force is discussed here, but this elongation is considered as a measure of comfort. The force that is applied to the fabric to achieve the required stretch is significantly less than the force that can be used to tear the fabric. By measuring how a fabric reacts to a small amount of force, comfort elongation is a better measure of comfort than tensile elongation. Tensile stretch is almost always associated with tearing, and not with stretch in terms of comfort. In the production of sewing products, as a rule, the materials are not subjected to very large loads, but the materials are still deformed under tension and weight, changing their dimensions and shape.

Initially, the fabric stretches as a result of the straightening and then elongation of the yarns in the direction of the applied force. The elongation of the fabric is directly dependent on the density and size of the yarn loops. The density of the stitches, in turn, depends on the cohesion and density of the fabric; however, the size of the loops depends on the thickness, softness, stretching during finishing, etc. of the yarns. As the density increases, the elongation of the fabric also increases. Since the weft yarns are curlier than the warp yarns, the elongation of the fabric is also greater in the direction of the weft yarns than in the direction of the warp yarns. As the load increases, the fabric begins to elongate as a result of the yarns elongating. In this case, the elongation of the fabric already depends on the construction of the yarns – the twist, the fineness of the fibres, the orientation and the stretchability.

If the fabric elongates under the influence of weight and returns to its original position immediately after the load is released, it is called resilient elongation. Elongation is elastic if the fabric recovers its position within a certain period of time after the load is released. The remaining part of the elongation, i.e. the stretching of the fabric under the influence of load, is called plastic elongation. The greater the proportion of springy retraction in the total elongation of the fabric, the higher the quality of the fabric. This type of fabric wrinkles less, keeps the product's shape better and is more wear-resistant.

When different fabrics are stretched under the influence of the same force, their elongation can be different, and the total elongation of the part of springy, elastic and plastic elongation is also different. Under the influence of small loads, mainly elastic elongation is formed; under the influence of large loads, plastic elongation. When worn, the elasticity of the fabric decreases, which is why clothes lose their shape over time and wear becomes more visible.

When testing elastic fabrics, attention is paid to three indicators:

- Stretch under weight – this is understood as the stretch length of the fabric from its initial state when it is affected by a certain amount of load.
- Stretching force – defines how much force is needed to stretch the fabric over a certain distance.
- Ability to regain the former form of the fabric after release from the force of load.

The most important factor among them is the last one: achieving the previous form of the fabric. It can be used to determine whether the fabric is elastic or not.

The elongation of the fabric is expressed as a percentage, which is the difference between the original length and the length immediately after the weight is removed for a specified period of time.

Stretch and elasticity testing

The stretching and elasticity test is based on the instructions for the SDL Atlas device *Fryma Fabric Extensometer*.

To perform the stretch and elasticity test, three sets of specimens were cut from each test material. Each set consisted of two test pieces, one with the longer side in the warp direction and the other with the longer side in the weft direction. The test pieces of woven fabrics were cut to the size of 75x220 mm, and the test pieces of knitted fabrics were cut to the size of 75x90mm.

The measurement points of all test specimens were marked directly on the specimens, and the specimens were then measured with a metal ruler before and after stretching.

The test specimens were stretched on the device by fixing the edges of the test specimen between clamps (Photo 61). Weight was added to the device based on whether woven or knitted fabric was being stretched. A weight of 6 kg

Photo 61. Testing elongation of knitted fabric in the vertical direction. Photo by Merje Beilmann

was used for woven fabrics and a weight of 3 kg for knitted fabrics. The percentage of stretch was determined on the device and the elasticity was calculated after stretching the test piece. Before the measurement, the test body was in a free state for 10 minutes.

