Benefits of Blending: Fibre Analysis Report
Fibre Information for Alpacas from Eighth and Mud

Prepared for Alpacas from Eighth and Mud

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1. Executive Summary

Fibres are blended to create new textile products with varying desirable properties. The benefits of blending allow for improved performance of a textile, which helps to create new properties and applications for existing fibres. Blending has the potential to reduce cost while maintaining desirable characteristics. Mixing expensive fibres, such as alpaca, with low cost fibres, such as cotton or lyocell, has the potential to make fibre products more accessible and desirable to different audiences. This report outlines the properties of natural fibres taking into account the durability and comfort of each fibre textile. In addition, this report is a great reference point for anyone that is interested to learn about natural fibres, the dye capabilities for each fibre, or each fibre's yield efficiency. The outlined fibres discussed within this report can be blended with alpaca fibres to create a new sustainable product, texture, and usage for the textiles.

2. Introduction

It seems that textiles these days can be made out of anything (Hoguet, 2014). However, many individuals strive for sustainability when it comes to their fibres. Sustainable fibres could be defined as a type of textile doing its job to provide strength and resistance, warmth, cooling, comfort, and so on. In spite of all these great characteristics, the most significant characteristic of them all is if the fibres are eco-friendly. Have they been sustainably grown?; have they been derived ethically?; how are they processed?; are they recycled properly?; and are they biodegradable? These are questions that may be considered when wanting a sustainable fibre. The question now is what constitutes a sustainable textile? There are four main factors when considering if a fibre is a sustainable textile. This includes: the raw material extraction, production, if chemical treatment is used, and the end of life cycle (Hoguet, 2014). Therefore, this analysis will discuss ten types of fibres: Bamboo, Cotton, Alpaca, SeaCell™, Merino, Lyocell (Tencel™), Silk, Cashmere, Qiviut, and Hemp.

3. Fibres

3.1 Merino Wool

Merino wool comes specifically from Merino sheep, a breed originating from Spain and now local to New Zealand and Australia (The Woolmark Company, n.d.). To achieve wool suitable for clothing, certain Merino sheep are specifically bred to increase wool quantity and quality, differentiated from sheep used in agriculture (The Woolmark Company, n.d.). Merino wool is commonly used in clothing today as yarn or soft fabrics, in knitwear and wovens, and can be blended with other fibres, such as silk and cashmere.

Once the sheep are sheared, the raw wool must first be processed through scouring. The fleece is sheared annually with no harm to the animal. Naturally, the fibres are covered with a grease called lanolin as they grow out of skin follicles (The Woolmark Company, n.d.). As the fibres grow longer, they pick up other contaminants, such as dirt and dust. Scouring is a washing process that involves the fibres moving through a series of bowls containing wash liquor to remove the lanolin and fresh bowls for rinsing followed by a continuous drier. Once dried, the wool is mechanically beat to remove remaining water insoluble compounds, such as sand and dust. After this step, the wool is left in a closed room to stand until its moisture content reaches equilibrium (The Woolmark Company, n.d.). Finally, the fibres are combed through to separate long and short fibres for use in different systems.

Depending on the desired end-product, the wool from merino sheep are processed in one of two ways: the worsted system or woollen system (Lyons, 2008). The worsted system produces smoother yarns and fabrics often used for garments directly in contact with skin, such as base layers and socks. The smooth texture is achieved by taking fleece from the back and sides of a sheep, where there are longer fibres (Williams & Winston, 1987). The woollen system produces fabrics with a hairy or raised appearance often used for sweaters and outerwear. Woollen-spun products use shorter fibres from fleece taken around the legs and underbody of the sheep, where vegetable matter, such as seeds and grass are more likely to be picked up while grazing (Williams & Winston, 1987). Therefore, fibres used in the woollen system need to undergo an additional cleaning step known as carbonising, to remove the vegetable matter. Carbonising is combined with scouring, using a chemical process to break down the vegetable matter into carbon (The Woolmark Company, n.d.). The use for chemicals during Merino processing is minimal, by using alkaline baths for cleaning.

Merino wool is highly valued for its soft touch and natural breathability for performance temperature control. It is able to absorb and evaporate moisture vapours as conditions around the material change, thus increasing comfort when worn (Lyons, 2008). There are many intrinsic properties of Merino wool that are desirable, such natural odour resistance and being water repellent. The surface of Merino is naturally hydrophobic due to a thin, waxy lipid coating bonded to the surface (Williams & Winston, 1987). This layer is not easily removed during the scouring process and extends over the overlapping scales on the fibre surface (Lyons, 2008). Merino wool can be divided into different categories based on fibre diameter and used to blend with other fibres.

3.2 Hemp

Industrial hemp is known as the non-psychoactive plant variety of the *Cannabis sativa L.* species used in various industries in addition to textiles; including food, cosmetics, construction, and agriculture. The hemp plant produces seeds used in the food industry for consumption or is extracted for oils. The stalk of the plant is separated into two parts: the **inner woody core** known as the **hurd** and the **outer layer** known as the **bast fiber** (Fortenbury & Bennett, 2004). The hurd is absorbent due to its high cellulose content, commonly used to make insulation and paper. The bast fiber is a stringed band running the length inside a hemp stalk, which is harvested for the textile industry (Fortenbury & Bennett, 2004). The hemp plant is well adapted to a wide range of environmental conditions, allowing for minimal biocide and water consumption (Frotenbury & Bennett, 2004). Additionally, hemp grown for fibre is competitive with weeds due to their closer growing arrangement, thus not requiring herbicide application making hemp favourable for agronomic and environmental reasons (Rawson, 1992).

