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Wool fibre quality in Danish prehistoric textiles: a 3,000 year survey

Abstract
During the last 15 years analyses by fibre diameter measurements of a wide range of yarn samples from Danish archaeological wool textiles dated from the Early Bronze to the Viking Ages (circa 1800 BCE to 1050 CE) have been made. The extraordinary preservation of these textiles makes them ideal for interpretations regarding wool fibre development and processing. The aim of this paper is to investigate possible changes in fibre quality through time that can be related to either differences in the raw wool or in the work process preparing the wool for spinning. The standard statistical calculations of the wool fibre diameters which form the basis for classifying prehistoric wool have been used but slightly elaborated to extract more detailed information and facilitate the interpretation of the collected data. The fibre qualities in the textiles from the different archaeological periods have been compared and the principles for wool development and processing assessed for each. The results have revealed that a similar kind of wool was used for a long period of time in the Danish area with only minor changes that could indicate adjustments of the production and processing to meet the demands for textile appearance. Further, the results show that a change took place in the textile fibre quality between circa 400 CE and 600 CE which indicates the introduction of a different sheep breed and processing strategy. In this way, new and more specific knowledge has been acquired about wool fibre development and the work, desires, and choices of prehistoric textile craftspeople through a long period of time.

Keywords: Danish prehistoric textiles, wool, fibre diameter analysis, fibre processing, textile design

Introduction

Through fortuitous environmental and microbiological coincidences, a large number of prehistoric textiles made from sheep wool has been preserved in Denmark, dating from the Bronze Age to the Viking Age (circa 1800 BCE to 1050 CE). They consist to a large extent of complete or fragmented pieces of garments and coverings recovered from bogs and burials (Bender Jørgensen 1986; Hald 1980). Evidence of the use of sheep wool for textiles before the Early Bronze Age has not yet been found in Denmark although sheep were introduced in Scandinavia with the neolithic lifestyle.

In recent years, this unique collection of well-preserved wool textiles has formed the basis for comprehensive studies regarding the complexity of interactions necessary for the production of textiles (Andersson Strand et al. 2024; Demant et al. 2021; Frei et al. 2017; Mannering et al. 2010; Skals and Mannering 2014; Skals et al. 2018, 2024; Vanden Berghe et al. 2009). The focus of the present study is the fibre composition of the wool spun into yarns and is based on statistical calculations of measurements of individual fibre diameters. For a long time the method has been used to develop an evolutionary theory of sheep and define differences in fleece types resulting from breeding (Rast-Eicher 2008; 2013; Ryder 1983a). The material selected for this study contains samples of warps and wefts from each sampled textile, in many cases two samples from each, and when possible, additional yarns such as sewing or embroidery threads and cords. It is ideal for tracking nuances in the fibre composition that may be related to the processing of the raw material. By comparing the results from the different yarns in the textiles from different time periods, it has been possible to distinguish differences that may either be interpreted as related to the raw wool or the processing. This approach emphasises the skills, desires, and choices of prehistoric textile craftspeople with regard to the available wool and contributes knowledge about the tacit part of textile production. These are important for understanding the quality and properties of the final product (Bender Jørgensen 2012).

The sampled textiles have all been preserved in their organic state but the conditions for their preservation were varied and resulted in different degrees of degradation. The Bronze and Early Iron Age textiles are from waterlogged conditions and are extremely well preserved while the Roman Iron Age textiles are from inhumation graves, primarily in sandy soil, and are much more degraded. One group of the Late Iron Age textiles is from graves and preserved by metals, although not yet mineralised, while another was found in a settlement. The Viking Age textiles have been found in both waterlogged and dry conditions. To what degree these different circumstances have influenced the diameter of the individual wool fibres is not thoroughly researched. The measurements from prehistoric wool fibre analyses in general can only be approximate (Skals et al. 2018). It is thanks to the large quantity of analyses representing a long period of time that this study can contribute knowledge regarding the use of wool in prehistory.

Research history

Sheep wool used as a textile material is believed to have developed through selective breeding during the transformation of wild sheep to domesticated breeds. The coat of the wild ancestor moulted yearly and consisted of long straight hair called kemp, covering short, differently pigmented fine wool. This wool was unsuitable for spinning into yarn but with time the domesticated woolly sheep developed a coat of slightly longer fine wool and coarse fibres which were not so thick. Early selective breeding seems to have resulted in the development of unpigmented fibres (Gleba 2012; Rast-Eicher 2012; 2013). The process started in areas around south-west Turkey and the Near East during the third millennium BCE and spread from there to Europe (Bender Jørgensen and Rast-Eicher 2018; Bender Jørgensen et al. 2023; Ryder 1983a; 2005). Through interdisciplinary research studies of Near Eastern archaeology, texts, iconography and archaeozoology, it is now known that two varieties of sheep with characteristically different fleeces co-existed in the Neolithic Near East (Breniquet 2014; Breniquet and Michel 2014; Vila and Helmer 2014).

The use of wool for making textiles is believed to have resulted in methodological innovations in textile production and possibly also new spinning and weaving tools. This development is documented by abundant finds of textile tools in the Aegean and Middle Eastern Early Bronze Age cultures (circa 3500 BCE to 3200 BCE), where textile finds are very rare, but where written sources and iconography testify to the presence of a large-scale textile production (Andersson Strand 2015; Breniquet and Michel 2014; Sabatini et al. 2019). In Scandinavia, the situation is reversed. Here many textiles are preserved from the Early Bronze Age, circa 14th century BCE and onwards but the tools, especially from the earliest periods, are rare (Andersson 1996; 2003; Lerke and Hjorth-Jørgensen 2015). A large number of textiles made from sheep wool has also been preserved in the salt mines at Hallstatt in Austria, dated between 1200 BCE and 700 BCE (Late Bronze and Iron Ages) (Grömer 2012; 2013; Grömer and Saliari 2018; Rast-Eicher 2013; Ryder 1990). Other Central European textile finds are most often mineralised and preserved in connection with metals but these finds have also been studied successfully using scanning electron microscopy (Gleba 2012; 2014b; Rast-Eicher 2008).

The material available for prehistoric wool studies consists of the woven textiles and in some cases skin items. The specific sheep breed from which the wool or skin has come is not known and wool fibres are far from identical. Their quality and thickness will depend on where on the body they grew as well as the age, gender, and health of each animal. Furthermore, no two sheep within the same flock will be similar (Andersson Strand and Mannering 2017). This means that the wool for each specific textile could have been specifically selected quite early in the process.

The wool can be spun immediately after plucking/shearing, but the quality of a finished textile greatly depends on how well the fibres are prepared. The wool has to be sorted by hand, according to criteria such as fibre fineness, colour, length and strength. Teasing the wool by hand or flogging it with a whip will help remove dirt and tangles. Finally, before spinning, long and short fibres are separated, and the fibres arranged parallel to each other using combs with long teeth (Andersson Strand and Mannering 2017; Christiansen 2004; Gleba and Mannering 2012).

Prehistoric wool fibre analysis

Prehistoric wool fibre analysis builds on modern industrial standards for classifying wool quality and to estimate the use and price of each fleece. These standards comprise evaluations of factors such as staple length and strength, the number of fibres with medulla (air-filled centres found in coarser fibres), the colour, and the mean fibre diameter of each fleece. Fibre diameters are measured in microns whereby 1,000 microns equal one millimetre. The finer the diameter of the fibres the softer the wool will feel to the skin. Generally, soft, non-prickly fibres measure less than 22 to 23 microns while rough and prickly fibres measure more than 32 to 34 microns (Wilson and Laing 1995). Dimensions on that scale need to be observed under magnification. In the wool industry, several thousand measurements from each sheep fleece are made automatically with different types of specialised equipment such as optical-based fibre diameter analysers, airflow apparatus or laser scan technology (www.nzwta.co.nz). Modern sheep can be bred to have fleeces with a uniform fine fibre profile, preferably with a mean diameter of less than 30 microns, and no outer hairs, and these characteristics have the highest market value (www.jwto.org).This differs from the so-called primitive sheep breeds which have fleeces closer to the ancient breeds consisting of an outercoat and an undercoat of coarse and fine fibres respectively.

