Textile standards in experimental archaeology

Krista Vajanto

ABSTRACT
This article sheds light to the textile standards that are testing methods of the textile industry. The breaking resistance of yarns, the colour fastness for perspiration and the tex value are discussed especially from the viewpoint of experimental archaeology. Standards for these parameters are applied to the test material made of Finnish machine- and hand-spun wool yarns, as well as yarns dyed with three different dyeing methods and three natural dyes: i.e., Dyer's madder (Rubia tinctorium), alder buckthorn (Rhamnus frangula), and rock tribe (Lasallia pustulata). The hand-spun yarns were found to be stronger than machine-spun and the tenacity correlated to the dyeing methods. Especially the double-coated wool suffered from dyeing with the boiling method, but retained the strength when dyed in a fermented alder buckthorn bath. The colour fastness for perspiration was found to be excellent in the yarns dyed with lupine and rock tribe that often are not valued by modern dyers due to low light fastness. The study offers new possibilities to understand the selections made for the yarns and dye materials in the past.

Keywords: tex value, breaking resistance, colour fastness for perspiration, wool, natural dyes, fermentation

1. Introduction

The *textile standards* are test methods made for the textile industry to test and compare different textile products and certain parameters with relatively simple test procedures. There are worldwide ISO standards, European EN standards, American AATCC and ASTM standards, and other national standards (*ISO.org*; Saville 2000, 298–299; Kadolph 2007, 42). However, textile standards are quite unknown in textile archaeological research. When researching replica material based on archaeological finds, it has been found that textile standards can give useful knowledge that is suitable to archaeological textile research. With a standardised test protocol of the empiric test methods, it is possible to produce comparable data that answers the demand for the repetitive and accurate research methods sought for experimental textile archaeology (Andersson Strand 2010, 1–3).

The basic element of most of the archaeological textiles is a yarn. Often the yarns have been studied by thickness, twist or ply as well as the spinning and plying angle (Seiler-Baldinger 1994, 3–4). To understand the differences between the hand-spun and machine-spun yarns, the replica yarns were measured with ISO 2062:2009 textile standard. This textile standard records the *breaking resistance* as well as the strain and the tenacity of the yarn. The *tex value*, presented in the textile standard ISO 1144:1973, was applied to find thin wool yarns that are near each other by linear density (Tevasta 2009, 10–12; *ISO.org*). The same textile standards were applied in order to study the effect of a dyeing method to the tenacity of a yarn.

The textile standard ISO 105-E04:2008 was applied to find out the *colour fastness* of the natural dyes *for perspiration*. Sweat stains can be considered as wear marks that can tell us about the history of a textile especially when a textile is large enough and armpit areas are present. For example, it can be questioned whether the funeral textiles had been made specifically for the funeral ritual or had been worn in the everyday life.

1. Espoo
2. Lohja
3. Eno
4. Archipelago Sea

Map 5. Placenames mentioned in the article of Vajanto. Illustration: K. Vajanto.

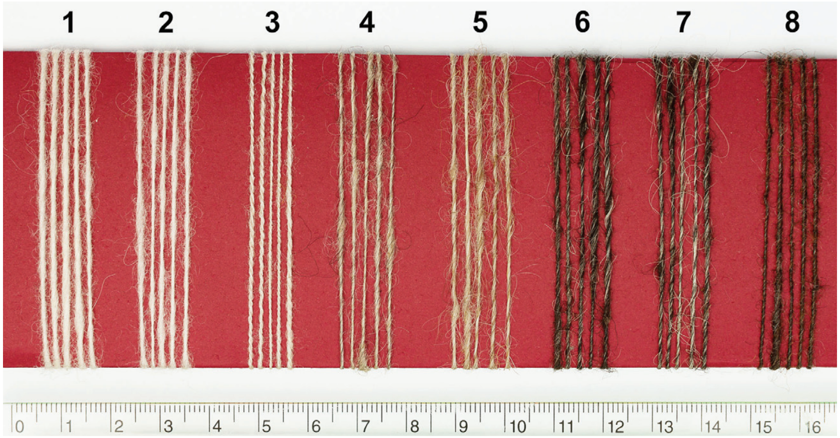


Fig. The hand-spun yarns I–VIII tested with the textile standard ISO 2062:2009. J. Markkanen.