Industrial hemp is harvested by chemical defoliation, which removes unnecessary leaf mass with chemicals followed by cutting, retting, baling, loading, and transport (Rawson, 1992). Retting is the process of obtaining textile-quality fibre by a microbial process to break the natural chemical bonds that hold the bast fibre bundles together (Frotenbury & Bennett, 2004). Retting can be done in two ways: water retting or field retting. **Water retting** immerses plant stalks in water, requiring higher labour and capital costs to produce a uniform, higher quality fibre. While **field retting** spreads the stalks in the field to rot and dry for two to three weeks, decreasing the labour but in turn produces inconsistency in the fibre quality (Frotenbury & Bennett, 2004). However, the environmental impacts of water retting are greater due to the substantial amounts of wastewater produced. To separate the bast fibre from hurds, dried and bailed stalks are sent to a processing mill to cut the stalks into pieces before separating. When harvested correctly, bast fibres from hemp plants can be stronger than steel (Rawson, 1992). Due to their strength, hemp fibres are often used to make composites with other materials to reinforce overall mechanical properties (Keller, 2003).

The crop production of hemp plants for fibre is identified as a low-impact crop (Werf & Turunen, 2008). Since hemp plants grown for fibre, they do not require nutrient-dense soils as their counterparts grown for hemp seeds. They are able to be grown within close proximities to each other to maximize yield. Furthermore, their tough stalks resist insects to allow for minimal pesticide use. By reducing use of petroleum-derived chemicals in the production, hemp plants can be a good sustainable option (Keller, 2003).

3.3 Qiviut

Qiviut fibres are derived from the muskox, a hoofed animal that lives in the arctic tundra of northern Canada, Greenland, and Alaska. Qiviut fibres are the fine undercoat that grows under the guard hairs, which serve to create an insulating air-filled layer near to skin for warmth (White, 2017). Qiviut is considered to be one of the finest commercial wool available and is known for its warmth, softness, and durability. The fibres that are on average 10-16 micrometre in diameter and grow to a length of around 4 – 8 cm, have a similar texture to cashmere (White, 2017). The fibre is traditionally collected in a 2-week shedding period in the springtime when large clumps of fibre are released from the muskox and can be found hanging on shreds and bushes (Wilkinson, 1974).

As it stands currently there are three methods of sourcing Qiviut:

1. **Wild harvesting:** This is the traditional method of qiviut collection and involves the collection from shrubs and trees, and is then sold in the local community or commercially. Qiviut can be a good source of agricultural income for local tundra communities.

2. **Close heading:** This would involve providing food and grazing for a muskox pack and the animals would then need to be rounded up during harvest time, which can be very difficult due to the undomesticated nature of the animals (White, 2017).

3. **Farming:** Animal agriculture can be used to grow qiviut. This would involve handling veterinary care, intensive breeding programmed and domestication. As it stands currently many of the domestication programs have been unsuccessful for the large-scale domestication of muskox. Most of the breeding programs end in the 1970s and as it

currently stands only a small number of breeding programs remain (White, 2017). The largest one is located in Palmer, Alaska and operates to domesticate and educate about the muskox, as the farm currently operates on a tourism and education revenue ("Muskox Farm | Gently Hand-Combed Qiviut | Palmer, Alaska," n.d.). The University of Alaska large animal agricultural station (LARS) is another non-profit operation that still continues to attempt to domestic these large animals (Dickie, 2017).

In contrast to wool or other animal fibres, qiviut is brushed off the animal or simply plucked off by hand (Wilkinson, 1974). Qiviut comes off the muskox in reliable chunks making brushing an easy way to collect the fibre without disrupting the animals. This can pose difficulties as the animal can become stressed by the process and can take multiple sessions to remove all of the qiviut. The animals are not tamed, which can pose some difficulty in brushing to reduce agitation towards the animals. Qiviut has a short season of production in the early springtime. Although qiviut production varies from each animal depending on its stage in life, a wild adult muskox will produce on average 2.6-3.5 kg of Qiviut annually; selective breeding has had no known effect on production (Wilkinson, 1974).

Qiviut is one of the world's most expensive fibres given that it is difficult to produce and its rarity due to its remote habitat. As it stands currently most of the fibre is collected by hand in the springtime by locals in the tundra regions. Qiviut has been known to be used by tundra native to make hats, mittens, and boots since the 17th century when French traders from the Hudson Bay Company observed the creation of socks and moccasins from this fibre. The Inuit people were known to use all parts of the muskox including the teeth, skin, and meat of the animal (Jean & Weidemann, 1973). Today the largest producer of qiviut products is an Alaskan co-op called Oomingmak, which is run by around 250 native Alaskan women producing 100% handmade Qiviut products that include scarves, stoles, tats, tunics and caps, and nachaq a traditional Eskimo scarf ("Oomingmak - Fiber & Yarn - Alaskan Qiviut Handknits," n.d.). Qiviut is often sold as prepared clothing items and can be bought as yarn from a few select suppliers.

There are many benefits working with qiviut. The fibre, as it is natural, is grease free unlike the lanolin produce by sheep. The grease-free nature makes it a clean fibre that requires minimal processing. The fibre is washed with a mild detergent, dehaired and then spun into yarn (Ghosh, 2013). There are very few mills that produce qiviut, with there being only one in the United States located in Alaska that specializes in qiviut production ("Fiber Mill — Arctic Qiviut," n.d.). The production of qiviut fibre is very similar to cashmere and mills that are equipped to handle cashmere can also process qiviut ("Fiber Mill — Arctic Qiviut," n.d.).

Qiviut is a natural product and does not need to be treated with solvents or wet processing. Qiviut is often found undyed and simply mixed with oil and spun. As a result, Qiviut is a biodegradable product with minimal environmental impact and minimal animal abuse as the majority of the fibre is scavenged without any direct interaction with the animal. The biggest threat to qiviut is the threat of climate change, which has already significantly reduce the natural range of the muskox. It has been observed that natural population has declined significantly over the past few decades and continues to do so ("About Qiviut — Arctic Qiviut," n.d.).
The remarkable fibre of qiviut makes it an excellent fibre for cold weather applications. Qiviut is known for its ability to trap air pockets making it some of the warmest fibre to wear and is

significantly warmer than superfine merino wool (White, 2017). The fibre is very smooth, making it durable and resistant to thermal shock and shrinking, contrary to sheep wool, which has this issue (“Oomingmak - Fiber & Yarn - Alaskan Qiviut Handknits,” n.d.). Qiviut has an appearance similar to cashmere with a super fine consistency making it extremely soft and non-irritable on bare skin (“Oomingmak - Fiber & Yarn - Alaskan Qiviut Handknits,” n.d.).