During the 1960s, the standards from the modern wool industry were adapted to analyses of prehistoric wool by Michael Ryder (Ryder 1964; 1969). The required standard number of diameter measurements was set to a minimum of 100 fibres per sample. These measurements were obtained using a projection microscope (Walton 1988) or on images from optical or scanning electron microscopy (Gleba 2014a; Rast-Eicher 2008; 2012; 2013; Skals et al. 2018). The extent of pigmentation and medullation is noted and quantified when possible but can be obscured by discolouration and staining due to degradation. Measuring fibre length was generally not possible because the analyses were made on small samples cut from yarn. The fibre diameter is therefore the primary indicator of fibre quality from ancient contexts.

In line with the industrial methods, Ryder's system calculated results with similar statistics and interpretations in terms of fleece types. By comparing fibres from prehistoric textiles and skins to wool from so-called primitive sheep breeds living in isolated areas in the 1960s to 1980s, Ryder developed an evolutionary theory of sheep and defined six fleece types to represent changes to the wool using the terms hairy, hairy medium, generalised medium, medium, fine, and short (Ryder 1983a). Standard histograms were used to illustrate the differences in the fibre profile from the earliest fleeces where the measurements were distributed in two groups of bars separated by a wide gap – in comparison to the 20th century fleece which formed a coherent and symmetrical curve. It was further discovered that the development towards more uniform fibre profiles resulted in a slight coarsening of the finest fibres, the appearance of medium fibres, and the disappearance of the very coarse fibres. These changes are considered to be important steps away from the primitive towards more evolved sheep breeds (Ryder 1983a).

In the late 20th century, several Danish Bronze and Early Iron Age textiles and sheep skins were analysed according to Ryder's system. A few samples

Table 1: Ryder's model of sheep fleece classification - attributed to Danish Bronze and Iron age skins and textiles						
DEFINITION				NUMBER OF SAMPLES		
MODE DIAM.	MAXIMUM DIAM.	DISTRIBUTION	CLASSIFICATION	BA TEXTILES	IA SKINS	IA TEXTILES
30-40 microns	> 100 microns	Continuous	Hairy (H)	4	7	
30 microns	> 60 < 100 microns	Skewed to fine	Hairy Medium (HM)	6		40
20 microns	55 microns	Skewed to fine	Generalised Medium (GM)			6
30-40 microns	60 microns	Symmetrical	Medium (M)			1
20 microns	35 microns	Symmetrical	Fine (F)	8		3
25 microns	40 microns	Symmetrical	Short (S)			8

Table 1: Ryder's model of sheep fleece classification attributed to Danish Bronze and Iron Age skin and textile finds. Ryder's model uses the mode, the maximum diameter, and the distribution of the results to classify the fleece types, with the hairy type being closest to the wild sheep. The majority of the prehistoric Danish wool and skin samples were classified as hairy medium. Samples with random very coarse fibres are classified as hairy

with extraordinary low mean measurements and very coarse kemp were defined 'Mouflon type' or 'Intermediate' between the wild and the hairy types but the majority were classified as hairy and hairy medium. A few exceptions interpreted as generalised medium, medium, fine and shortwool were seen as evidence of the co-existence of differently evolved sheep breeds (Bender Jørgensen and Walton 1986; Ryder 1983b; 1988; Walton 1988) (table 1).

Ryder's method was subsequently disputed because it neglected to take the process of fibre selection, sorting and preparation for spinning into account (Andersson Strand 2012; 2015; Christiansen 2004; Gleba 2012; Good 1999; Nosch et al. 2013). A different classification system was developed by Antoinette Rast-Eicher based on a fleece type definition from the late 19th century which identified four main types termed hairy, mixed, coarse and fine, and fine. Their differences are, as in Ryder's system, exemplified by standard histograms and seen as evolving towards the more uniform fibre types. Medullation, pigmentation and fibre lengths added further information to the evolutionary stage of the wool (Rast-Eicher 2008; 2013; Rast-Eicher and Bender Jørgensen 2013).

The two least developed types, hairy and mixed, are most relevant for prehistoric wool studies and defined as consisting of an outer coat of coarse hair fibres and an undercoat of fine wool fibres. The terms fine, medium and coarse are used to describe relative differences in the fibre dimensions although not specifically defined. A medulla will, according to this system, only appear in the coarser hair fibres and will be interrupted in the mixed fleece type. Both fibre types can have dimensions in the medium range. The histogram of the hairy type has two separated curves whereas, in the case of the mixed fibres, the two curves are connected (Rast-Eicher and Bender Jørgensen 2013).

In addition to the wool-type identification, Rast-Eicher created a system of 11 categories, AAA to F, to assess the processing. This system is based on analyses of prehistoric Central European textiles. The processing of each sample is defined by differences in the percentage profiles of fibres measuring less than either 25, 30, or 40 microns and 60 microns used to define the outliers (Bender Jørgensen and Rast-Eicher 2018; Rast-Eicher 2008; 2012; 2013).

The Danish wool fibre study

Rast-Eicher's system was used from the beginning of the Danish fibre study which consisted of the Early Iron Age textiles. Based on the fibre measurements alone, the fleece type for this group of textiles could in all cases be defined as hairy because of a very large number of very fine and a few random coarse fibres (interpreted as outliers), although medullas were observed in fibres measuring less than 20 microns as well as in coarser fibres.

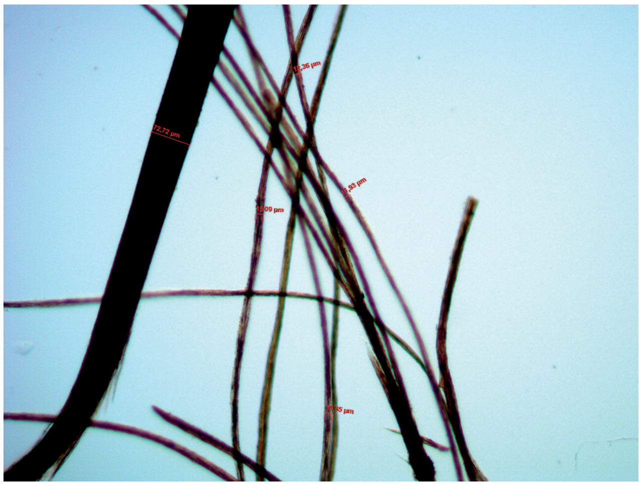

Fig. 1: Wool fibres seen with transmitted light microscopy at circa 100x magnification. The wool used in Danish textiles dating from 1800 BCE to 400 CE consist of a large number of very fine fibres and a few random very coarse fibres. This fibre diameter distribution is clearly visible with the naked eye (Image: Irene Skals)

During the work, it was realised that Rast-Eicher's categorisation system failed to reveal the subtle nuances in the fibre profiles of the different Danish yarn samples. It was noted that yarn samples picked from the same textile and in several cases from the exact same yarn in the weaving fell into different categories. Thus, the system did not distinguish the diversity of handcrafted wool textiles to a satisfactory degree. It was assumed that the reason for this was the structure of the statistical system (the percentage profiles measuring less than 25, 30, 40 microns respectively and 60 microns or more). The Danish textile samples generally appeared homogeneous with large majorities of very fine fibres (less than 25 microns), almost no fibres in the medium range (25 to 40 microns), and random coarse fibres measuring more than 60 microns (fig. 1). One random coarse fibre among 99 very fine fibres could in this way cause the classification to shift from AAA to B (table 2).