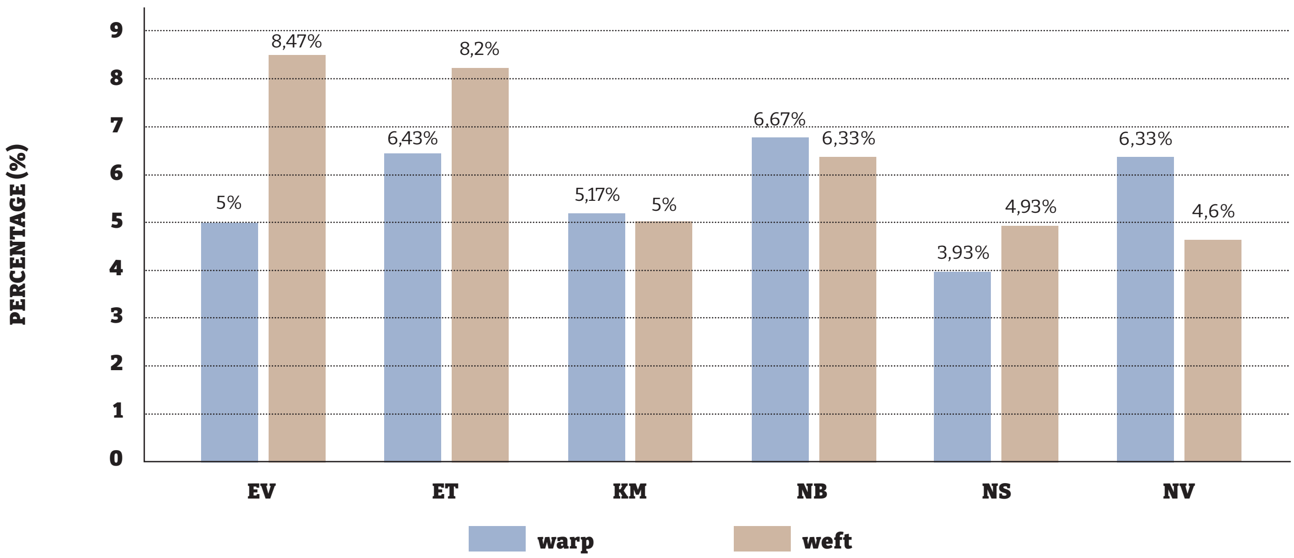


Figure 26. Elongation of woven fabrics

The elongation in the direction of the warp was relatively uniform for all woven fabrics, falling between 4-7% (Figure 26). *Norwegian Blæset, Old Norse sheep* and *Estonian Blackhead sheep* wool fabrics stretched the most under the influence of weight. The elongation of the fabrics in the weft direction was very uneven when comparing the fabrics with one another. The fabrics with the least stretch *(Old Norse sheep)* and the most stretch *(Estonian Whitehead)* differed by 2 times in terms of indicators.

It is also remarkable that the fabrics of some sheep breeds stretched more in the warp direction, and some more in the weft direction. The elongation of *Kihnu native sheep* breed fabrics was the same in both weft and warp direction.