A unique property of quvit is that it becomes softer as it is washed and does not shrink or have a textile memory, such as sheep's wool, making it a very user-friendly textile. In addition, Qiviut is easily blended with other fibres including wool, alpaca, cashmere, and silk. When blended with other fibres, qiviut can impart the softness, warmth, and durability that the fibre naturally has.
Given quiviut's fine texture, it does not hold its structure very well (“About Qiviut — Arctic Qiviut,” n.d.). Blending it with alpaca or wool fibre allows it to possess this property (“About Qiviut — Arctic Qiviut,” n.d.). The largest drawback to qiviut is the very high cost of the fibre given its rarity with scarves and hats made of 100% qiviut, in which would cost around $300-600 USD (“Oomingmak - Fiber & Yarn - Alaskan Qiviut Handknits,” n.d.). The benefit of blending with qiviut is that the natural properties of the fibre can be maintained while providing a lower cost item. Thus, Qiviut’s unique properties and suitability to cold climates makes it a wonderful fibre to work with. Given the ease of bendability, qiviut can be combined with alpaca to make luxurious cold weather clothing items.

3.4 Cotton

After being around for thousands of years, cotton remains one of the most versatile and comfortable fibres. It is the most utilized textile fibre in the world being used for a range of apparel including sheets and towels to astronauts’ in-flight space suits, to pharmaceuticals and medical supplies (Cotton Australia, n.d.). It had an annual production of 26 million tonnes in 2015 and was grown in over 35 countries making it a crucial commodity for international trade (Organic Cotton, n.d.). Today the biggest producers of cotton are India, China, United States, Pakistan, Brazil, and Uzbekistan with the United States and Africa as the largest exporters of cotton seeds (Organic Cotton, n.d.).

With one of the longest growing seasons with approximately 150 to 180 days, cotton is the longest annually planted crop in any country (National Cotton Council of America, 2018). Cotton is both a food and fibre crop where it starts off as a cotton seed, which eventually turns into cotton bolls (Cotton Australia, 2018). It is a soft fibre that grows in the form of a ball around the seed of the cotton plant. Sufficient cotton growth requires about 2000 acres on a farm to be economically viable (produces about 1.5 bales or 340 kg) and a long sunny growing season with about 160 frost-free days (Bryk, 2018). The planting process involves heavy use of pesticides, such as insecticides, fungicides, and herbicides that are used to enrich the soil, and remove diseases and insects that can cause harm to the plants (Bryk, 2018). Cotton uses only about 3% of the world’s farmland, but approximately 25% of the world’s pesticides (Yates, 1994). Cotton is a natural fibre and unlike synthetic fabrics it has no added chemicals and is derived from a renewable resource that is intrinsically biodegradable (Chen and Burns 3, 2006). However, despite this reputation, the extensive use of pesticides have been associated with negative environmental problems, which have lead to a generation of waste and social impacts including severe health problems (Myers and Stolton, 1999). Pesticide use on cotton extends to the oil and food industry as well. Oil extracted from the cotton seeds during textile operations is used for processed foods in the United States and these foods contain chemical residue that have been tied back to cotton (Imhoff, 1999). To combat this issue a few nonconventional strains of cotton have been grown using selective breeding from natural mutants under environmentally friendly conditions with natural fertilizers (manure), which is marketed as organic cotton (Robbins, 1994).

Cotton is a soft, absorbent, and breathable natural fibre. These qualities make it an ideal fibre to use for clothing especially clothing worn very close to the skin, such as undergarments. Cotton fibres are spiral with twists in opposite directions, which makes it suitable for spinning into thread (Maritime Museum, 2018). The production process to turn cotton seeds into clothes starts off with planting the cotton seeds, which are mechanically planted by machines and are placed about 1.9-3.2 cm deep (Bryk, 2018). After about six weeks the flower buds start to form and mature, then fall off after blossoming and a tiny ovary is left on the cotton plant that ripens and enlarges into a pod, known as a cotton boll. The cotton plant is sprayed with defoliant, a chemical usually by a machine, which removes the leaves. This process minimizes the staining that could occur on the fibre and reduces or eliminates a source of excess moisture (Bryk, 2018). Once the cotton is harvested it is stored in modules, which hold approximately 14 bales in water resistant containers (Bryk, 2018). The cotton is cleaned, compressed, and tagged which are then banded and wrapped, ready for transport. It is classed on the basis of the samples cut from the bales based on a “grade” received according to the standards established in the country of origin regarding factors, such as cleanliness, degree of whiteness, length of fibre, and fibre strength (Textile School, 2010). Cotton in its natural state isn’t strong therefore it is spun and twisted to make it into a strong yarn that can be eventually woven into cotton cloth. It isn’t mixed with anything it simply requires physical processing. Once the cotton has been woven into a cloth, it can be knitted, dyed, printed, and embroidered in order to be used for apparel.

The cellulose of cotton is arranged in a way that gives cotton unique properties of strength, durability, and absorbency. It feels good against human skin, which makes it an ideal fibre to mix with the alpaca fibres for clothing production purposes. It absorbs water, which also helps attract moisture away from the body. Moisture passes freely through cotton aiding in evaporation and cooling, and it is also an excellent heat conductor. Cotton allows heat to dissipate making it a wonderful fibre to maintain a comfortable sleeping temperature. It can hold up to 27 times its own weight in water and becomes stronger when wet (Cotton Australia, n.d.). It is non-allergenic and is one of the easiest fabrics to dye because of its high rate of absorbency.

3.5 Tencel™ (Lyocell)

TENCEL™ also known by its generic name Lyocell, is considered to be a low environmental impact version of rayon/modal, a cellulose-based synthetic fibre (“What is TENCEL™ ” n.d.). Lyocell is made using regenerated cellulose and the fibre processing method of ‘TENCEL™ fibre processing’, with the main advantage being that the solvent used in this process is 99% recyclable, which reduces contaminate pollution significantly in comparison to typical rayon (Hassanin, 2014).