At this point, more fibre data had been collected and now included results from the Early Bronze and Roman Iron Age textiles which could show that the raw material through this long period of time changed very little (Skals and Mannering 2014). Compared to this, the now added results from the Late Iron and Viking Ages indicate an interesting development of the raw wool in this area but it was necessary to find

Table 2: Rast-Eicher's model of fibre classification - attributed to Danish Early Iron Age textiles		
WOOL TYPES: HAIRY TYPE, MIXED FIBRE TYPE, COARSE AND FINE FIBRES, FINE WOOLS		
DEFINITION		
% FIBRES OF DIFFERENT DIAMETERS	WOOL QUALITY CLASS	NO. OF EARLY IRON AGE SAMPLES
92% < 25 µm, 8% > 25.1 µm, 1% > 30 µm, max. 40 µm	AAA	35
85% < 25 µm, 15% > 25.1 µm, 3% > 30 µm, max. 60 µm	AA	8
93% < 30 µm 7% > 30.1 µm, 1% > 40 µm, max. 60 µm	A	0
80% < 30 µm, 15% > 30.1 µm 2% > 40 µm, max. 60 µm	AB	0
75% < 30 µm, 25 % > 30.1 µm, 2% > 40 µm	B	16
66% < 30 µm, 10% > 45 µm, 1% > 50 µm	C	0
80% < 40 µm, 20% > 40.1 µm, 2% > 60 µm	CD	2
66% < 40 µm, 34% > 40.1 µm, 5% > 60 µm	D	0
60% < 40 µm, 40% > 40.1 µm, 10% > 60 µm	E	1
50% < 40 µm, 50% > 40.1 µm, 15% > 60 µm	EE	0
50% < 30 µm, up to 50% > 60 µm	F	0

Table 2: Rast-Eicher's model of fibre classification attributed to Danish Early Iron Age textiles. This model differentiates between four different wool types, the hairy type being the most primitive. Eleven categories defined by different proportions of fibre groups classify the quality. More than half of the 62 Early Iron Age samples were categorised as AAA. One or two coarse fibres seen in wool with otherwise very similar fibre results caused a shift to Category B

a way to obtain an easy overview of the large quantity of data and to more easily differentiate between details in the finer fibre profiles believed to relate to the wool processing before spinning.

As all the results had been calculated and grouped in accordance with Rast-Eicher's categorisation system, it was easy to select the following three fibre groups to describe the data: fine fibres (less than 25 microns), medium fibres (from 25 to 40 microns) and coarse fibres (more than 40 microns). In this manner the

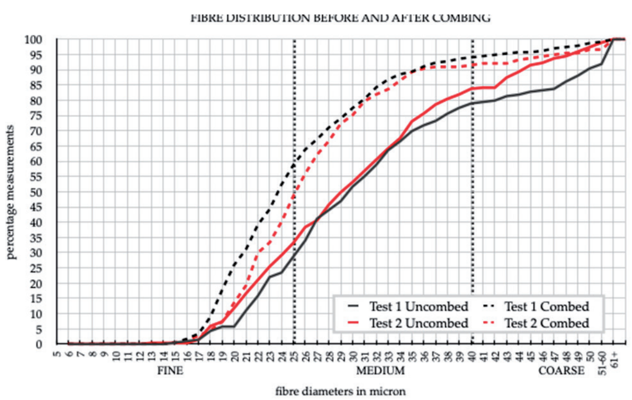

Fig. 2: Cumulative frequency diagram of two tests comparing uncombed and combed wool staples shows that combing results in a higher number of fine and medium fibres and fewer coarse fibres as shown by a steepening of the curves (Diagram: Irene Skals)

fibres in the medium range, which are important in the development away from the primitive sheep, become more apparent, and the coarsest fibres are defined as everything above 40 microns.

Comparing the percentage profiles of these groups in the results from the first three archaeological periods (Bronze Age to Roman Iron Age) revealed differences that could be explained by different production traditions resulting in different textile appearances and the distinctions between the three fibre groups also turned out to be valuable for the analyses of the results from the Late Iron and Viking Age textiles. Fortunately, the large number of measurements from each sample compensated for measurement uncertainties and the fact that the diameter of a wool fibre varies along its length.

In combination with the standard histograms which display the frequency of the results at every second micron, the diagrams of the cumulative frequency shown here present the sum of the percentages of fibres at each different diameter as a curve. The steepness of the curve is a measure of the uniformity of the fibres in each sample. When comparing two or more samples, it is easy to see where along the curve the differences appear and to evaluate them in relation to the raw wool and the processing respectively.

To further corroborate this interpretation, a test to analyse to what degree combing affected the fibre profile was established. Two wool staples from a

Table 3: The effect of combing on the fibre content										
	UNCOMBED WOOL STAPLE					COMBED WOOL STAPLE				
Test	%Fine	%Medium	%Coarse	Range-µm	Category	%Fine	%Medium	%Coarse	Range-µm	Category
1	34	45	21	14-18, 20-58	E	64	30	6	14-43, 45-50, 54	CD
2	38	45	16	12, 16-40, 42-51, 53	CD	56	36	8	14-36, 39-40, 43-47, 49, 51, 55, 57, 60	CD

Table 3: Effect of combing a wool fibre staple. The fibre diameter distributions and the calculations of the fibre results from the uncombed and combed wool staples show that this process results in an increased number of fine fibres and a decreased number of coarse fibres. The number of medium fibres was unchanged in Test 1 and the categorisations were unchanged in Test 2. Minimum and maximum measurements did not change significantly

modern so-called primitive sheep fleece were combed by three strokes each. Fibre analyses were made of samples picked before the first and after each consecutive stroke. The results from both samples suggested that the number of fine fibres gradually increased, and the number of coarse fibres decreased (fig. 2, table 3). Although the number of coarse fibres in the prehistoric raw wool is unknown, its processing can be assessed by comparing the remaining quantities of coarse fibres in the different yarns.

Method

The fibre diameter measurements in this study were made on digital photographs captured by transmitted light microscopy using camera software (a Primo Star iLED microscope from Zeiss with a 10x objective, equipped with an AxioCam ERc5s camera) with a minimum of 100 fibre diameters per sample, and with statistical data processing in Excel. The natural pigmentation of the fibres and the extent of medullated fibres were noted and evaluated with regard to the wool development where possible. It is on this basis that the percentage results of the fibre diameters were calculated, and cumulative frequency diagrams created (Skals et al. 2024). The results were further calculated according to Rast-Eicher's categorisation format (Rast-Eicher 2008; Rast-Eicher and Bender Jørgensen 2013) and the percentage results sorted into fine (less than 25 microns), medium (25 to 40 microns) and coarse (more than 40 microns) fibres groups.

The interpretation of the changes recorded in the fibres that signify the development of the raw wool through time was approached by:

- Comparing the profile of the three fibre groups: fine, medium, and coarse in the different time periods
- Comparing the range of fibres in each specific period. For this purpose, the most and the least uniform samples from each period were compared. They were defined by the steepest and gentlest cumulative frequency curves, the largest and smallest numbers of fine and coarse fibres and the minimum and maximum measurements
- Comparing the dimensions of the coarsest fibre from each period

The processing was viewed as two separate steps consisting of the selection of wool for different purposes and the combing:

- Selection and sorting:
  Differences in the fibre dimensions were dependent on the age and health of the sheep and where the fibres grew. Variations in the concentrations of similar fibres were therefore used to evaluate the selection. They were very subtle and most clearly illustrated by the heights of the peaks in the histograms and the widths of the coherent curves. In the samples from the first three periods, they were mainly found within the fine fibre range
  Sorting according to colour was part of this work process.
- Combing:
  The extent of combing was assessed by comparing the quantities of coarse fibres remaining in the different yarns.

The nuances in the fibre composition in the different yarns from each textile due to processing were assessed by comparing their cumulative frequency diagrams and the different combinations of the three fibre groups: fine, medium, coarse.