2. Materials

2.1 Wool yarns

Eight different wool yarns were selected for the breaking resistance test (Yarns I–VIII, Table 1 and Fig). The yarns were tested not only as undyed, but also as dyed with three different plant dyes with different dyeing methods. Yarn I was machine-spun Finnsheep wool by *Pirtin kehräämö* and yarn II was by *Virtain villa*; both are available from Finnish yarn manufacturers. Yarns I, II, as well as the hand-spun yarn III contained Finnsheep wool. Miscellaneous machine-spun yarns, made of white Finnsheep wool, were selected for the colour fastness for perspiration test (Yarns 1–15, Table 2). The Finnsheep wool is homogenous and of Semi Fine (SF) type (Ryder 1974, 1984, 1987; Vajanto 2013b). Yarns IV–VIII (Table 1) were spun from double-coated wool of the Finnish Jaalasheep. The wool is a primitive type with under wool and outer coat hairs (Manninen 2012, 13; Vajanto 2011a; 2013b). The wool types of yarns IV–VIII were Hairy medium/Generalised medium (HM/GM), Hairy medium (HM) and Hairy (Table 1), of which the Hairy type (H) contains the most distinct populations of underwool and outer coat fibres (Ryder 1974, 1984, 1987; Vajanto 2013b).

Before the hand spinning, the wool staples were washed gently without any detergents by leaving the staples in fresh water for some days at room temperature; they were then dried on a horizontal level. All of the hand spun yarns were spun with a drop spindle with a whorl of 17 g and spindle shaft of c. 27 centimetres. Yarns I and II were machine-carded wool. Yarns III, V, VI and VIII were combed with small wool combs, but yarns IV and VII were carded with hand carders. The spinners were skilled and able to produce thin and even yarn from different wool types with a speed of 37–57 metres per hour.

2.2 Dyes

According to Finnish folklore, all the selected dyes have been used by folk people in Finland from the late 19th to the early 20th centuries. The folklore was mainly collected in surveys conducted by the scholars of The Finnish Literature Society and carried out by interviewing old folk people about almost forgotten old habits and skills. Another important source of plant folklore is the herbarium, *Flora Fennica,* written by Elias Lönnrot in 1860. It was the first herbarium written in Finnish, and contains abundant knowledge of the medical, dye and editable plants and folkloric variants of plant names.

According to the folklore, the red dyes were obtained from the roots of local bedstraws, i.e. Lady's bedstaw (*Galium verum*) and northern bedstraw (*Galium boreale*) and imported roots of Dyer's madder (*Rubia tinctorium*). Red was also obtained from the roots of the common tormentil (*Potentilla erecta*), bark of alder species (*Alnus glutinosa* and *Alnus incana*), alder buckthorn (*Rhamnus frangula*), and bark of silver birch (*Betula pendula*).[1]

1 MV:KTKKA. Haahti, Kerttu 1936: Kasveilla värjäys, 29–39; SKS/KRA. Inkeri. Mannonen, Ulla 12 d, h, i, j, s: 4409/1937; SKS/KRA. Kirvu. Pärssinen, Sirkka E 142: 14–16/1938; SKS/KRA. Orivesi. Hörtsänä, Hugo 3058/1953

Table 1. The technical data of undyed yarns researched in the breaking resistance test using the ISO 2062:2009 textile standard.

No.	Wool	Wool type	Carding/ Combing	Spinning	Twist	Spin/ply angle (°)	Diameter (mm)
I	Finnsheep white	SF	Machine carders	Machine	z	30	1
II	Finnsheep white	SF	Machine carders	Machine	z	30	0.75
III	Finnsheep white	SF	Wool combs	Hand	Sz	40/55	0.5–1
IV	Finnish Jaalasheep grey	HM/GM	Hand carders	Hand	z	20	0.5–1
V	Finnish Jaalasheep beige	HM	Wool combs	Hand	z	20	0.5–1.5
VI	Finnish Jaalasheep black and white	H	Wool combs	Hand	z	20	1–1.5
VII	Finnish Jaalasheep black and white	H	Hand carders	Hand	z	20	1–1.5
VIII	Finnish Jaalasheep brown	HM/GM	Wool combs	Hand	z	33	0.5–1

The folklore records show that yellow came from evergreen plants such as heather (*Calluna vulgaris*), wild rosemary (*Rhododenrdon tomentotosum*), bog rosemary (*Andromeda polifolia*), and crowberry (*Empetrum nigrum*) (Linnilä et al. 2002, III/231, 245). Bright yellow came from the leaves of the silver birch (*Betula pendula*), especially when collected in early spring.[2]

The fresh, blue berries of the alder buckthorn (*Rhamnus frangula*), blue cornflowers (*Centaurea cyanus*)[3] and purple flowers from heartsease (*Viola tricolor*) were used for shades of blue and turquoise (Linnilä et al. 2002, III/91–92). For this study the turquoise was taken from everywhere abundantly growing lupine (*Lupinus polyphyllus*) to protect the more rare species (Vajanto 2013a, 7–9.)