Lyocell is considered a regenerative cellulose fibre, which is created by dissolving cellulose fibre in a solvent and reforming them into the new fibre (“Regenerated Fibers,” n.d.). Lyocell is created by dissolving the wood pulp into N-methyl-morphine-N-oxide (NMMO) to form a paste, which is then heated and put through a dissolving unit to create a clear high viscosity solution. The solution is then filtered and spun with concentrations of NMMO to precipitate out the cellulose fibre, then it is dried and washed to create a stable fibre (Borbely, 2008). The waste liquors can be passed through a solvent recovery system to retrieve 99% of the original NMMO making lyocell a closed loop production system (Hassanin, 2014). NMMO is a low toxicity solvent that causes little skin irritation making Lyocell a skin safe product. TENCEL™ is a relatively new fibre and has yet to be recycled on a largescale (Chen and Burns, 2006).

Lyocell produces a very smooth fibre that has high strength in both its wet and dry state. The fibre it creates is silk-like and fluid, and is the only synthetic fibre that is stronger than cotton in its wet state (Stankute et al., 2010); this is because the synthetic fibres are hydrophobic and do not absorb water into the fibre structure, but simply sit on the fibre's surface (Schuster et al., 2006). Lyocell has both high water absorbing properties and water vapour distributing properties, resulting in a high heat capacity and heat balancing effects that result in superior thermoregulating properties. As a result of the thermoregulating properties of lyocell, it is often used in activewear clothing and sportswear for its moist wicking effect. Similarly, the thermoregulating effects can be used as an insulating fabric for various cold and warm climate conditions (Schuster et al., 2006). The smooth nature of TENCEL™ combined with its water wicking properties results in a fibre that is very gentle on the skin as friction is reduced and low water retention levels reduce fibre clinging, which can contribute to discomfort (Schuster et al., 2006)

Lyocell can is more expensive to produce then rayon, but can be used in any application that rayon or cotton are used in. Some application includes sportswear, casual clothing, substitutes for silk, bed sheets, towels, undergarments, mattresses, and duvet fillings (Schuster et al., 2006). As a synthetic fibre, it is considered low maintenance and user-friendly. Lyocell experience very slight shrinking features and given its silk/drapability texture, it is wrinkle resistant and does not require special washing requirements. Lyocell also takes well to dye and vibrant colours are producible ("Lyocell," n.d.) In addition, Lyocell is easily blended with other fibres including alpaca, cotton, silk, polyester, and wool. When mixed with alpaca fibres it can provide it with structure and the ability for the textile to impart a lustrous silk-like texture with vibrant colour potential, moisture wicking, and easy and user-friendly wash qualities.

3.6 Bamboo

Bamboo is known to be the most popular natural fibre plant in the world (Majumdar and Arora, 1997, p. 285). It is claimed the most fastest plant grown (Legacy Lane, n.d.). This plant is most prevalent in India, which is the second largest reserve of bamboo in the world (Majumdar and Arora, 1997, p. 285). However, bamboo can also be found in Central America, South America, South Africa, East Asia, Japan, and North Australia (Simpilif Fabric, 2018). Interestingly, bamboo fibres are derived from the tallest bamboo species *Phylostachys edulis* (Majumdar and Arora, 1997, p. 285). Natural bamboo is claimed to have antibacterial properties, biodegradable properties, a good absorption capacity, UV protection, and is comfortable on the skin (Majumdar and Arora, 1997, p. 285).

Important distinctions of bamboo fibres are its characteristics, whether it is of natural origin or the plant has been regenerated (Majumdar and Arora, 1997, p. 286). One mode of utilization of the fibre is through a **natural process**, which allows the pure bamboo fibre to be of 2mm staple length by means of physical and chemical treatment (Majumdar and Arora, 1997, p. 286). Another mode of utilization is called **spinning regenerated**, which provides bamboo viscose filaments (Majumdar and Arora, 1997, p. 286). However, the latter method is problematic because the regenerated viscose (regenerated bamboo cellulose) only leaves a small amount of the original bamboo within it and does not provide the same benefits as natural bamboo fibre (Majumdar and Arora, 1997, p. 286, 301).

The extraction of bamboo fibres occurs one of three ways: mechanical, chemical, and/or a combination of mechanical and chemical production.

1. **Mechanical processing** of bamboo is done using multiple methods. It starts by cutting and crushing the wood part, which is treated with a natural enzyme that allows the bamboo to soften for an easier break, and the fibres can be easily combed out afterwards and spun into yarn (Majumdar and Arora, 1997, p. 286). Moreover, the **steam explosion method** is another way to extract the fibre from the plant, by which the heat helps separate the cell walls to produce the pulp (Zakikhani et al., 2014, p. 821). But, this form of method does not remove lignin from the plant and as a result a mixing machine is used to help remove lignin from the fibres (Zakikhani et al., 2014, p. 821). Steaming bamboo enables the cell wall of the plant to break and soften the fibre, which leaves the fibre to have a low shear resistance (Zakikhani et al., 2014, p. 821). Thus, this process method is environmentally friendly and less time consuming, but can be labour intensive and expensive to produce (Majumdar and Arora, 1997, p. 286).

2. **Chemical processing** of bamboo is completed with the use of "alkali or acid retting, chemical retting, Chemical Assisted Natural (CAN), or degumming to reduce or remove the lignin content of the elementary fibres" (Zakikhani et al., 2014, p. 823). However, this method is most commonly used when a regenerated bamboo viscose fibre is wanted and the stalks need to be removed from lignin and hemicellulose (Majumdar and Arora, 1997, p. 287). Through chemical processing, the bamboo leaves and shoots are cooked in the chemical solvents and then it goes through an alkaline hydrolysis and multi-phase bleaching combination (Majumdar and Arora, 1997, p. 287). However, "to produce regenerated bamboo or bamboo viscose fibre, the leaves and inner pith of hard bamboo tree trunk are extracted, crushed and soaked in [a] sodium hydroxide (NaOH) solution" (Majumdar and Arora, 1997, p. 287). After this step, the alkali cellulose is strained out of the solution and goes to the shredding process in order to create more surface area to allow a simple cellulose process to occur (Majumdar and Arora, 1997, p. 287). The shredded cellulose is air-dried and carbon disulphide is added for gelling to occur to the cellulose, and any excess will be evaporated (Majumdar and Arora, 1997, p. 287). Once this step is completed, the bamboo is "ripened, filtered, degassed…[and] the bamboo viscose is wet-spun" (Majumdar and Arora, 1997, p. 287).