Results

The textile finds were grouped according to their context and dating. A total of 350 yarn samples were analysed and the data set constitutes 65,000 fibre diameter measurements:

Table 4: Textiles from the bronze age circa 1800 to 500 BCE				
Location	Textile		No. of samples	
Borum Eshøj A	Cape	B1397	warps, wefts, sewing thread	7
	Wrap around garment	B1399	warps, weft, sewing thread	4
	Belt	B1400	cord	1
	Foot cloths	B1402	warp, weft	2
Borum Eshøj B	Cape	B1405	warp, weft	2
	Wrap around garment	B1406	warp, weft	2
Borum Eshøj C	Net	B679	sprang, cord	2
	Blouse	B680	warp, weft, sewing thread	3
	Skirt	B681	warps, weft, sewing thread	4
	Belt	B682	dark and light warps, weft	3
	Belt	B683	warp, weft	2
	Piece of cloth	B684	warp, weft, sewing thread	3
Egtved	Blanket	B11833	warp, dark and light wefts	3
	Blouse	B11834	warps, wefts, sewing thread	5
	Belt	B11835	warp, weft	2
	Corded skirt	B11836	cord, weft, yarns from belt, sewing thread	5
	Cord	B11847	cord	1
	Bundle	B11849	warp, weft	2
Guldhøj	Cap	B5065	warp, weft, sewing thread	3
Hvidegård	Piece of cloth	9220e	warp, weft	2
L. Dragshøj	Fragment of cap	19464	warp, weft, embroidery threads	4
Muldbjerg	Cape	B3320	warp, weft	2
	Wrap around garment	B3321	warp, weft	2
	Piece of cloth	B3322	warp, weft	2
	Foot cloths	B3323	warp, weft	2
Nybøl	Textile type A	ÅBMx64	warp, weft	2
	Textile type B	ÅBMx64	warp, weft	2
	Textile type C	ÅBMx64	warp, weft	2
	Textile type D	ÅBMx64	warp, weft	2
	Textile type E	ÅBMx64	warp, weft	2
Skrydstrup	Net	B12961	sprang, cord	2
	Blouse	B12962	warp, weft, embroidery threads	3
	Belt	B12963	warp, weft	2
	Skirt	B12964	warp, wefts, sewing thread	4
	Foot cloth	B12966	warp, weft, sewing thread	3
	Blanket	B12969	warp, weft	2
Toppehøj	Fragment of cap	MDCCLXXXV	warp, weft, embroidery thread	3
Trindhøj	Cape	B19909	warp, weft, embroidery thread	3
	Wrap around garment	B19910	warps, wefts, sewing thread	5
	Belt	B19910	warp, weft	2
	Blanket	B19911-12	warp, weft	2
	Foot cloths	B19913	warp, weft	2
	Cap	B19914	embroidery thread	1
	Cap	B19918	sewing thread	1
V. Doense	Fragment	B3416	warp, weft	2
Voldtofte	Fragment	24636	sewing thread	1

Table 4: The textiles sampled from the Bronze Age in this study come from 14 finds

- The Bronze Age textiles (BA) consisted of finds from the oak coffin burials representing the period circa 1800 BCE to 500 BCE. Analyses were made of 118 samples from 46 textiles (table 4)
- The Early Iron Age textiles (EIA) consisted of finds from bogs representing the period circa 500 BCE to 1 CE. Analyses were made of 62 samples from 29 textiles (table 5)
- The Roman Iron Age textiles (RIA) consisted of grave finds representing the period circa 1 CE to 400 CE. Analyses were made of 79 samples from 37 textiles (table 6)
- The Late Iron Age textiles (LIA) consisted of finds from graves and a settlement representing the period circa 620/630 CE to 800 CE. Analyses were made of 31 samples from 17 textiles (table 7)
- The Viking Age textiles (VIK) consisted of finds from graves and settlements representing the period circa 800 CE to 1050 CE. Analyses were made of 76 samples from 35 textiles (table 8).

Wool development circa 1800 BCE to 400 CE

From the Bronze Age to the end of the Roman Iron Age, the wool in the Danish textiles appeared very similar. It was characterised by a majority of very fine fibres. In some cases, only fine fibres were recorded, with very sporadic medium fibres, and a few coarse fibres. The percentage profiles are listed and compared in tables 9 to 11 (based on 259 yarn samples from 107 textiles). This mixture of very fine and very coarse fibres classifies the wool as hairy, meaning that it is close to wild sheep with regard to sheep fleece development. Between the Bronze Age and the Early Iron Age, the diameter of the coarsest fibres becomes finer. In the Bronze Age, textile fibres measuring more than 100 microns and sometimes even 200 microns appear quite often, but they were rarely recorded in Early and Roman Iron Age textiles. Furthermore, in the Roman Iron Age, there was a slight increase in the number of medium fibres (table 10) which results in a small change in the variety of fibre types, although the

Table 5: Textiles from the Early Iron Age circa 500 to 1 BCE				
Location	Textile		No. of samples	
Auning	Fragment	KHM 233-74	sewing thread	1
Borremose I	Fragment	C26451	warp, weft	2
Bredmose	Textile with checks	C24623	warp, weft, sewing threads	4
	Textile with composite bands	C24624	warp, weft, sewing threads	4
	Cap	C24626	sprang	1
	Scarf	C24627	warp, weft	2
Haraldskær	Fragment	3706	warp, weft	2
	Fragment, scarf?	3707 C1	light warp, light weft	2
	Fragment with checks	3707 C2	dark, light warp and wefts	4
	Cap	C37143	sprang	1
Huldremose I	Skirt	C3473	dark, light warp and wefts	4
	Scarf	C3474	dark, light, medium warp and wefts	6
Huldremose II	Tubular garment	D3505	warp, weft	2
Karlby	Textile with checks	D4854a	sewing thread	1
Krogens Mølle	Fragments with checks	D1310a	dark, light warp and wefts	4
	Fragment with stripes	D1310c	dark warp, light weft	2
	Fragments with checks	D1310e	dark, light warp and wefts	4
	Fragment	D1310i	sewing thread	1
	Fragments	D1310j-l	warp, weft	2
	Textile with two components	D1310m	dark, light warp and wefts	4
	Skirt	D1310n-r	dark, light warp, weft	3
Skærsø	Rectangular textile	MKH 336	warp, weft	2
Unknown Prov.	Tubular garment	C37142	dark, mixed sewing threads	2
Ømark	Rectangular textile	C25184	warp, weft	2

Table 5: The textiles sampled from the Early Iron Age in this study come from 11 finds

Table 6: Textiles from the Roman Iron Age circa 1 to 400 CE				
Location	Textile		No. of samples	
Corselitze	Fragment	7325a	warp, weft	2
	Scarf	7325b	warp, weft	2
Hammerum	Dress		warp, wefts, ribbon, fringes, sewing thread	7
	2nd textile		warp, wefts	3
	3rd textile		warp, weft	2
Lønne Hede 1	Textile 1		warp, wefts	3
	Textile 2		warp, weft	2
	Textile 3		red warp	1
	Textile 4		red and blue yarns	2
	Textile 5		red warp, weft	2
	Textile 6		sample	1
Lønne Hede 1	Textile 1		warp, wefts	3
	Textile 2		warp, weft	2
	Textile 3		red warp	1
	Textile 4		red and blue yarns	2
	Textile 5		red warp, weft	2
	Textile 6		sample	1
Lønne Hede 2	Textile 1.3		warp, weft	2
	Textile 1.5		warp, wefts	4
	Textile 1.6		warp, wefts	3
	Textile 1.7		weft, sewing thread	2
	Textile 2.2		warp, weft	2
	Textile 2.3		warp, weft	2
	Textile 2.6		warp, weft	2
	Textile 6.2		sample	1
	Textile 12.1		warp, weft	2
	Textile 12.3		sample	1
Vorbasse I	Textile 1.1.7		warp, weft	2
	Textile 4.4.9		warp, weft	2
	Textile 4.4.67		warp, weft	2
	Textile 4.4.70a		warp, weft	2
	Textile 4.4.70b		sample	1
	Textile 4.4.B		warp, weft	2
	Textile 4.4.C1a		warp, weft	2
	Textile 4.4.Fa		warp, weft	2
	Textile 4.4.Fb		warp, weft	2
	Textile 4.4.Ha		warp, weft	2
	Textile 5.5.61		warp, weft	2
	Textile 5.5.ex		warp, weft	2
	Textile 13.13.8A		warp, weft	2
	Textile 13.13.8B		warp, weft	2
	Textile 15.15.10		warp, weft	2
Vorbasse III	Textile 2SB 2.2		warp, weft	2