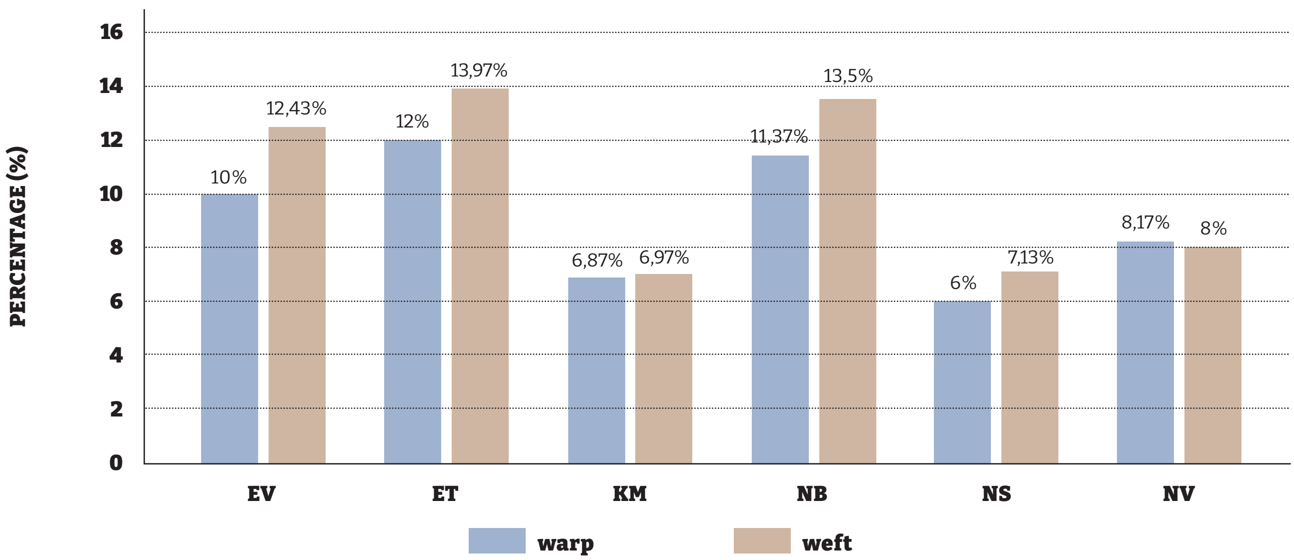


Figure 27. Elongation of felted woven fabrics

Felting made the differences in elongation between the fabrics significantly greater (Figure 27). The elongation of the fabrics of three sheep breeds increased significantly in both the warp and weft direction (for example, the elongation of fabrics made from the wool of the *Norwegian Blæset* sheep breed increased twice), and the elongation of the three sheep breeds changed relatively little (for example, the elongation of the fabrics of the *Kihnu native sheep* increased by only 1.5% during felting).

After felting, all fabrics stretched more in the weft direction than in the warp direction.

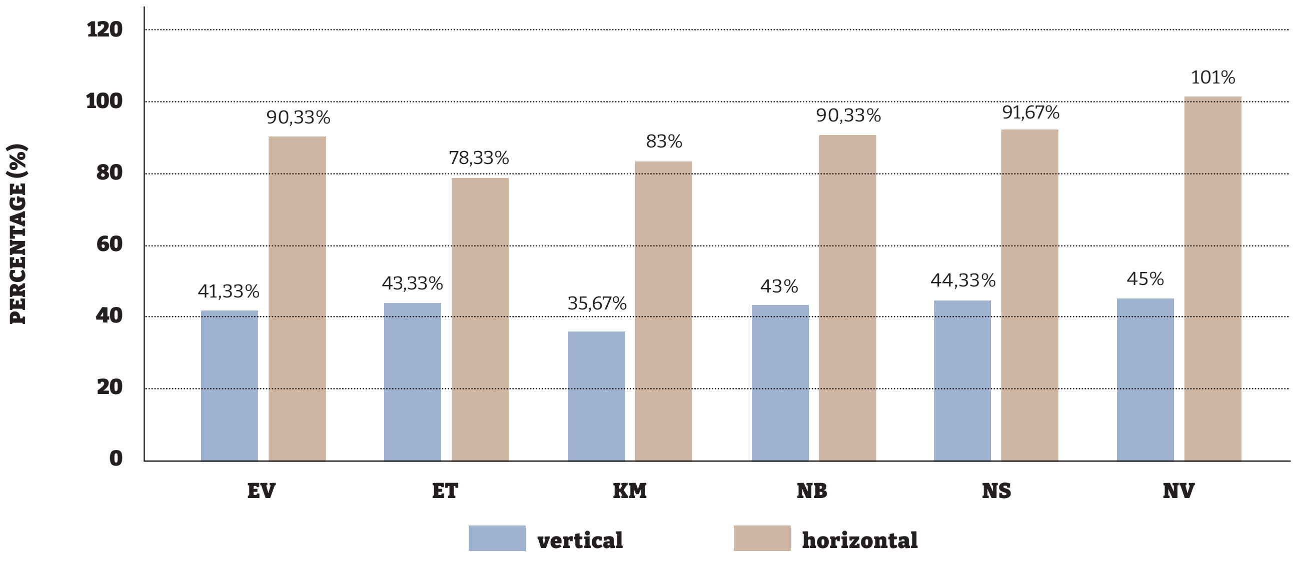


Figure 28. Elongation of knitted fabrics

Due to the structure of the knitted fabric, their elongation is significantly higher compared to woven fabrics – 3-4 times in the warp direction, but even up to 10 times in the weft direction (Figure 28). Knitted fabrics, regardless of which breed of sheep they are made from, elongated relatively similarly – the stretch remained within the limits of approximately 40%. All fabrics elongated similarly in the weft direction as well – between 80-100%.