   The chemical processing method raises some concerns in regards to it being economically friendly. For example, carbon disulphide used during the gelling phase is known to be toxic, affecting the individuals working with this chemical and the environment due to its toxic emissions and water waste (Majumdar and Arora, 1997, p. 288).

3. ***Combination of mechanical and chemical processing*** of bamboo is another method for extraction of its fibres. It is done by using alkali and then putting the bamboo through a compression moulding technique and roller mill technique to extract the fibre (Zakikhani et al., 2014, p. 823). The combination of alkali and mechanical processes, it is said to be easier to separate the strips of individual fibres (Zakikhani et al., 2014, p. 823). Furthermore, this bamboo extraction method is commonly used to produce paper and within the pulp industry, rather than in the textile industry (Majumdar and Arora, 1997, p. 288).

The type of extraction used will determine the quality characteristics the bamboo fibre has (Majumdar and Arora, 1997, p. 289). For example, when the bamboo fibres are mechanically processed, they exhibit a rough and stiff texture (Majumdar and Arora, 1997, p. 290). Whereas chemically processed bamboo fibre ("woven out of viscose-type") has a soft texture and a good drape (Majumdar and Arora, 1997, p. 290). Moreover, pure bamboo fibres have many advantages. These include: high breathability, high thermo regulating properties, comfortable to wear, low shrinkage, high absorption (due to its high hygroscopicity), good colour clarity, good wrinkle resistance, good water and moisture absorbency, low irritation properties (e.g. an allergic reaction), anti-bacterial properties, good UV radiation absorbent, and it is biodegradable in soil (Majumdar and Arora, 1997, p. 290-292). Bamboo fibres are porous and hold a dye well, and are great for mixing with other fibres such as alpaca fibres (Legacy Lane, n.d.).

3.7 SeaCell™

This is a fabric that not only protects the skin, but allows it to absorb nutrients. After years of intensive research, seacell was created. Seacell is a variant on lyocell and is made from brown algae called *Ascophylllum nodossum*. Cellulose fibre serves as a host for the seaweed and therefore contains the seaweed's revitalizing properties (Ross, 2017). It is a fibre that is manufactured similar to the lyocell process, and provides health and skincare promoting benefits due to the trace elements that are added to the cellulose before the spinning process, which that eventually is released into the body once worn (Ross, 2017). This unique fibre does not come from animals or involve farming, rather from the depths of our oceans from seaweed. The substances found in seaweed help to activate cell regeneration, which helps in reducing inflammation, sooth itchiness, and relieve skin diseases (Smartfibre AG, 2014). The fibres can be used for a variety of areas from fashion clothing to home textiles.

Seacell contains iron, vitamin A, vitamin C, vitamin E, vitamin B12 (helps prevent anaemia), and iodine (important for thyroid function) (Avci et al., 2017). It also contains antioxidants and silver ions in its fibres. These properties make seacell a healthy source of fibre for the skin. Natural body moisture promotes the transfer of these nutrients when the skin comes in contact with the fibre (Avci et al., 2017). It is breathable, lightweight, and feels soft against the skin and absorbs sweat faster than cotton, which makes it ideal for undergarments. Even with its extravagant properties, there has been controversy regarding the Seacell's seaweed contents and the amount that is actually in it. The cellulose fibre makes up only 5 % of the product due to its main component of the fibre being wood pulp and seaweed as an additive (Ross, 2017). The extraordinary properties of cellulose can be deemed attractive by many, but the amount of seacell needs to be considered upon purchase. Further, the seacell fibre has to undergo numerous tests to receive their labels to guarantee the effect of the nutrient's present and applicability from the fibre to the skin.

Seacell is an eco-friendly fabric made from seaweed. Seaweed is a natural resource available in the earth's aquatic ecosystems, which is cut once every four years (Ross, 2017). The harvesting process is done using special machines, which ensure the cut is above the regenerative part of the plant so it remains sustainable, and does not permanently damage the seaweed (Ross, 2017). The fibre is produced using sustainable raw materials (wood and seaweed). Hence, it is completely biodegradable. The dried seaweed is crushed and finely grounded to incorporate into cellulose fibre to create yarn and eventually into a wearable fabric (Smartfibre, 2014). After the spinning process, it is dissolved in a solvent containing water and then it is spun through spinnerets (Smartfibre, 2014). Seacell blends well with other types of fibres including alpaca and is suitable for activewear due to its breathability and softness characteristics.

3.8 Alpaca Wool

There are two types of alpaca breeds: Huacaya and Suri, which are typically derived from South America (Lupton et al., 2006, p. 211-212). Specifically, alpacas originate from the Andean highlands of South America and it is stated that approximately 90% of Peruvian alpacas contribute to the world's fibre production (Lupton et al., 2006, p. 212). However, it was considered that alpacas were native to their environment, yet this species has become prominent in countries such as Canada, United States, Australia, England, France, and New Zealand (Lupton et al., 2006, p. 212). With this in mind, independent family farmers raised American type alpacas for thousands of years (Apple Mountain Alpacas, 2018). Also, male alpacas' fibre has shown to be stronger than female alpaca fibres (Lupton et al., 2006, p. 211).