Table 6: The textiles sampled from the Roman Iron Age in this study come from six finds

Table 7: Textiles from the Late Iron Age circa 620/630 to 800 CE			
Location	Textile	No. of samples	
Nørre Sandegård Vest	9 258-3 k-l	loose threads	1
	9 258-3 n	warp?	1
	9 259 layer 3	warp, weft	2
	9 259.1 layer 1	warp, weft	2
	9 259.1 layer 2	warp, weft	2
	20-36 g-i	cord	1
	20-447 2c	warp, weft	2
	32-466	warp, weft, cord	3
	32-471	warp, weft	2
	70-810-11	warp, weft	2
	70-810-11 2a	warp, weft	2
	811-11 2d-e	cord	1
	70-815	warp, weft	2
Ribe	x1098	warp, weft	2
	x1228	warp, weft	2
	x1232	warp, weft	2
	x1387	warp, weft	2

Table 7: The textiles sampled from the Late Iron Age in this study come from two finds

coarse fibres were less frequent in this period (table 11). The lack of variety through this long period of time is illustrated by the closeness of the cumulative frequency curves representing the most and the least uniform samples from each period (fig. 3). The three most uniform samples almost consist of only fine fibres with resulting narrow ranges, and they have very fine minimum measurements. The least uniform samples still had large numbers of fine fibres but they were mixed with medium or coarse fibres and had slightly higher minimum measurements and wider ranges (table 12).

The development away from the very coarse fibres towards more varied fibre mixtures could be the result of breeding. Similarly, a slow development away from natural pigmentation is distinguishable. Pigmented fibres were seen in all three periods, but more distinctly in the Bronze Age wool than later, and white or lightly pigmented fibres appear more often in the Roman Iron Age textiles.

As the Bronze Age fibres were heavily pigmented, the possible presence of a medulla was often obscured. However, medullas were observed in fine fibres under 20 microns as well as in fibres in the 20 to 30 microns range in all three periods. They appeared both as continuous and interrupted in form but, because of the small sample sizes, this was difficult to determine precisely.

Wool processing circa 1800 BCE to 400 CE

High concentrations of similar fibres were very distinct especially in the textiles from the Bronze and Early Iron Ages. This was interpreted as the result of specific selection and as an indication of a definite preference for very fine fibres. A remarkable example of this meticulous selection is found in the textiles

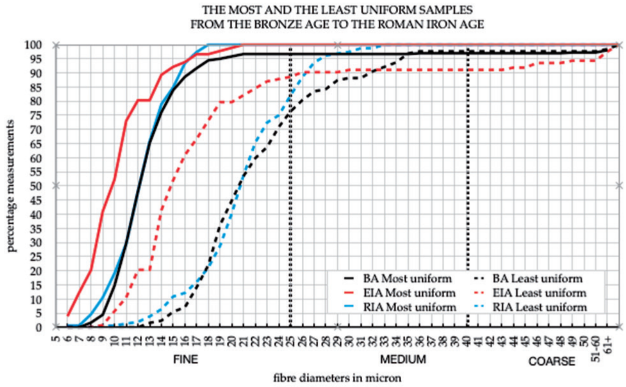

Fig. 3: Cumulative frequency diagram showing the most and least uniform samples from each of the three early time periods. They all have similar steep curves because of the large quantities of fine fibres, but the two Early Iron Age curves lie closer together than the curves from the Bronze and Roman Iron Ages because of the more uniform fibre results from that period. The curves also show that very few fibres were recorded within the medium range (Diagram: Irene Skals)

Table 8: Textiles from the Viking Age circa 800 to 1050 CE				
Location	Textile		No. of samples	
Fløjstrup	Twill	C9266	warp, weft	3
	Tabby	C9266	warp, weft	2
Hedeby	Face mask, felt	14D	sample	1
	Stocking	H2	warp, weft	2
	Upper garment	H7	sample	1
	Caftan?	H11	warp, weft, lining	3
	Fragment, spencer dress?	H14 A-B	warp, weft	2
	Fragment, sleeve	H28A	warp, weft, dark textile	3
	Fragment, trousers	H39 A-B	warp, weft, sewing thread	3
	Fragment. felt	H42	dark, light samples	2
	Fragment, upper garment	H53 A-B	warp, weft	2
	Sleeve	H57	dark and light warps, and wefts	4
	Fragment, trousers	H72B	warp, weft	2
	Fragment (part of H72 A-B)	H91A	warp, weft	2
	Fragment, upper garment	H72C	warp, weft	2
	Liripipe hood	S3	warp, weft	2
	Band	S26	warp	1
	Fragment, upper garment	S28	warp, weft	2
Hvilehøj	Fragment	C4280a	warp, wefts	3
	Fragment	Ad C4290d	warp/weft unidentified and one random sample	3
	Rolls of woven textile	Ad C4291	warp/weft unidentified	2
	Bundle of wool fibres	Ad C4273-97 Plate 1	fibres	1
Jelling	Fragment	C43096	warp, weft	2
	Fragment	19999	warp/weft unidentified	2
Mammen	Embroidered garment	C135a	warp/weft from two fragments; one random warp; embroidery	6
	Open tabby weave	C135b	warp/weft unidentified	2
	Tabby fragments	C135c	warp/weft unidentified	2
	Tabby band	C135d	warp/weft unidentified	2
	Tablet woven band	C136a	dark and light warps/weft	3
	Braided band	C136c		1
	Padding	C138		1
	Padding	C139		1
	Pillow	C144	warp/weft/embroidery	3
	Wool fibre bundle	C150		1
Slotsbjergby	Padding	C9166	warp/weft unidentified	2
Trelleborg	Fragment	C37040	warp, weft	2

Table 8: The textiles sampled from the Viking Age in this study come from seven finds

Table 9: Percentages of fine fibres in wool yarns circa 1800 BCE to 400 CE																							
		100-80% of fibres measuring less than 25µm																					
PERIOD	SAMPLES	**100**	**99**	**98**	**97**	**96**	**95**	**94**	**93**	**92**	**91**	**90**	**89**	**88**	**87**	**86**	**85**	**84**	**83**	**82**	**81**	**80**	
BA c. BCE 1500-500	% of 118	2	5	14	19	10	14	14	6	5	3	3	2	1	1	0	1	0	1	0	0	1	100
EIA c. BCE 500-1	% of 62	26	40	13	11	2	3	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	100
RIA c. 1-400 CE	% of 79	18	13	13	18	9	6	5	1	4	3	3	0	1	1	3	0	1	0	1	1	0	100

Table 9: The number of fine fibres in the wool yarn samples dated circa 1800 BCE to 400 CE. Fine fibres rarely constitute less than 90% in samples from the Bronze to the Roman Iron Ages. The majority in the Bronze Age vary between 98% and 94%, and between 100% and 97% in the other two periods

Table 10: Percentages of medium fibres in wool yarns circa 1800 BCE to 400 CE																						
		0-19% fibres measuring 26-40µm																				
PERIOD	SAMPLES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
BA c. BCE 1500-500	% of 118	17	24	14	13	14	3	7	1	1	3	0	1	0	0	1	0	0	2	0	0	100
EIA c. BCE 500-1	% of 62	40	39	13	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
RIA c. 1-400 CE	% of 79	22	11	16	16	8	5	3	4	3	3	1	1	1	3	1	0	0	0	1	1	100

Table 10: The profile of medium fibres in wool yarn samples dated circa 1800 BCE to 400 CE. Medium fibres rarely exceed 10% in samples from the Bronze to the Roman Iron Ages. In the Early Iron Age, 5% was the largest percentage recorded whereas more varied results were seen in the wool from the other two periods

Table 11: Percentages of coarse fibres in wool yarns circa 1800 BCE to 400 CE													
		0-10% fibres measuring more than 40µm											
PERIOD	SAMPLES	0	1	2	3	4	5	6	7	8	9	10	
BA c. BCE 1500-500	% of 118	14	24	28	22	7	3	1	0	1	1	0	100
EIA c. BCE 500-1	% of 62	63	29	3	0	0	2	2	0	0	2	0	100
RIA c. 1-400 CE	% of 79	77	13	9	0	1	0	0	0	0	0	0	100