Natural alum mordant was made from club moss (*Lycopodium species*)[4], which was boiled for several days (Hassi 1981: 46). Crottle (*Parmelia saxatilis*)[5] was used for browns and rock tribe (*Lasallia pustulata*) was used for purple (Warg 1790; Westring 1805: 160–183; Casselman 2001, 11; Tetri 2013, 172–173).

2.3 Dyeing methods

Because there are slight, but possibly important variations, the dyeing recipes are explained here in detail to encourage other researchers and dyers to repeat them. Before dyeing, the yarns were not washed with detergents, just wetted. The water was Finnish tap water, which is pure, soft and has a pH value of 7.5–8. After dyeing, all the yarns were rinsed with lukewarm water, without any detergent and dried avoiding direct sunlight.[6]

2.3.1 Fermented tannins

A dye bath was prepared with the fermentation method from plants and wood ash lye. Two litres of birch wood ash was collected to a bucket from a sauna stove. The lye was prepared by pouring eight litres of boiling water over the ash (Hassi 1981, 25–26; Dean 1999, 58; 2007, 38). After three days the lye had a pH value 10 and it was sieved.

Then dry, chopped bark of alder buckthorn and chopped dry birch bark were added to the buckets that contained the sieved lye. The ratio of the plant materials and lye was 1:10. The fresh and chopped roots of tormentil were used with the same ratio. The fermentation process of the dye baths took four weeks at room temperature and the pH value of the baths decreased from 10 to 6. Then the skeins (Yarns 1–3, Table 2) were added to these bubbling baths that had the odor of red wine and were dyed for two weeks at room temperature (Vajanto 2010a; Vajanto 2011b, 287–231; Vajanto 2011c, 34–36).

2 SKS/KRA. Orivesi. Hörtsänä, Hugo 3058/1953

3 SKS/KRA. Inkeri. Mannonen, Ulla 12 d, h, i, j, s: 4409/1937; SKS/KRA, Hausjärvi. Salminen, Kaarina E 177: 5/1947.

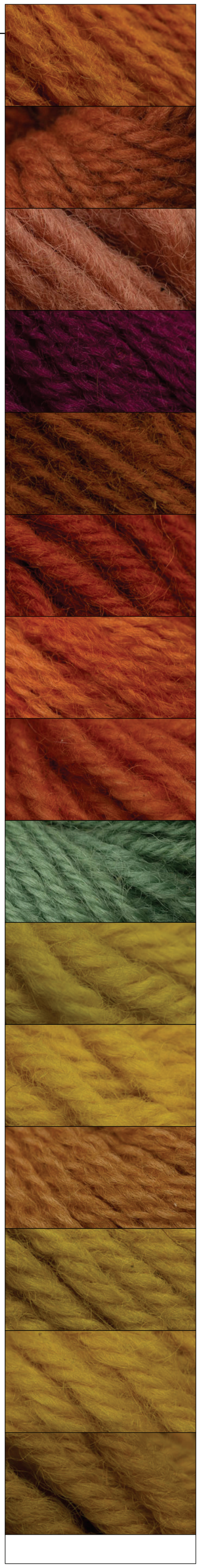
4 SKS/KRA. Rautu. Snellman, Kirsti E 134: 6–7/1936

5 SKS/KRA. Kirvu. Pärssinen, Sirkka E 142: 14–16/1938; SKS/KRA. Rautu. Snellman, Kirsti E 134: 6–7/1936

6 Northern bedstraw roots, silver birch bark, rock tribe, common lupine flowers, silver birch leaves, heather, crowberry and wild rosemary were collected in Espoo. Chopped Dyer's madder and alnus buckthorn were bought from TetriDesign dye shop www.tetridesing.fi, crottle was collected in the Archipelago Sea, clubmoss in Eno and common tormentil roots in Karjaa. See Map 5 for the sites of plant collection.

Table 2. CIELAB values of the dyed yarns before the colour fastness for perspiration test ISO 105-E04: 2008. Photos: J. Markkanen