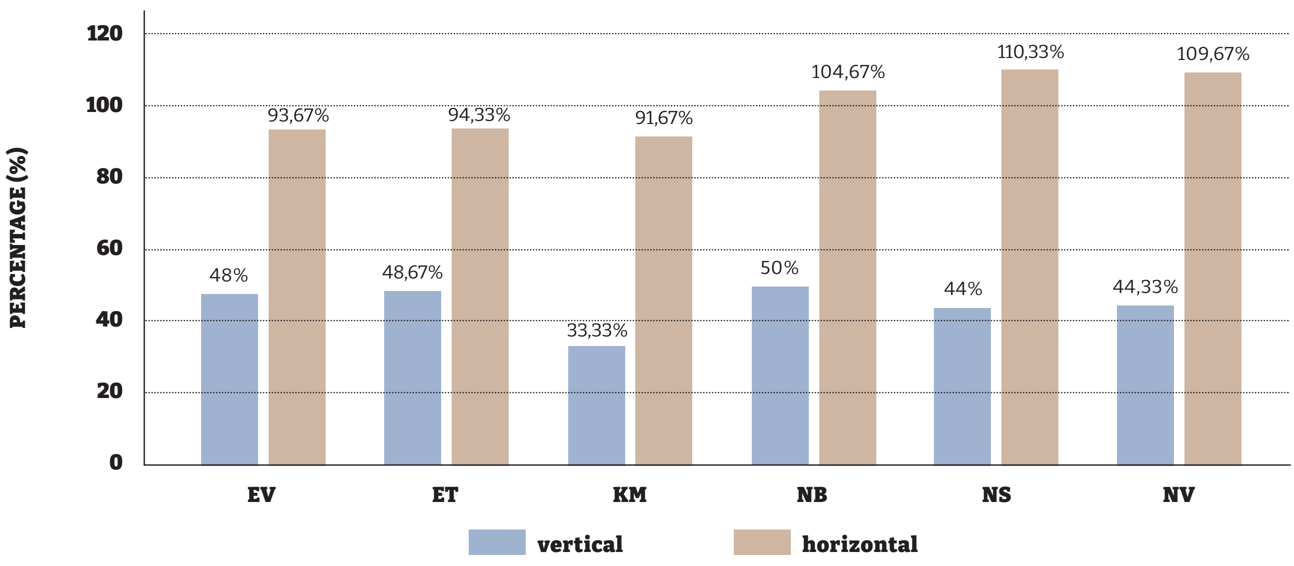


Figure 29. Elongation of felted knitted fabrics

Unlike with woven fabrics, elongation was not significantly affected by felting on knitted fabrics – with average increases of 10% in the weft direction (Figure 29). In the direction of the warp, the elongation remained the same or, for example in the case of *Kihnu native sheep* woolen fabrics, it even decreased by a few percent.

2.3. RECOMMENDATION FOR THE USE OF THE WOOLS FROM DIFFERENT SHEEP BREEDS

Estonian Whitehead (EV)

The notable results of woven fabrics made from wool of the *Estonian Whitehead sheep* breed are: relatively good felting (weight gain 24%); **high tensile strength** of both untreated and felted fabric, especially in the weft direction; low breaking elongation; excellent **stretchability in the weft direction on untreated fabric**; **excellent tearing strength on felted fabric** in both warp and weft direction; low abrasion resistance, especially on untreated fabric.

Knitted fabric has **very good pilling resistance**, especially for an untreated fabric; felted knitted fabric has excellent **abrasion resistance**; in the horizontal direction, fabric has **a high breaking elongation**, especially for an untreated fabric; **remarkably low air permeability**, which decreased relatively little as a result of felting (37%).

Estonian Blackhead (ET)

The notable results of woven fabrics made from wool of the *Estonian Blackhead sheep breed* are: **very good felting** properties (24.5% increase in weight); relatively low tensile strength in the direction of the fabric's warp, both on untreated and felted fabric; very low breaking elongation of untreated fabric; **excellent stretchability** in both the warp and weft direction **of the felted fabric**; low tear strength on untreated fabric of the warp direction; very low pilling resistance on felted fabric.

Knitted fabric felts relatively little (weight gain 18%); untreated fabric has **very good abrasion resistance**; **high tensile strength** in both vertical and horizontal directions; untreated and felted fabric has a **high breaking elongation** in both warp and weft directions.