Table 11: The number of coarse fibres in wool yarn samples dated circa 1800 BCE to 400 CE. Coarse fibres rarely exceed 5% in samples dated from the Bronze to the Roman Iron Ages. In a majority of yarns from the Early and Roman Iron Ages, none were recorded, whereas they appear more often in the Bronze Age

Table 12: The overall fibre variety in the wool from the Bronze to the Roman Iron Ages								
	MOST UNIFORM SAMPLE				LEAST UNIFORM SAMPLE			
Period	%Fine	%Medium	%Coarse	Range in µm	%Fine	%Medium	%Coarse	Range in µm
BA	99	0	1	5, 7-17	80	17	2	12-29, 31-35, 60, 87, 100
EIA	100	0	0	5, 7-17	90	1	9	8-11, 13-25, 29, 43, 45, 48, 53, 55, 67, 109, 115
RIA	100	0	0	5, 7-17	81	19	0	8–31, 35–36

Table 12: The overall fibre variety in the wool from the Bronze to Roman Iron Ages. In the calculated numbers, the variations found in yarn samples from the Bronze Age and the Roman Iron Ages consist of differences in the percentages of fine and medium fibres. In the Early Iron Age, the differences lie in the percentages of fine and coarse fibres

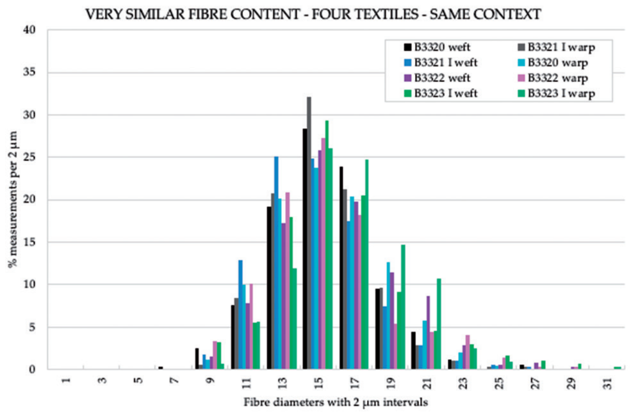

Fig. 4: Histogram showing the fibre diameter measurements of warp and weft samples from four textiles found in the same Early Bronze Age grave, Muldbjerg, in Denmark dated to 1365 BCE. The eight yarns have similar fibre diameter concentrations (Diagram: Irene Skals)

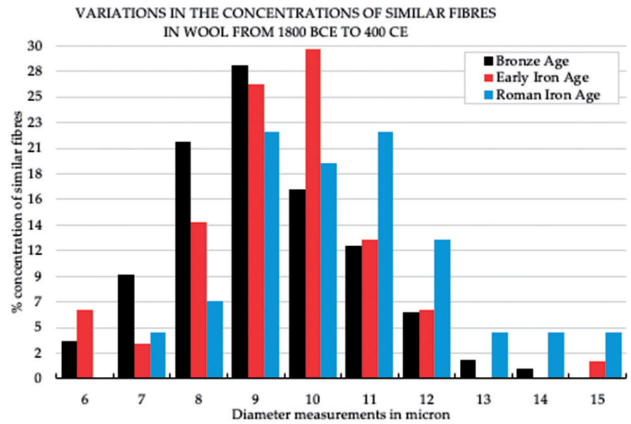

Fig. 5: Histogram showing the percentage variations in the concentrations of similar fibres in wool yarn samples from the Bronze to the Roman Iron Ages, circa 1800 BCE to 400 CE (Diagram: Irene Skals)

from the Bronze Age man's grave from Muldbjerg which contains an oval cloak (B3320), a wrap-around garment (B3321), a blanket (B3322) and two foot cloths (B3323). The eight yarn samples from these textiles have similar fibre distributions (fig. 4) with histograms showing high peaks and narrow curves, indicative of a very similar selection of raw wool.

The Roman Iron Age results differ from the two earlier periods with slightly lower concentrations of similar fibres and wider curves (fig. 5). It has been suggested that broad curves and low peaks in the histograms could indicate that wool from different sheep of the same flock was mixed (Rast-Eicher and Bender Jørgensen 2013). If so, the Roman Iron Age results could then signify a different manner of selecting or sorting the wool.

To select and sort wool according to its natural pigmentation was common practice in the Early Iron Age (Mannering et al. 2011). The wool colour differences were used to create textile patterns such as checks and stripes (Hald 1980). In the Bronze Age, most textiles were monochrome in dark naturally pigmented wool colours – although a striped woven belt and a textile made completely in white wool have been preserved (Broholm and Hald 1940).

Likewise, dyeing was commonly undertaken in the Early Iron Age, including textiles already patterned with naturally pigmented wool (Vanden Berghe et al. 2010), whereas the use of dyes in the Bronze Age has not been detected (Frei et al. 2017). During the Roman Iron Age, dyeing occurs less often than in the earliest part of the Iron Age (Andersson Strand et al. 2024; Møbjerg et al. 2019). Whether this is due to a craft change or the different preservation conditions in bogs and graves, respectively, is not known.

Wool development circa 600 CE to 1050 CE

The Late Iron Age results reveal that the wool fibre composition in the textiles changed sometime during the transition from Roman to Late Iron Age. The very high concentrations of fine fibres so common in the earlier periods were replaced with a wool mixture in which fine and medium fibres were recorded in equal quantities. This new kind of wool composition

Table 13: Percentages of fine fibres in wool yarns circa 620 to 1050 CE																			
		90% to less than 10% of fibres measuring less than 25µm																	
Period	Samples	90-86	85-81	80-76	75-71	70-66	65-61	60-56	55-51	50-46	45-41	40-36	35-31	30-26	25-21	20-16	15-11	< 10%	
LIA c. 620-800 CE	% of 31	3	10	3	0	3	6	6	16	6	6	13	13	6	0	3	0	3	100
VIK c. 800-1050 CE	% of 76	1	3	4	5	4	1	9	9	8	12	9	5	9	4	3	7	7	100

Table 13: The profile of fine fibres in wool yarn samples dated circa 620 CE to 1050 CE. As opposed to the earlier time periods the percentages of fine fibres vary from les than 10% to 90%

Table 14: Percentages of medium fibres in wool yarns circa 620 to 1050 CE																		
		8 - more than 70% of fibres measuring 26-40µm																
Period	Samples	8-11	12-15	16-19	20-23	24-27	28-31	32-35	36-39	40-43	44-47	48-51	52-55	56-59	60-64	65-69	>70	
LIA c. 620-800 CE	% of 31	3	3	6	3	0	13	10	13	3	16	10	3	3	6	3	3	100
VIK c. 800-1050 CE	% of 76	0	3	7	5	7	4	18	14	12	7	5	9	5	4	0	0	100

Table 14: The profile of medium fibres in wool yarn samples dated circa 620 CE to 1050 CE. There were between 8% and more than 70% medium fibres in the Late Iron Age yarns with the highest concentrations between 40% and 51%. In the Viking Age yarns, 12% to 64% medium fibres were recorded, and the highest concentrations were from 32% to 43%

Table 15: Percentages of coarse fibres in wool yarns circa 620 to 1050 CE																	
		0% to more than 66% of fibres measuring more than 40µm															
Period	Samples	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	>66	
LIA c. 620-800 CE	% of 31	10	39	19	13	6	0	3	3	3	0	0	0	0	3	0	100
VIK c. 800-1050 CE	% of 76	7	24	14	12	8	5	9	5	1	3	3	5	0	3	1	100

Table 15: The profile of coarse fibres in wool yarn samples dated circa 620 CE to 1050 CE. In the Late Iron Age, the coarse fibres make up less than 15% (except in one cord sample) whereas the Viking Age samples were more varied as a result of the use of coarse fibres in the warps

became even more apparent in the Viking Age. The percentage profiles are listed in tables 13 to 15 (based on 100 yarn samples from 48 textiles). In terms of wool development, this kind of wool can be interpreted as the mixed type in Rast-Eicher's system. The appearance of medium fibres was the only main difference in the wool. There were no indications of changes to the dimensions of the coarsest fibres, and naturally pigmented wool, like the wool in the Roman Iron Age, was also still present. Consistent with the definition of the wool type, medullas are only recorded in medium range fibres and appear interrupted.