Alpaca fibres are known to be one of the strongest natural fibres (Apple Mountain Alpacas, 2018). One positive outcome from using alpaca fibres is that the animals are not harmed in the process. The alpacas are shorn once a year and this also helps alpacas during the summer months to not become susceptible to overheating (Apple Mountain Alpacas, 2018). Approximately 2.27-4.54 kg of alpaca fibre is collected per alpaca per year (Emery, n.d.). Hence, alpaca fibre is quite renewable, easily obtained, and no damage done when collecting the fur. Once the alpacas are shorn, their fur goes through a milling production process. One way of processing alpaca fibre starts with the alpaca fur being assessed on the quality (condition) and weight prior to going through the washing stage (Legacy Lane, n.d.). Second, the fur takes up to three hours to be washed with only 10 lbs. used at a time in 140°F (Legacy Lane, n.d.). After being washed, the fur is laid out to air dry with the use of fans that takes up to 24 hours to become fully dried (Legacy Lane, n.d.). Third, the now washed and dried alpaca fur is moved to the picking stage in the milling process. This is done through the use of the "picker machine" that gently opens the fibre, and is sprayed with vegetable based conditioner to lubricate and remove any static present (Legacy Lane, n.d.). Then a fibre separator machine is used to find any outlier hairs or vegetation and separate that from the alpaca fibre (Legacy Lane, n.d.). The alpaca fibre now goes through a stage called carding, which combs the fibres to remove any unwanted fleece and now the fibre gets moved to the next step of the process (Legacy Lane, n.d.). The drawframe is used to help align the fibres from the carding stage to a small circumference in preparation for spinning (Legacy Lane, n.d.). During the spinning stage, this may differ, but different spindle spinners may be used such as an eight-spindle spinner to spin the fibre into a single ply of yarn (Legacy Lane, n.d.). Finally, the plying machine would take the spun fibre and twist it to create the completed yarn, which is placed onto cones from the bobbins for steaming in order to set and loft the yarn's twist (Legacy Lane, n.d.).

This type of fibre is also soft and softer than sheep's wool (Alpaca Collection, 2018). It is not only soft and breathable, but also lightweight, comfortable on the skin, absorbent, and more durable than cashmere (Alpaca Collection, 2018; Morton, 2018). Alpaca fibres are a hollow fibre making it great to dye due to its ability to take dye well and not fade or bleed away (Fine Quality Alpacatrax Alpacas, 2016; Morton, 2018). For instance, alpaca fibre is known to have hypoallergenic properties with no lanolin present and has the insulating capacity like sheep's wool (Morton, 2018; Fibershed, 2018). Moreover, alpaca fibre is great for repelling water, soaks away any unnecessary moisture, and contains anti-odour properties (repels odour) (Fibershed, 2018). Lastly, alpaca fibre is a 100% natural fibre making it a biodegradable fibre (Fibershed, 2018), and the fibre mixes well with other natural fibres, such as Merino wool.

3.9 Cashmere

Cashmere is obtained from a specific type of goat: cashmere goats. It is finer, stronger, lighter, and softer than sheep's wool, and it is three times more insulating (Wikipedia, 2018). Cashmere is known for its softness and is appreciated for its hygroscopic properties (Ferme-Mohair, 2018). As a matter of fact, such a property allows cashmere to adjust itself depending on the hair humidity, which is why it shows to be more warm than sheep wool, while being lighter (Ferme-Mohair, 2018).

Cashmere is considered as a luxurious product because it is rare. To be considered as cashmere, the goat hair must have a diameter smaller than 19.5 microns and be constituted by at least 30% of undercoat (Ferme-Mohair, 2018). Such hair can be found under the goat's wool (Ferme-Mohair, 2018). One goat produces about 150 grams of cashmere per year (Ferme-Mohair, 2018). For example, one 100% cashmere scarf needs about 180 grams of cashmere, and one stole needs 600 grams (ferme-mohair.com, 2018). 75% to 80% of the production is based in Asia (Ferme-Mohair, 2018). With 10,000 metric tons per year, China is the largest producer of raw cashmere, and it represents 50% of the annual world clip (Wikipedia, 2018). Once the animal grease, dirt, and coarse hairs from the fleece are removed, the 20,000 metric ton of raw cashmere becomes 6,500 tons of pure cashmere (Wikipedia, 2018).

Cashmere goats naturally shed their winter coat during the spring moulting season between March and May (UMRAO cashmere, 2010). The double fleece produced to keep them warm during winter fall at the same time (UMRAO cashmere, 2010). This soft undercoat of hair is mingled with guard hair, composing the outer coating of the goat fur (UMRAO cashmere, 2010). Once picked up, the fleeces are inspected, checked, and then classified for different uses as a raw material, depending on their value : it is the grading step (blackgoatcashmere.com, 2015). Then, each fleece is washed in order to remove grease and dirt from the fibre (Black Goat Cashmere, 2015). Raw cashmere is then passed through squeeze rolls and dried in a hot air chamber (Black Goat Cashmere, 2015). The fibre must then be de-haired, which the guard hairs must be removed to have pure cashmere (UMRAO cashmere, 2010). This step can be mechanized, but it is still done by hand in some regions using a comb (UMRAO cashmere, 2010). After this step, the fibre is pure cashmere. It must be straighten with a wire rollers system during the carding step to be prepared for the spinning step of the process (Black Goat Cashmere, 2015). For this step, the wool is transformed into yarn. By twisting the threads together, this step increases the strength of cashmere (Black Goat Cashmere, 2015). The fibre is then ready to be used for knitting.

Cashmere is difficult to launder and due to its scale, during laundering, the fibre produces felting, which is not wanted (Li, 2012). To prevent this adverse reaction, chemical anti-felting treatment can be added, using the potassium permanganate oxidizing method for example (Li et al., 2012). Mixing with other fibres reduces the price of cashmere cloths and helps prevent felting. Today, 100% cashmere clothes are exclusively made by hand (Ferme-Mohair, 2018).

According to APLF (2015), the longer the fibre is, the better the cashmere quality is. Having a long fibre prevents the cloth to stretch out of shape. To identify the high quality of a cashmere cloth, it is needed to be inspected closely and tested. If the cloth looks too fuzzy it means that it has been made with short fibres, which are too short to hold the shape (APLF, 2015). Also, stretching it, it may return to its original shape, then it is can be considered a good quality cashmere (APLF, 2015). In addition, quality labels are also used to prove cashmere quality (APLF, 2015).