Kihnu native sheep (KM)

The notable results of woven fabrics made from the wool of the *Kihnu native sheep* breed are: **very little felting properties** (15% increase in weight) with a considerable decrease in air permeability (27%); **excellent abrasion resistance** on both untreated and felted fabric; relatively **good tensile strength** in the direction of the warp on untreated fabric; **very low elongation breakage** and **stretch** in the weft direction of the felted fabric; **excellent tear strength** on untreated fabric in both the warp and weft directions.

The knitted fabric also **felts very little** (17% increase in weight); felted fabric has low pilling resistance; fabric has **high tensile strength** in the vertical direction in both untreated and felted fabric; **very little stretch** in both vertical and horizontal directions in untreated and felted fabric; The felted fabric has a very **low air permeability**, and the air permeability decreases significantly (53%) when felted.

Fabrics (woven and knitted) made from the *Kihnu Native Sheep* breed have common characteristics: very little felting properties and at the same time a large decrease in air permeability during felting of the fabrics.

Norwegian Blæset (NB)

The notable results of woven fabrics made from the wool of the *Norwegian Blæset* sheep breed are: **very good pilling resistance** and fabric **stretchability** in the warp direction on untreated fabric; low tensile strength in the direction of the warp on both untreated and felted fabric and **low elongation at break** in the direction of the warp on the untreated fabric; both untreated and treated fabrics have **very low air permeability**, and the air permeability almost does not change during aging.

The felted knitted fabric has very **low pilling resistance** and **abrasion resistance**; the felted fabric **stretches very well** in the direction of the warp.

Norwegian Spælsau (NS)

The notable results of woven fabrics made from the wool of the *Norwegian Spælsau* sheep breed are: the felted fabric has very **low abrasion resistance** and **tear strength** and **low stretchability;** both untreated and felted fabrics have very **good air permeability;** both untreated and felted fabrics have very **good tensile strength in the warp direction** and **breaking elongation** in both the warp and weft directions, while in direction of the weft, the tensile strength of the untreated fabric is relatively low.

The felted knitted fabric has very **low pilling resistance** and **tensile strength** in the vertical direction; the **elongation at break is low** both in the vertical and horizontal direction, especially on felted fabric; felted fabric has very good stretch in the horizontal direction; a**ir permeability** is also very **good** in both the untreated and felted fabrics.

All fabrics made from the wool of the *Norwegian Spælsau* sheep breed (both knitted and woven) are characterized by very high air permeability. The fact that knitted fabrics have a very high elongation at break, while woven fabrics have a very low elongation, is usual.

Old Norse sheep (NV)

The remarkable results of woven fabrics made from the wool of the *Old Norse* sheep breed are: both the untreated and felted fabrics have a very **low resistance to pilling**; untreated fabric has very **good abrasion resistance and air permeability**; air permeability decreases significantly (27%) during felting; untreated fabric has a slight stretch in the weft direction; the felted fabric has relatively **weak tensile strength and tear strength** in the weft direction, and the fabric has little breaking elongation in the weft direction.

The knitted fabric has good felting properties. Untreated fabric has a **low abrasion resistance**; **tensile strength is low** in both the warp and weft direction, both on untreated and felted fabric; the elongation at break in the direction of the warp is also small; untreated fabric has **very good stretch and air permeability** and air permeability decreases significantly with felting (55%).

Untreated fabrics (both woven and knitted) made from the wool of the *Old Norse sheep* are characterized by very good air permeability and a significant decrease in air permeability when felted.

Table 8 shows the most significant results (the highest and lowest) of all 24 different fabrics compared to the same type of fabric from different breeds. According to the specific characteristics of the properties, there are also recommendations for possible areas of use. The higher and lower values are related to the numerical values of the results and do not represent the best and worst values. Whether the value is good or bad depends on the intended use of the product and the expected properties.