The much greater fibre variety is illustrated by the large gap between the curves of the most and least uniform samples from these two periods as opposed to the Roman Iron Age (fig. 6). The most uniform samples have very large numbers of fine fibres mixed with some medium fibres. The least uniform samples have very high numbers of coarse fibres mixed with some medium fibres, a fibre profile not seen in the earlier textiles (table 16). It is noteworthy that the curves of the most uniform samples from the Late Iron and Viking Ages coincide with the least uniform sample from the Roman Iron Age. The changes observed in the wool seem to happen abruptly and may indicate the introduction of a different kind of sheep breed into this area between the Roman and the Late Iron Ages rather than the results of deliberate breeding.

Wool processing circa 600 CE to 1050 CE

The above-mentioned change in the wool fibre composition in the textiles seems to have altered the manner of selecting and sorting. Yarns with a majority

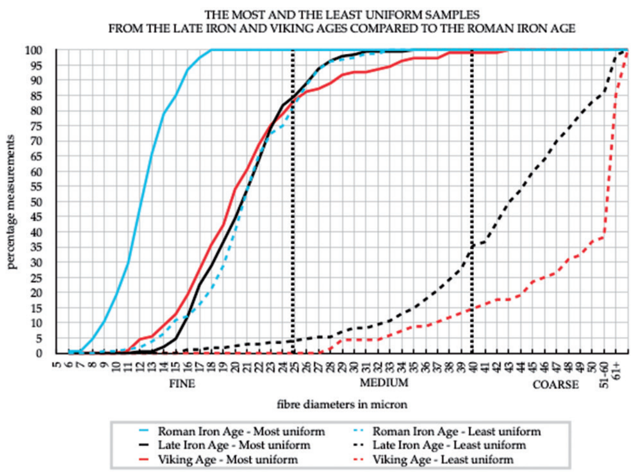

Fig. 6: Cumulative frequency diagram showing the most and least uniform samples from the Roman Iron, Late Iron and Viking Ages. The increased numbers of medium and coarse fibres that appear in the last two time periods are shown by the distance between the curves of the most and least uniform samples from each period. The most uniform Viking Age sample has a slightly larger number of fine fibres than the Late Iron Age sample, but the curves correspond with regard to the most uniform fibres (Diagram: Irene Skals)

Table 16: Overall fibre variety in the wool from the Late Iron and Viking Ages								
	MOST UNIFORM SAMPLE				LEAST UNIFORM SAMPLE			
Period	%Fine	%Medium	%Coarse	Range in µm	%Fine	%Medium	%Coarse	Range in µm
LIA	89 %	11 %	0 %	11, 13-30, 34 µm	5 %	31 %	64 %	15, 17, 19-20, 22, 24-26, 28-29, 31-57, 60-61, 63, 68 µm
VIK	86 %	14 %	0 %	7-37, 44 µm	0 %	15 %	85 %	27-28, 32-34, 36-41, 43-60, 62-65, 67 µm
RIA	100 %	0 %	0 %	5, 7-17 µm	81 %	19 %	0 %	8–31, 35–36 µm

Table 16: The overall fibre variety in the wool from the Late Iron and Viking Ages. The most and the least uniform samples in the Late Iron and Viking Ages differ distinctly in all three fibre groups. This variety enabled the use of different fibre types for different yarn functions

Table 17: Majority of fine fibres in Viking Age yarns							
LOW CONTENT COARSE FIBRES				HIGH CONTENT COARSE FIBRES			
warps	wefts	other	unid.	warps	wefts	other	unid
4	12	2	3	3	4	4	5
Total: 37							
MAJORITY OF MEDIUM FIBRES IN VIKING AGE YARNS							
LOW CONTENT COARSE FIBRES				HIGH CONTENT COARSE FIBRES			
warps	wefts	other	unid	warps	wefts	other	unid
1	4	1	3	7	5	1	2
Total: 24							
MAJORITY OF COARSE FIBRES IN VIKING AGE YARNS							
warps	wefts	other	unid				
7	0	1	3				
Total: 11							

Table 17: Fibre types and yarn functions in Viking Age textiles. In the Viking Age textiles, there is a distinct manner of sorting the wool with the intended function of the yarns in the weaves in mind

of fine fibres comparable to earlier were still seen, but so were yarns with equal or almost equal quantities of fine and medium fibres and yarns with a majority of medium or coarse fibres. Viewing these differences with respect to the functions of the yarns, very specific preferences were obvious (table 17). Wool consisting of a majority of fine or medium fibres was found in wefts and only in warps from textiles where warp and weft had similar fibre profiles. Wool with a majority of medium and a large number of coarse fibres or with a majority of coarse fibres was used for warps. This use of the coarse fibre differs distinctly from the earlier periods. It is not possible to know if this specific raw wool was characterised by a larger number of coarse fibres than in the earlier periods or that a societal demand for using all available fibre types initiated this different way of producing textiles. Nevertheless, this specific way of sorting the wool must have required organisation and training in new skills.

There are no preserved textiles from the Late Iron Age that document wool sorting according to natural pigmentation to make patterned textiles, but it was practiced in the Viking Age. From Hedeby, two textiles have dark warps and unpigmented wefts (Hose H2 and Caftan H11). One textile is made with both one dark and one unpigmented warp and weft (Sleeve H57), and one felt textile is patterned with dark and unpigmented fibres (H42). Dyes have been detected in some Viking Age textiles (Vanden Berghe et al. 2023) while the Late Iron Age textiles have not been thoroughly analysed yet.

Rast-Eicher's categorisation system, which was found to inadequately characterise the early wool samples with the very large number of fine fibres, provides the Late Iron Age and Viking Age wool with much more nuanced results (table 18). In the Late Iron Age textile samples, the categories vary between AA and CD, and, in the Viking Age samples, between AB and EE. A few samples had fibre profiles which fell outside the categorisations.

Discussion

Wool fibre preparation is a very important part of the process of producing a textile. It has a significant

Table 18: Rast-Eicher's model of fibre classification attributed to Late Iron and Viking Age textiles			
% FIBRES OF DIFFERENT DIAMETERS	WOOL QUALITY CLASS	NO. OF LATE IRON AGE SAMPLES	NO. OF VIKING AGE SAMPLES
92% < 25 µm, 8% > 25.1 µm, 1% > 30 µm, max. 40 µm	AAA	0	0
85% < 25 µm, 15% > 25.1 µm, 3% > 30 µm, max. 60 µm	AA	1	0
93% < 30 µm 7% > 30.1 µm, 1% > 40 µm, max. 60 µm	A	2	0
80% < 30 µm, 15% > 30.1 µm 2% > 40 µm, max. 60 µm	AB	2	5
75% < 30 µm, 25 % > 30.1 µm, 2% > 40 µm	B	4	4
66% < 30 µm, 10% > 45 µm, 1% > 50 µm	C	5	11
80% < 40 µm, 20% > 40.1 µm, 2% > 60 µm	CD	11	25
66% < 40 µm, 34% > 40.1 µm, 5% > 60 µm	D	1	7
60% < 40 µm, 40% > 40.1 µm, 10% > 60 µm	E	3	12
50% < 40 µm, 50% > 40.1 µm, 15% > 60 µm	EE	1	5
50% < 30 µm, up to 50% > 60 µm	F	0	0
No category		1	7

Table 18: Rast-Eicher's model of fibre classification attributed to Late Iron and Viking Age textiles. This classification appears more nuanced when used for the wool from these periods.

impact on the quality and properties of the final product. Considering this, it is important to keep in mind that sheep breeding is, and was in prehistory, the result of a cooperation between the sheep farmers and the needs and desires of their immediate society. Sheep breeding for wool may have differed from sheep breeding for meat and, just as today, the quality of the product depended on the demand. The cause and effect of changes in the wool fibre composition and its processing were therefore interdependent and influenced by the sheep owners, the craftspeople, and the technology available to them, all of which were expressed in the textile design.