No.	Plant	CIELAB (D 65)
1.	Alder buckthorn (*Rhamnus frangula*), bark	L* 46.09 C* 44,70 a* 23.10 h* 58.88 b* 38.26
2.	Common tormentil (*Potentilla erecta*), roots	L* 37.09 C*34.07 a* 25.87 h* 40.59 b* 22.17
3.	Silver birch (*Betula pendula*), bark	L* 48.06 C* 22.35 a* 17.86 h* 36.97 b* 13.44
4.	Rock tribe (*Lasallia pustulata*), whole lichen	L* 24.68 C* 20.31 a* 18.83 h* 338.04 b* -7.59
5.	Crottle (*Parmelia saxatilis*), whole lichen	L* 33.02 C* 40.23 a* 22.27 h* 56.39 b* 33.51
6.	Dyer's madder (*Rubia tinctorium*) roots + Club moss (*Lycopodium*), whole plant	L* 32.14 C* 43.96 a* 32.03 h* 43.23 b* 30.11
7.	Dyer's madder (*Rubia tinctorium*), roots	L* 47.82 C* 47.78 a* 33.15 h* 46.07 b* 34.41
8.	Northern bedstraw (*Galium boreale*), roots	L* 42.09 C* 43.13 a* 32.84 h* 40.41 b* 27.96
9.	Common lupine (*Lupinus polyphyllus*), flowers	L* 39.87 C* 15.54 a* -10.33 h* 131.67 b* 11.61
10.	Silver birch (*Betula pendula*), leaves	L* 59.70 C* 68.58 a* 6.42 h* 84.63 b* 68.28
11.	Heather (*Calluna vulgaris*), whole plant	L* 61.98 C* 61.43 a* 6.50 h* 83.93 b* 61.09
12.	Crowberry (*Empetrum nigrum*), whole plant, collected in winter	L* 50.03 C* 30.90 a* 14.97 h* 61.02 b* 27.03
13.	Crowberry (*Empetrum nigrum*), whole plant, collected in summer	L* 61.87 C* 46.13 a* 4.21 h* 84.77 b* 45.94
14.	Wild rosemary (*Rhododendron tomentosum*), whole plant	L* 58.83 C* 53.21 a* 7.45 h* 81.86 b* 52.68
15.	Bog rosemary (*Andromeda polifolia*), whole plant	L* 55.79 C* 63.00 a* 12.11 h* 78.91 b* 61.83



2.3.2 Urine bath

A dye bath was prepared from dried rock tribe and human urine. First, the urine was stored for ten months at 4°C under a lid and two months in a warm storage in a container without a lid. Finally, it reached a pH value of 10. The dyestuff was yielded from 100 g of dried rock tribe by soaking the lichen in three litres of fermented human urine at the temperature of 4°C and in darkness. This took three months. After that, the skein (Yarn 4, Table 2) was dyed in the dye bath that still contained the lichen material. The dyeing took two weeks in darkness at a temperature of 4°C (Vajanto 2010b).

2.3.3 Lichen bath with no added mordant

No chemicals or additional natural mordant is needed for a crottle dye bath, which itself works as a mordant. The skein (Yarn 5, Table 2) was just boiled one hour with dried crottle using 200 g of lichen and ten litres of water (Goodwin 2003, 90–91; Hassi 1981, 122).

2.3.4 Alum mordant baths

Club moss is a natural source of alum. A mordant bath was prepared from 200 g of fresh plant and ten litres of water. During one week, the dye bath was heated once a day to 80°C, but kept meanwhile at a temperature of 30–50°C. Slowly, the bath attained a lemon juice odor and pH value of 5. The skein (Yarn 6, Table 2) was added to the sieved bath and mordanted by boiling for 45 minutes (Hassi 1981, 46). After mordanting, the yarn was dyed by boiling it in eight litres of water with a temperature of 90°C for 45 minutes. The ratio of dry plant material and yarn was 2:10. The remaining yarns were mordanted by boiling them for 45 minutes with 12 g of alum and 4 g of cream of tartar (Yarns 7–15, Table 2).

The mordanted yarns (Yarns 6–15, Table 2) were *not* rinsed after mordanting. The mordanted yarns 7–9 (Table 2) were dyed with eight litres of water with fresh, cleaned and chopped roots of northern bedstraw, or fresh flowers of purple lupine or fresh silver birch leaves. There the ratio of fresh plants and yarns was 2:1. For the mordanted yarns 10–15 (Table 2), the dye baths were prepared by boiling 300 g of fresh plant materials in eight litres of water for 1.5 hours. After this, the baths were sieved and cooled down. The mordanted yarns were dyed in the dye baths by boiling them in 90°C for 45 minutes (Hassi 1981, 48, 52–54).

3. Research methods

3.1 Breaking resistance

The *breaking resistance* is measured using the ISO 2062:2009 textile standard (Tevasta 2009, 382–391, *ISO.org*). It tells how strong a yarn is, how large a load is needed to break the yarn, and how much the yarn can be stretched before it breaks (Saville 2000, 115–118). The *tenacity* (cN/tex) of the yarn is the ratio of the breaking force (cN) and the *tex value* (tex).