			HIGHEST RESULTS	LOWEST RESULTS	SUGGESTIONS FOR APPLICATIONS
EV	W		Tensile strength and stretching in the weft direction	Abrasion resistance, elongation at break on the warp direction	For products that need to be strong, but abrasion resistance and elongation isn't important.
		F	Tensile strength in the weft direction, tearing strength	Elongation at break on the warp direction	For products that need to be particularly resistant to tearing.
	K		Resistance to pilling, tensile strength in the warp direction, elongation at break in the weft direction	Air permeability	For products that need to be strong, have an appearance that is resistant to use, and that need to be heat-proof.
		F	Abrasion resistance, tensile strength in the weft direction		For products that need to be abrasion-resistant
ET	W			Tensile strength in the warp direction, elongation at break, tearing strength in the warp direction	For products where the tensile strength does not need to be high.
		F	Stretching	Resistance to pilling, tensile strength in the warp direction	For products that should be stretchy, but not strong, and the change in appearance during use is not that important.
	K		Abrasion resistance, tensile strength in the warp direction, elongation at break		For products that must be very durable – abrasion-resistant, strong and stretchy.
		F	Tensile strength in the weft direction, elongation at break		For products that need to be strong and stretchy.
KM	W		Abrasion resistance, tensile strength in the weft direction, tearing strength		For products that need to be very durable – abrasion-resistant, strong and tear-resistant.
		F	Abrasion resistance	Elongation at break and stretching in the weft direction	For products that need to be very abrasion-resistant, but not stretchy.
	K		Tensile strength in the warp direction	Stretching in the warp direction	For products that need to be strong but not stretchy.
		F	Tensile strength in the warp direction	Resistance to pilling, stretching, air permeability	For strong, elastic and dense technical textiles, interior fabrics
NB	W		Resistance to pilling, stretching in the warp direction	Tensile strength in the warp direction, air permeability	For products that should be warm, stretchy, pilling-resistant but not strong.
		F		Tensile strength and elongation at break in the warp direction, air permeability	For products that should be warm, but don't have to be stretchy or strong.
	K				For different kinds of use – clothing fabrics, interior textiles.
		F	Stretching in the warp direction	Resistance to pilling, abrasion resistance	For products that should be strong, but not abrasion resistant.

			HIGHEST RESULTS	LOWEST RESULTS	SUGGESTIONS FOR APPLICATIONS
NS	W		Tensile strength in the warp direction, elongation at break, air permeability	Tensile strength and tearing strength in the weft direction,stretching in the warp direction	For products that should be breathable, warp-stretched and strong, but not elastic.
		F	Tensile strength in the warp direction, elongation at break, air permeability	Abrasion resistance, tearing strength and stretching in the warp direction	For products that should be breathable, stretchy, and strong, but not abrasion-resistant, elastic, and tear-resistant.
	K		Air permeability	Elongation at break in the weft direction	For products that should be breathable and not very stretchy.
		F	Air permeability, stretching in the weft direction	Resistance to pilling, tensile strength in the warp direction, elongation at break	For products that should be breathable, but not strong and stretchy, and whose appearance may change with use.
NV	W		Air permeability	Resistance to pilling, stretching in the weft direction	For products that should be breathable, not stretchy, and whose appearance may change with use.
		F	Abrasion resistance	Resistance to pilling, tensile strength, elongation at break and tearing strength in the weft direction	For products that should be resistant to abrasion, but not strong, not stretchy, and whose appearance may change with use.
	K		Stretching, air permeability	Abrasion resistance, tensile strength and elongation at break in the warp direction	For products that should be highly elastic and breathable, but not abrasion resistant.
		F		Tensile strength in both direction and elongation at break in the warp direction	For products that do not need to be very strong and stretchy.

Table 8. The most significant results of testing (the highest and lowest) of all 24 different fabrics

Comparing single- and double-layer sheep breeds, there are no differences in properties for knitted fabrics, but there were some differences for woven fabrics. For example, the felting of woven fabrics made from double-layer sheep breeds was less than for single-layer sheep breeds. As a result, their air permeability was also higher. Additionally, elongation of the woven fabrics of double-layered sheep breeds was significantly lower, especially for felted fabrics.

As a result of the tests, it can be concluded that the properties of the fabric are affected by the structure of the fibres, the yarn, and the technic. The influence of the technique used in the production of fabric may even be the biggest. For example, the yarn made from the wool of the Norwegian Spælsau sheep for knitwear was the strongest compared to other yarns, but the knitwear fabric made from the same yarn had almost the lowest tensile strength compared to other fabrics.