Through the results of these fibre analyses, it has been possible to trace about 3,000 years of development and use of wool in textile production in Denmark. Assuming that the quality of the wool was adjusted to demand, it is interesting to observe at what point in time changes appear.

The results show that wool from the Danish Bronze Age until the end of the Roman Iron Age was very similar with two distinct fibre types and almost no fibres in the medium range. During the transition between the Roman and the Late Iron Ages, this was replaced with wool with a wide range of medium fibres. From this, it can be deduced that the textile producers used the same wool from the beginning of the Bronze Age to the end of the Early Iron Age, when a new fibre type seems to appear.

The decreased thickness of the coarsest fibres is one of the first parameters used to indicate a development away from the primitive wool towards the evolved wool. This characteristic change happens between the Danish Bronze and Early Iron Ages around 500 BCE. These results indicate no further fibre changes in this regard except for a significant change in the dimensions of the coarsest fibres shown by an increased number of fibres ranging from 40 to 80 microns in the Late Iron Age textiles (table 19). The appearance of fibres in the medium range is interpreted as yet another sign of development, and, in the Roman Iron Age results, a slight increased fibre variety was found, although it is not sufficiently significant to indicate the use of a different wool type.

Fibre roots and tips have not been observed in this study but both have been detected in Hallstatt wool by scanning electron microscopy and, in the same study, it was possible to establish the use of fibre combing in the individual yarns by studying the direction of the scale patterns on the fibres (Rast-Eicher 2013). With

Table 19: Changes in the dimensions of coarsest wool fibres throughout the prehistoric period					
Periods	40-59 µm	60-79 µm	80-100 µm	above 100 µm	Max. µm
% of 118 BA samples	3	7	14	64	224
% of 62 EIA samples	8	10	6	15	124
% of 79 RIA samples	11	9	8	6	125
% of 31 LIA samples	55	19	6	10	134
% of VIA samples	41	41	11	3	119

Table 19: This table shows changes in the dimensions of the coarsest wool fibres throughout the prehistoric period. The sizes of the coarsest fibres were comparable in the Bronze and Early Iron Age samples. Fibres measuring between 40 and 80 microns increase in the Late Iron and Viking Ages. Fibres larger than 100 microns were characteristic for the Bronze Age samples

respect to deliberate choices of fibres, these results show that some yarns were made with uniform fibre profiles whereas others were slightly more varied. This most likely signifies conscious choices at work: the uniform fibre profiles with no medium or coarse fibres may indicate meticulous wool practices in the Early Iron Age.

It is not possible to determine whether the wool or the textiles from the early periods were locally produced or imported from these analyses. The results appear homogenous, and the use of the wool seems founded on similar standards and traditions. A distinct set of characteristics in the Danish Bronze Age wool, which so far has only been recorded in a few textiles outside Scandinavia, is the extreme fineness of the minimum size fibres, the large quantities of very fine fibres, and the almost complete lack of medium fibres. There are theories that a different sheep breed existed in this area compared to others (Rast-Eicher and Bender Jørgensen, 2013; Ryder 1983a; 1988; Walton 1988). The extensive uniformity of the fibre profiles results in very narrow ranges of measurements, few very high peaks in the histograms, and very steep slopes in the cumulative frequency diagrams. So far, similar results have only been recorded in two Italian textiles, from Castione dei Marchesi dated to about 1100 BCE and from Cogion dated to about 300 BCE, and in a textile from Pustopolje, Bosnia-Herzegovina, dated to 1600 BCE to 1200 BCE. None of the published Hallstatt results from Austria have comparable narrow ranges and fine minimum measurements (Gleba 2012; Grömer et al. 2018; Rast-Eicher and Bender Jørgensen 2013).

Yarn thickness and weave types differ in the different archaeological periods depending on the desired shape and drape of the textiles. This has required changes to the fibre profiles and the need for different wool processing. In this respect, the quantities of coarse fibres in the early wool are interesting. Experimental archaeology studies have documented that it is difficult to spin thin yarns if the coarse hair and kemp are not removed (Grömer and Saliari 2018). It was suggested here that the number of coarse fibres decreases when teasing and combing the wool. The amount of sorting and combing and the thickness of the yarns are therefore interdependent. This means that the extent of coarse fibres in the yarns was a deliberate choice. In this respect, there were slightly larger numbers of coarse fibres in the wool from the Danish Bronze Age samples than in others. The yarns in these weaves were generally quite thick with a diameter of about one millimetre, single and evenly spun with a hard twist. In contrast, the decorative embroidered piles on the surface of the caps found in several men's graves were made with very thin plied yarns measuring about 0.3 mm (Skals 2020). The fibre analyses from these do not differ in any significant way, and it appears that both thick and thin yarns were made from wool with similar fibre composition.

In the Early Iron Age results, the number of coarse fibres was very small (see table 9 to table 11) but samples of sewing threads, especially when used for repairs, generally have higher numbers of coarse fibres, perhaps indicating the intention of making a stronger yarn. A remarkable lack of coarse fibres is seen in the results from the Roman Iron Age where the wool in other ways appears quite similar to the earlier periods. It seems unlikely that the coarse fibres simply disappeared from the raw material and therefore this characteristic could be the result of thorough processing.

The coarse fibres cannot be used to interpret and understand the processing of the wool from the Late Iron and the Viking Age textiles. The selection and sorting of the different fibre types was now performed with the function of the yarn as warp or weft in mind and clearly illustrates the interdependence of the different processes in textile production. All fibre types were used in the textiles. The coarse fibres were used for making strong warps, whereas the fine and medium fibres were preferred for the wefts. Similar practices have been documented in Central European Iron Age textiles (Rast-Eicher and Bender Jørgensen 2013) and that tradition continued for several centuries in Scandinavia, as documented by analyses of the archaeological textiles from the Norse settlements in Greenland dated from about 1000 CE to 1400 CE (Walton 2003).

Conclusion

Although there is no evidence of the use of wool for textiles before the Early Bronze Age, there are no preserved textiles which indicate unprofessional workmanship. All the textiles appear to have been created by knowledgeable and experienced people. The terminology used to describe prehistoric wool and textiles often contributes to subjective impressions of them as primitive. The terms coarse and fine are, as this study shows, used in wool fibre analyses, and the results are interpreted with regard to the development of the wool from the coat of the wild or the primitive to the domesticated or the developed animal. Similarly, sheep breeds with undercoats of fine wool and overcoats of coarse hairs now living are called primitive breeds. This use of value-laden words colours the general impression of the quality of the textiles, and they are often thought to be prickly to the skin and uncomfortable to wear. These studies of the wool fibres tell a different story.

Reconstructions of prehistoric textiles are often made using wool from the modern primitive sheep breeds, but so far, finding a proper wool for reproducing the Danish Bronze and Iron Age textiles has proved almost impossible. The very fine fibres which have been the main component of these textiles cannot be matched with the fine underwool from today's primitive sheep breeds, but when it concerns the Viking Age wool quality, the situation is much better. A recent research project aiming at reproducing several different Viking Age textile qualities successfully found and processed comparable modern wool from primitive sheep breeds (Skals et al. 2024).

The way of evaluating the results from wool fibre analyses presented here has been possible because the Danish material is so extensive. The work was initiated by the need and desire to reveal the subtle information hidden in the large quantity of collected data, as well as the need to make the results accessible to people working with reconstructions of prehistoric textiles and wool fibre preparation. It has been surprising to find that the differences in the yarns which can be interpreted as the results of processing are very subtle. The degree of similarity found in each archaeological period seems to indicate great skill but also that specific standards were taught and passed on over long periods of time.

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