The tex value, ISO 1144:1973, expresses the linear density of a yarn, in other words the mass per unit of length (i.e., 1 g/1000m = 1 tex) (Taylor 1994, 63). The resulting tenacity value of the breaking resistance test is dependent on such factors as the thickness of the yarn, spin and ply properties, and type of fibres. Therefore, the values measured from the individual fibres vary from the values measured from the yarns. For the individual fibres, the textile standard ISO 5079:1995 is recommended (*ISO.org*).

The breaking resistance test was made with SDL Testometric MTCL 250 that is a Constant Rate of Elongation (CRE)-type apparatus. The yarn was inserted to a tension between two gauges that stretched the yarn (Saville 2000, 132). The yarns were pre-tensioned with a 50 g weight. All the sampled yarns were 25 centimetres in length and dry. The *Strain* of a yarn was observed at its breaking point. The measurement was stopped manually at the point of the break. The measurement was made until the point, at which the last fibre of the measured yarn broke.

For industrial purposes, the textile standard ISO 2062:2009 requires 50 measurements for unplied yarns and 20 for plied ones. Unfortunately, this requirement was too stringent for the unique hand-spun and plant-dyed yarns that formed most of the research material. Because of this, each yarn was measured only five times. However, the values measured from each yarns were very consistent. The results can be taken as an example of the actual method as well as a source of inspiration for the understanding of the behaviour of different types of yarns.

3.2 Colour fastness for perspiration

Sweat tolerance of dyes was measured using the textile standard ISO 105-E04: 2008 (Tevasta 2010, 261–275; *ISO.org)*. For the test, two kinds of artificial human sweat were prepared according to the test protocol (Saville 2000, 252–253; Taylor 1994, 204). The acidic sweat had a pH value of 5.5 and the alkaline sweat a pH value of 8.

The dyed yarn samples were sewn within two white adjacent fabrics (Saville 2000, 246). The recommended adjacent fabrics are determined in the textile standard ISO 105-F01–F07:2009, that contains fabrics made from both natural and synthetic fibres. For this research single-fibre adjacent fabrics of wool (ISO 105-F01:2009) and cotton (ISO 105-F02:2009) were selected, because these materials are also known in archaeological materials (Gleba and Mannering 2012, 5–7). The acidic and alkaline sweat was infiltrated to the test samples by following the ISO test protocol. After this, the samples were placed in the test device under the necessary pressure and kept in the warmth of 37°C for four hours.

The results were valued from the dried yarns with so-called *grey scales* using the textile standard ISO 105-A03:1993 (Saville 2000, 245; Taylor 1994, 198–199; *ISO.org*). The change of colour was valued with a card that has five steps from light grey to dark grey and staining with a card that has five steps from white to black. In addition, the values can be announced with half steps, as in 1/2, 2/3, 3/4, 4/5. The best result with no colour change or staining received the value 5, and the worst the value 1.

In order to get objective measurement data about the colour changes, all the colour values were also measured in the CIELAB colour space. The measurements were done with the Minolta CM 2600D Spectrometer, with the Spectra Magic programme and the D65 illuminant (Trotman 1984, 548). The measured area was eight millimetres in diameter.

3.3 Test conditions

The test conditions are instructed in the descriptions of the ISO 139:2005 textile standard. In practice, it is not always possible to achieve recommended test environment that has relative humidity of 65% and a temperature of 20°C (*ISO.org*; Kadolph 2007, 83). For this study, the environment had the relative humidity of 45% and the temperature of 22°C. The tests were carried out in similar conditions to each other; thus the results are comparable.

Wool and other fibres behave in relation to humidity and temperature. Dry wool is stronger than wet, but wet wool can be extended more (Saville 2000, 27–28, 135–136). The yarns were not preconditioned due to an incomplete test environment. The skeins were loosened and let to rest in the test environment for 24 hours. If the measurements had been carried out in a moister standard atmosphere, the measured breaking resistance values could have been slightly smaller and strain values higher.

4. Results

4.1 Stronger and weaker yarns

The data of the measurements is presented in Table 3. The values are presented as averages of five measurements and rounded as recommended in the textile standard. The highest forces were needed to break the hand spun yarns. In general, the high tenacity seemed to correlate with the primitive type of wool, combing, high degree of twist and ply as well as the fermentation dyeing method.

Table 3. Results of the breaking resistance test (ISO 2062:2009).