CONCLUSIONS AND POSSIBLE FURTHER STUDIES

The journey of this project has been extremely interesting and educational. At first glance, the simple task of finding out the properties of the wool of different sheep breeds has turned out to be a much more complex and multifaceted research question. A special feature of the project was the collaboration between craft practitioners, wool processors and industrial fabric testers. As a result, all parties received new and interesting information about the activities and practices of other parties, which, in turn, has provided new information about the entire field and helped better understand wider problems.

The project has investigated the two different wool value chains in Estonia and in Norway. Through the collection of wool for the project, the students, researchers, and practitioners, were able to compare the systems and point out possible ways to improve the different levels of the value chain. The lack of an organized wool collection system in Estonia is a good example.

The project has brought to light new information concerning the textile properties of the processed wool from the six local sheep breeds that were investigated. The results show that the wool from these breeds is indeed strong, and can have many different uses. By comparing the results, it is possible to chose wool from the different sheep breeds for specific textiles. This is of importance, not only for the participants of the project, but may also for others who wish to work with wool from heritage sheep breeds.

The methods used in the project, especially the textile testing system, provide an initial pathway for the testing of textile properties of wool from heritage sheep breeds that can be a model for further methodological developments and research.

The results from this project inspire further work. The parallel investigation of wool from heritage sheep breeds of two different, but also similar heritages, is very interesting and inspiring. There is a lot of possibility for further examination and study.

The wool station system might be an interesting area to focus on. How can a wool station system be developed in Estonia? Should it be only for the heritage sheep breeds, or for all wool? What is the best solution for scouring? Is large scale scouring or small scale washing the most sustainable solution?

Now, we know quite a bit about the textile qualities of wool from the six investigated sheep breeds, but the results are limited to a few colours and two yarn types. It could be interesting to investigate wool of more colours, from other national sheep breeds, and different yarn types and qualities.

We have some knowledge about the traditional use of local wool from heritage sheep breeds and can compare traditional knitting and weaving between Estonia and Norway; assessing differences, similarities, and traces of the transfer of craft traditions. We can utilise the results from this project to develop and design contemporary and sustainable textiles that involve the input of new students and designers. For the next research phase, it would also be good to compare the results with other textile materials.

Unfortunately, at the end of the current project, the materials of the participating countries are not fully comparable. When repeating a similar project, it would be good to limit the choice of yarns to be tested and follow very similar starting conditions in all stages of processing. Even within these parameters, the results could still be incomparable and not exactly repeatable, because there are many influencing factors: from the properties of the wool to the skills and experience of the spinners. Even if this uniqueness is not good from a scientific point of view, it supports cultural diversity and creates opportunities for new developments. New facts have emerged as a result of the project, which can be used as a starting point for subsequent projects. For instance, more information was gathered regarding the differences between single and double-coated wool. In any case, it would be important to proceed with product development that takes into account the results of this research, which would help to provide connections between the types of wool and their processing, and the desired properties of the products. It would also be interesting to test the practical uses of the finished products and compare them with products made from other industrial materials. A narrower focus on how the methods of material processing affect the properties of fabrics will also be important in further research.

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APPENDIX

APPENDIX 1

A list of Estonian sheep and their blood characteristics used in this project:

	NUMBER	GENDER	BREED	BLOODLINE	OWNER
1	EV 3845011A	Ewe	EV	TEX 62% EV 26% DOR 12%	MAATAR OÜ
2	EV 5079391A	Ewe	EV	DOR 84.5% EV 15.5%	MAATAR OÜ
3	EV 6132927A	Ewe	EV	TEX 64.64% EV 19.86% DOR 15.5%	MAATAR OÜ
4	EV 6133412A	Ewe	EV	DOR 57.68% EV 21.43% TEX 20.89%	MAATAR OÜ
5	EV 4179191A	Ewe	EV	TEX 58% EV 36% DAL 6%	OÜ FOREST HALDUS
6	EV 4179641A	Ewe	EV	TEX 68% EV 32%	OÜ FOREST HALDUS
7	EV 4179689A	Ewe	EV	TEX 66% EV 34%	OÜ FOREST HALDUS
8	EV 4179740A	Ewe	EV	TEX 66% EV 34%	OÜ FOREST HALDUS
9	EV 5861729	Ewe	EV	TEX 46.87% DOR 34.25% EV 18.88%	OÜ FOREST HALDUS
10	EV 5878581	Ewe	EV	DOR 37% TEX 36.5% EV 14% DAL 12.5%	OÜ FOREST HALDUS
11	EV 5861132	Ewe	EV	TEX 36.06% DOR 28% DAL 21.87% EV 14.07%	OÜ FOREST HALDUS
12	EV 5144082A	Ewe	EV	TEX 76.78% EV 23.22%	URMAS AAVA
13	EV 5144099A	Ewe	EV	TEX 76.78% EV 23.22%	URMAS AAVA
14	EV 5144297A	Ewe	EV	TEX 75% EV 25%	URMAS AAVA
15	EV 5144501A	Ewe	EV	TEX 75% EV 25%	URMAS AAVA
16	EV 5751570A	Ewe	EV	TEX 76% EV 24%	URMAS AAVA
17	EV 6088316A	Ewe	EV	TEX 75% EV 25%	URMAS AAVA
18	EE0005505081	Ewe	ET	SUF 71.81% ET 15.69%	ALLIKA TALU OÜ
19	ET 4603146B	Ewe	ET	GER 45.31% SUF 25% ET 23.44% OXF 6.25%	ALLIKA TALU OÜ
20	ET 5505036B	Ewe	ET	SUF 81.12% ET 18.88%	ALLIKA TALU OÜ
21	ET 5505043B	Ewe	ET	SUF 53.12% GER 22.65% ET 16.42% OXF 7.81%	ALLIKA TALU OÜ
22	EE0005238262	Ewe	ET	SUF 53.12% GER 22.65% ET 16.42% OXF 7.81%	ALLIKA TALU OÜ
23	ET 3030622A	Ewe	ET	SUF 56.25% ET 43.75%	ALO SINIMÄE
24	ET 4672470A	Ewe	ET	SUF 67.18% ET 26.57%	ALO SINIMÄE
25	ET 5778812	Ewe	ET	SUF 78.12% ET 21.88%	ALO SINIMÄE
26	ET 5778867B	Ewe	ET	SUF 70.31% ET 29.69%	ALO SINIMÄE
27	ET 5779130B	Ewe	ET	SUF 68.75% ET 28.13%	ALO SINIMÄE
28	ET 3812549A	Ewe	ET	SUF 68.75% ET 31.25%	LAIRE KÄIS
29	ET 4364610A	Ewe	ET	SUF 68.75% ET 31.25%	LAIRE KÄIS
30	EE0004048558	Ewe	ET	SUF 69% OXF 18% ET 13%	LAIRE KÄIS
31	EE0003454626	Ewe	ET	SUF 25% ET 16.41% OXF 8.59%	LAIRE KÄIS
32	EE0004048701	Ewe	ET	SUF 62% ET 19% OXF 19%	LAIRE KÄIS
33	EE0005368945	Ewe	ET	SUF 81% ET 9.5% OXF 9.5%	LAIRE KÄIS
34	ET 2222363A	Ewe	ET	GER 68.75% ET 31.25%	SIRELI TALU
35	ET 2572956A	Ewe	ET	GER 37.5% ET 31.25% SUF 25% OXF 6.25%	SIRELI TALU
36	ET 4308874A	Ewe	ET	SUF 38% ET 34% OXF 16% GER 12%	SIRELI TALU
37	ET 4308560A	Ewe	ET	SUF 38% ET 31% GER 22% OXF 9%	SIRELI TALU
38	ET 4603825A	Ewe	ET	SUF 37.5% ET 34.38% OXF 15.62% GER 12.5%	SIRELI TALU

	NUMBER	GENDER	BREED	BLOODLINE	OWNER
39	Viilivalli	Ewe	KM		
40	Vessa	Ewe	KM		
41	Veneetsia	Ewe	KM		
42	Kiire	Ewe	KM		
43	Luige	Ewe	KM		
44	Selma	Ewe	KM		
45	Tamburiin	Ewe	KM		
46	Taiga	Ewe	KM		
47	Võhumõõk	Ewe	KM		
48	Siidisaba	Ewe	KM		