3.10 Silk

Silk is a protein filament produced by the silkworms when they pupate in their cocoon (Canadian Conservation Institute n.d.; Les fibres naturelles, 2018). The major specie of silkworm is known as *Bombyx mori* (New World Encyclopedia, 2015). The characteristics of the protein filament are several amino acids that end up producing a hydrophobe fibre (New World Encyclopedia, 2015). One silk yarn can reach more than 2 km in length (Canadian Conservation Institute, n.d.; Les fibres naturelles, 2018). The silk production process is called sericulture. To produce 1 kg of silk, about 3000 silkworms must eat 35 grams of mulberry leaves, which is a total of 104 kg of mulberry leaves. It takes about 1.6 kg of silk to make a pure silk kimono, which corresponds to about 5000 silkworms (Chaotic Fibres, 2016).

Since World War II, the use of silk in the cloth industry has decreased due to chemical and synthetic fibres, like nylon (New World Encyclopedia, 2015). But silk remains a valued product for luxurious clothes and lingerie. Silk industry represents less than 0.2% of the textile fibre world market, but this still represents more than 150,000 tons of silk produced every year (New World Encyclopedia, 2015). 90% of silk world production comes from Asia (Dressing Responsable-Les fibres textiles: La soie, 2015).

According to New World Encyclopedia (2015) and TexereSilk (2018), the extraction process of silk begins with the production of silk raw material that is left behind the silkworms after breeding. The first step of the process is the hatching of the eggs (TexereSilk, 2018). Producers capture silk moths and prepare special paper to lay the eggs on (New World Encyclopedia, 2015). There needs to be a controlled environment and the eggs are then examined to ensure they do not have any diseases (TexereSilk, 2018). One female silk moth produces three hundred to four hundred eggs at a time (TexereSilk, 2018). Once the eggs are mature, they hatch and the caterpillars live on the special paper (New World Encyclopedia, 2015). Now starts the feeding period. The silkworms are surrounded by fresh mulberry leaves (New World Encyclopedia, 2015). The result of the worms consuming mulberry leaves during feeding is origin of very finest silk (TexereSilk, 2018). During this period, all the worms do is eat. After thirty-five days of feeding and about four moltings, the caterpillars are ready to begin spinning a cocoon (New World Encyclopedia, 2015). The silkworms attach themselves to a straw shaped piece and the action of building a cocoon is based on the silkworm moving its head in a pattern (World Encyclopedia, 2015). It takes two to three days for a silkworm to complete about three hundred thousand head movements to spin about a kilometer of filament that will then trap itself in the cocoon (TexereSilk, 2018).

From there, the work of the caterpillar is complete. However, during the reeling filament process, the silkworm is killed (New World Encyclopedia, 2015). To kill the silkworms, the cocoons are treated with hot air or soaked in boiling water (New World Encyclopedia, 2015). This step is necessary because it kills the caterpillar without damaging the cocoon, which allows to soften the protein that holds the one-kilometer fibre within the cocoon shape (TexereSilk, 2018). This protein is called sericin and this step is not enough to remove it completely. The fibre has to be washed out (TexereSilk, 2018). When it is completely free of sericin, the product will end up being 30% lighter (TexereSilk, 2018). One cocoon is composed of one single thread (New World Encyclopedia, 2015). To find its edge, the cocoons are wiggled with a little broom or a rice straw, as done in China (New World Encyclopedia, 2015). One single thread of silk is too fine to be used, which then the producers spin together three to ten strands in order to produce one single commercially usable thread of silk (TexereSilk, 2018). Thus, when cooled they become weld together (TexereSilk, 2018).

Once the raw material is turned into a fibre, the producers can begin the fibre processing. The first step for creating silk yarn is throwing (TexereSilk, 2018). This step helps to avoid spliting the thread (TexereSilk, 2018). Depending on the number of threads twisting together and the way they are twisted, four different types of silk can be made: crepe, tram, thrown singles, and organize (TexereSilk, 2018). Afterwards, the threads are weaved to produce the fabric.
According to Dressing Responsable-Les fibres textiles: La soie (2015), the silk industry does not benefit of industrial revolution big innovations. The core property of the silk is its finesse, which does not need to be processed to become thinner (dressingresponsable.com, 2015). However, mechanization of the textile industry has helped the process to become faster through the means of weaving quicker (Dressing Responsable-Les fibres textiles: La soie, 2015).

Silk cultivation uses several chemical substances and products that may be dangerous and harmful for the environment (TexereSilk, 2018). The silkworms need to be treated with antibiotics and hormones in order to increase their productivity and avoid bacteria (TexereSilk, 2018). Also, on an environmental scope, silk production has a large impact (IPFS – Silk, n.d.).
As it is an animal-derived fibre, it needs fertilizer and water for its production, and its carbon and water footprint is considerable (IPFS – Silk, n.d.).

To harvest silk, a large amount labour is needed. Most of the production is based in low developing countries, such as Ouzbekistan, where men, women, and children comprise the working force; which can be considered as slavery in these countries (Dressing Responsable-Les fibres textiles: La soie, 2015). Their working conditions are even harder during the reeling step (Dressing Responsable-Les fibres textiles: La soie, 2015). The atmosphere is over heated to soften the cocoon, and the workers must support these temperatures (Dressing Responsable-Les fibres textiles: La soie, 2015). When buying silk clothes, if you do not want to support these companies, you should pay attention to the environmental labels as part of fair trade (Dressing Responsable-Les fibres textiles: La soie, 2015). These labels are a guarantee for biological agriculture, as well as working conditions (Dressing Responsable-Les fibres textiles: La soie, 2015).

According to TexereSilk (2018), silk is the strongest natural fibre known as today. It is a good isolator from the heat in the summer and from the cold in the winter (Texersilk, 2018). However, silk loses 20% of its strength when wet and if it suffers great stress and stretching, it will not go back to its original form (Understanding Textile Fibres, 2018). If it is kept dirty for tool long, insects can attack it and it can also become weak if it is exposed to solar light (Understanding Textile Fibres, 2018). Silk resists organic acids, but will be dissolved by mineral acids (Understanding Textile Fibres, 2018).