No.	Yarn, wool and dye	Tex value	Load at breaking point (cN)	Strain (%)	Tenacity (cN/tex)
I Finnsheep, machine spun, machine carded					
Ia	Undyed	220	326	60	1.5
Ib	Alder buckthorn	184	366	53	2.0
Ic	Dyer's madder	182	287	50	1.6
Id	Rock tribe	164	329	55	2.0
II Finnsheep, machine spun, machine carded					
IIa	Undyed	125	211	51	1.7
IIb	Alder buckthorn	138	441	48	3.2
IIc	Dyer's madder	132	127	52	1.0
IId	Rock tribe	134	252	41	1.9
III Finnsheep, hand spun, combed, plied					
IIIa	Undyed	109	530	11	4.9
IIIb	Alder buckthorn	111	656	17	5.9
IIIc	Dyer's madder	113	567	20	4.9
IIId	Rock tribe	113	539	20	4.8
IV Finnish Jaalasheep, hand spun, carded					
IVa	Undyed	159	620	48	3.9
IVb	Alder buckthorn	124	622	31	5.0
IVc	Dyer's madder	155	407	29	2.6
IVd	Rock tribe	150	389	55	2.6
V Finnish Jaalasheep, hand spun, combed					
Va	Undyed	186	460	61	2.5
Vb	Alder buckthorn	185	323	54	1.8
Vc	Dyer's madder	191	324	73	1.7
Vd	Rock tribe	159	226	51	1.4
VI Finnish Jaalasheep, hand spun, combed					
VIa	Undyed	227	767	34	3.4
VIb	Alder buckthorn	243	733	25	3.0
VIc	Dyer's madder	151	285	37	1.9
VId	Rock tribe	139	389	40	2.8
VII Finnish Jaalasheep, hand spun, carded					
VIIa	Undyed	215	508	22	2.4
VIIb	Alder buckthorn	213	796	30	3.8
VIIc	Dyer's madder	268	248	36	0.9
VIId	Rock tribe	200	305	28	1.5
VIII Finnish Jaalasheep, hand spun, combed					
VIIIa	Undyed	164	822	15	5.0
VIIIb	Alder buckthorn	188	812	15	4.3
VIIIc	Dyer's madder	190	725	14	3.8
VIIId	Rock tribe	198	766	25	3.9

As instructed in the textile standard ISO 2062:2009 the *breaking force* is presented in the Table 3 in centiNewtons (cN) with three significant figures. The *Strain* of a yarn at its breaking point is announced in percentages with two significant figures. The *tex value* is expressed with three significant figures and the *tenacity* with two.

4.2 Sweat on dyed yarns

The colour fastness to perspiration was evaluated according to the protocol instructed in the textile standard ISO 105-E04: 2008. The tested yarns were compared with the grey scales and the original shades of colours. The results of the acidic test are presented in Table 4 and alkaline in Table 5. The greatest changes in colour were on alder buckthorn and wild rosemary yarns. Staining was scanty in all yarns.

5. Discussion

5.1 Tenacity of the yarns

In the test presented in textile standard ISO 2062:2009, the hand-spun yarns were found to be stronger than the machine-spun ones. There are several explanations for this phenomenon. One comes from the wool processing: if the fibres lie in a parallel position, that is, if they have been combed, the linear density grows and the yarn is stronger. In the carded wool, the fibres are in disorder and the yarns are weaker. This is easily seen in the tenacity values of the yarns VIa and VIIa, that contain an identical fibre distribution and yarn diameter. The first one has been spun from combed wool and the latter of carded wool; the carded one was found to be weaker.

The fibre distribution was found to be significant to the yarn's strength. The machine-spun yarns contained Semi Fine Finnsheep wool, which achieves the staple length of 4–10 centimetres (Ryder 1983, 524). The Jaalasheep wool contained a primitive kind of wool, that consisted of underwool with a length of c. five centimetres and the outer coat hairs with a length even 20 centimetres. The spinning experiments have proven, that both underwool and long outer coat hairs are needed, in order to spin thin and strong yarns (Andersson and Batzer 1999, 13, 18–19; Andersson 1999, 23–25).

A high degree of twist and plying strengthen the yarns (Seiler-Baldinger 1994, 3). The hand-spun yarn, VIII, which had a spinning angle of 33°, was found to be the strongest. The hand-spun yarns IV, V, VI and VII had a spinning angle of 20°, but nevertheless they were stronger than the machine-spun yarns I and II that had a spinning of angle 30°. With the same spinning angle, the hand-spun and the machine-spun yarns might have had an even greater contrast. Yarn III, despite having been spun from short Finnsheep wool, was strong. It was of combed wool, spun with a spinning angle of 40° and was tightly plied with an angle of 55°. These tricks probably compensated for the shortness of the wool fibres. This yarn had the lowest elongation values that can be explained by a high degree of twist and tight ply.

Table 4. Colour fastness for acidic perspiration (ISO 105-E04: 2008).

No.	Dye plant	Value of staining	Value of colour change	Visual assessment	Change on CIELAB (Δ*E)
1.	Alder buckthorn	4/5	4	more yellowish	8.04
2.	Common tormentil	5	5	no change	2.97
3.	Silver birch	5	5	no change	4.73
4.	Rock tribe	5	4/5	more blue	1.64
5.	Crottle	5	5	no change	2.89
6.	Dyer's madder + Club moss	4/5	5	more intensity	4.24
7.	Dyer's madder	5	5	more intensity	2.45
8.	Northern bedstraw	4/5	4/5	darker	1.81
9.	Common lupine	5	5	no change	9.78
10.	Silver birch	4/5	5	lighter	1.67
11.	Heather	5	5	no change	4.66
12.	Crowberry	5	4/5	more red	8.96
13.	Crowberry	5	4/5	lighter	2.76
14.	Wild rosemary	5	4/5	lighter	9.56
15.	Bog rosemary	5	4/5	colder	5.01

In the past, the yarns were most likely not a result of random selection, but rather intentionally selected from the fittest materials. The weavers of the past probably knew the strength-increasing effect of the long hairs. Indeed, often the yarns from the European Bronze until the Middle Ages contain fibres from both the underwool and the outer coat (Nahlik 1963; Bender-Jørgensen and Walton 1986; Ryder 1978, 1990; Kirjavainen 2005; Rast-Eicher 2008; Brandenburgh 2010). This phenomenon is clearly present in the early medieval textiles found in Greenland. In these finds, the warp yarns, which require a higher tenacity than the weft yarns, have systematically had more hairs than the weft yarns (Walton 2004, 83–87).

5.1 Dyeing methods and tenacity

The strongest tested yarns were found to be either undyed or dyed with a fermented alder buckthorn bath. The weakest dyed yarns consistently came from the Dyer's madder bath. The yarns from the alkaline rock tribe bath received values between the other two.

The effect of the dyeing method is most likely connected to the different temperatures of the dye baths as well as the different pH values. Wool as a protein fibre withstands well an acidic environment, but degrades in an alkaline one. However, the test indicated, that dyeing in the alkaline dye bath and especially in cold temperature is not as harmful to the fibre as is often assumed. In fact, the common boiling method of dyeing can be more harmful.

The yarns IVb, Vb, VIb and VIIIb, that contained Jaalasheep wool, maintained their strength in an alder buckthorn bath. The yarns IVc, Vc, VIc and VIIIc became fragile and sticky when dyed with the Dyer's madder. The greatest loss of strength can be seen in the yarns VIa, VIc, VIIa and VIIb. The alder buckthorn dye and the fermenting in room temperature might be a recommended dyeing method, at least when working with the yarns spun from the double-coated wool. Knowledge of the best fitting dyeing method for different wool types might be important for weavers. For example, when weaving a yarn spun from the primitive kind of wool on a warp-weighted loom (Hoffmann 1964), the warp is highly tensioned and the weak yarns do not stand.

5.2 Colour change and staining of the dyes

The test ISO 105-E04: 2008 for the colour fastness confirmed the empiric knowledge of the dyers, i.e., the natural dyes sustain their shades very well. For the industrial dyes, value 4 is adequate and all the studied dyes were found to sustain at least this value, or even better.

The grey scales were found to need a very accurate visual assessment and to be a clumsy tool when assessing particular types of colour changes. Problematic cases appeared, if the yarn became

Table 5. Colour fastness for alkaline perspiration (ISO 105-E04: 2008).

No.	Dye plant	Value of staining	Value of colour change	Visual assessment	Change on CIELAB (Δ*E)
1.	Alder buckthorn	4/5	4	more red	8.15
2.	Common tormentil	5	5	no change	3.72
3.	Silver birch	5	5	no change	3.63
4.	Rock tribe	4/5	4/5	more red	2.33
5.	Crottle	5	5	no change	2.12
6.	Dyer's madder + Club moss	5	4/5	more intensity	5.55
7.	Dyer's madder	4/5	4/5	darker	5.71
8.	Northern bedstraw	4/5	4/5	colder	7.99
9.	Common lupine	5	4/5	more yellow	8.97
10.	Silver birch	4/5	5	lighter	3.49
11.	Heather	5	5	no change	2.39
12.	Crowberry	5	4/5	colder	4.17
13.	Crowberry	5	4/5	lighter	3.97
14.	Wild rosemary	5	4	lighter	10.18
15.	Bog rosemary	5	4/5	brighter	4.39

brighter (Yarn 15, Table 5), darker (Yarn 8, Table 4; Yarn 7, Table 3) more intense (Yarns 13 and 14, Table 4; Yarn 6, Table 5), or the shade of colour preserved the same lightness value, but turned to a different hue (Yarn 4, Table 4; Yarn 4, Table 5).

In general, the grey scale values were in alignment with the CIELAB measurements. For unevenly dyed yarns, the grey scale cards suited better than the CIELAB measurements, because human eyes can define the amount of change from whole yarn at a glance. This probably explains why the common lupine-dyed yarn (Yarn 9, Table 4) was defined as unchanged in visual assessment, but with the CIELAB measurement, this yarn received one of the highest Δ*E values.

The staining of the tested dyes was small. For example, common tormentil, silver birch leaves, heather and lupine-dyed yarns did not stain at all. Because of the good colour fastness properties, it might be difficult or impossible to find any sweat stains from ancient textiles. In addition, if a textile comes from the ground, there might be secondary stains caused by the soil. In certain natural environments, natural dyes can leak out of the fabrics, migrate and stain other fabrics (Ringgaard 2010, 238–240; Bruselius Scharff and Ringgaard 2011).

Nowadays the dyed textiles are expected to last brilliant forever, which can be an acceptable demand of the synthetic dyes, but it is unknown, what was the desired resistance of the dyes in the past. It is possible that the dyes were not meant to sustain over generations. Bright purple rock tribe-dyed yarn fades in two weeks to lilac grey when placed in a sunny window with Δ*E 33, but nevertheless this lichen was an important dye source during the 18th century (Cardon 2007, 485–492).

In Finland, turquoise anthocyanin dyes from purple flowers were seen as "good enough" and used despite of the tendency of textiles dyed with them to fade. Moreover, it was possible to re-dye the faded textiles and refresh or change the shades of colours. Blue-giving woad (*Isatis tinctoria*) with good light fastness rarely grows at seashore areas of Finland and was sometimes even cultivated (Linnilä et al. 2002, III/ 63–64). Because of the difficult dyeing method, it was used only by the most skilled dyers. The dyeing with purple flowers was simple and in the agrarian environment the blue flowers were easily available to folk crafts people.

6. Conclusions

The empiric experiments made with the eight different yarns were in alignment with what is commonly known about the parameters of yarns: the long fibres, the high degree of twist and the ply increase the strength of a yarn. This data was achieved by testing the yarns that had a close tex value (ISO 1144:1973) with the textile standard (ISO 2062:2009), which measures the breaking resistance.

The tenacity of the yarns was found to be dependent not only on the yarn and wool properties, but also on the dyeing methods. The strongest yarns of this test were found to be either undyed or dyed with alnus buckthorn (*Rhamnus frangula*) and the fermentation method. Most clearly, the effect of the dyeing was found to be present in the yarns that contained both underwool and outer coat hairs. The fermented buckthorn bath produced a red yarn that retained the original strength, or even added it. The selection of the dyeing method might have been important in the past, when the yarns spun from the double-coated wool were woven on the warp-weighted loom.

The yarns that were mordanted and dyed with the boiling method with Dyer's madder (*Rubia tinctorium*) were quite regularly the weakest ones. The rock tribe (*Lasallia pustulata*) and the fermented urine bath was as harmful to some yarns, but in general this alkaline dyeing method was less degrading to the yarns than one would assume.

In the tests made with the textile standard ISO 105-E04:2008 the natural dyes were found to stand perspiration very well. The traditional Finnish dye plants i.e. the root of common tormentil (*Potentlla erecta*), silver birch bark (*Betula pendula*), crottle (*Parmelia saxatilis*) and heather (*Calluna vulgaris*) did not fade or stain at all. This observation suggests that it could be very difficult find any sweat stains from prehistoric dyed textiles, especially if the textiles have been dyed with these plants.

Excellent tolerance values for perspiration were also found in the yarns that were dyed with rock tribe and purple lupine flowers (*Lupinus polyphyllus*). These dyes faded soon in direct sunlight and are not favoured by present-day dyers. However, there is historical evidence that tells about the use of rock tribe and purple flowers as sources of dyes. Perhaps the expectations and demands for the permanence of dyes in the colourful textiles have changed during the history. Possibly people did not expect the colours to last forever, but accepted the fading and possibly re-dyed the textiles when needed.

The standardised textile testing methods that are commonly used in the textile industry produced repetitive data that fits well to the experimental textile archaeology. Perhaps we should abandon the term *experimental* and call this kind of study *empiric textile archaeology* based on empiric research methods.

Acknowledgements

I want to thank the Finnish Alfred Kordelin Foundation for supporting this research. In addition, I want to thank my Reviewers and the following people: my supervisor PhD Riikka Räisänen (University of Helsinki), spinner Maikki Karisto (Metropolia University of Applied Sciences) and spinner Päivi Ollila for the carefully spun yarns and sheep owner Riina Suominen for all the wool.

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