An example that supports silk strength would be the following: in 2015, Dutch divers found a 400 years old shipwreck with packages buried in the sand (Romey, 2016). After digging it up and bringing it back to the surface, they discovered a silk dress in a remarkably good shape compared to the other items they found, that have spent centuries buried underwater (Lewis, 2016).

4. Decision Phase Diagram

4.1 Fibre Category Descriptions

In this section, different types of criteria regarding the discussed fibres are assessed (alpaca fibre not included). In order to ease the comparison of each fibre, they are graded according to several different criteria to evaluate the sustainability of each fibre and benefits of blending with alpaca fibre. The criteria category descriptions are as follows:

1) **Wear and Tear:**
    a. How well the final product is able to hold its original shape after several wears.
    b. If the product can be put through a regular washing process (ie. not specially dry-cleaned or hand washed).
2) **Ability to Build Dye:**
    a. If the pigment remains the same after a certain amount of time.
3) **Bacteria:**
    a. If the final product has natural anti-bacterial properties that is sustained through processing.
4) **Biodegradability:**
    a. Product made from 100% natural fibres that do not include any synthetic properties.
    b. How easily the final product degrades.
5) **Temperature Control/Isolation:**
    a. Moisture buffering: the textile's ability to adapt to changing environments by absorbing moisture vapour from the microclimate above the skin when a rise in

humidity occurs (i.e., when body temperature rises), and release it should the humidity drop (i.e., when body temperature cools).

6) **Softness:**
   a. If the final product can be worn against the skin without itching or irritation.
   b. The roughness of the fibre taking into account the scaling and texture of the surface.
7) **Renewability:**
   a. If sustainable fibre can be collected without damage to the source (i.e., the plant/animal is able to continue growing after being harvested).
8) **Yield Efficiency:**
   a. What is the production efficiency and the availability of each fibre.

4.2 Plant Fibre Table and Diagram

a) Plant Fibre Table

Plant fibres	Wear & Tear	Biodegradability	Ability to Build Dye	Bacteria	Temperature Control / Insolation	Softness	Renewability
Cotton	4	5	4	4	3.5	3.5	3.5
Bamboo	5	4	5	4	5	4	5
Lyocell	3	3	3	4	4	3	3
Hemp	4	5	4	0	2	2	5
Seacell	4.5	5	3	5	4	4	3

Table 1: Plant fibre values of each fibre for each category criteria.

b) Plant Fibre Phase Diagram

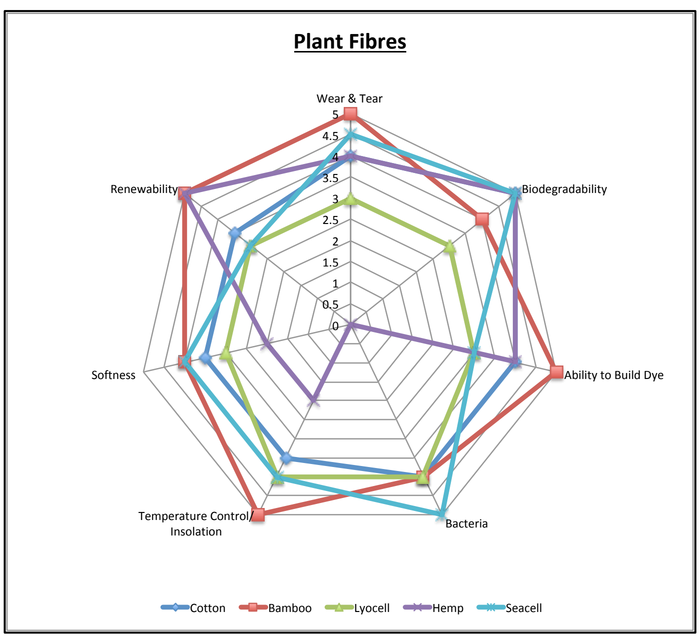

Figure 1: Plant fibre values of each fibre for each category criteria compared to each plant fibre.

4.3 Animal Fibre Table and Diagram

a) Animal Fibre Table

Animal fibres	Wear & Tear	Biodegradability	Ability to Build Dye	Bacteria	Temperature Control/Insolation	Softness	Yield Efficiency
Merino	3.5	2	5	4.5	5	4	5
Silk	1	3	4	1	4	4	1.5
Cashmere	5	2	5	2	5	5	2
Qiviut	4	4	0	0	5	5	3

Table 2: Animal fibre values of each fibre for each category criteria.

b) Animal Fibre Phase Diagram

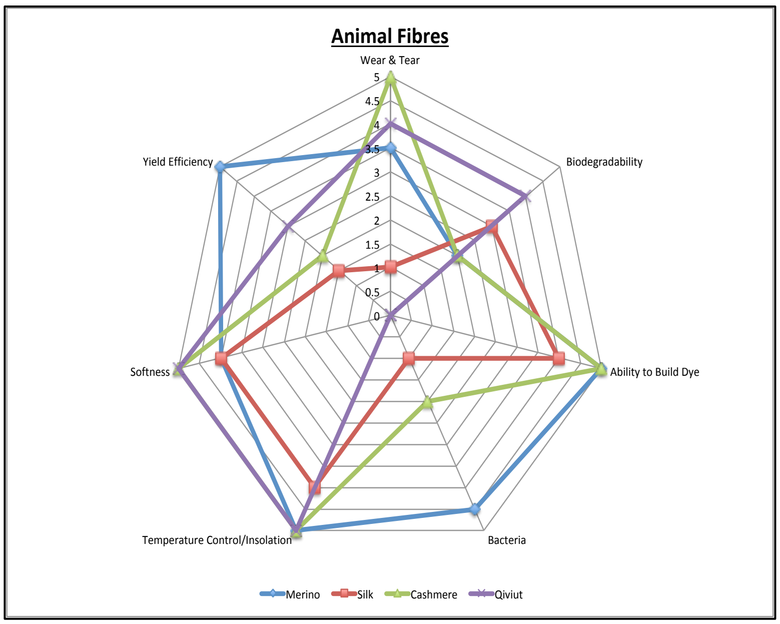

Figure 2: Animal Fibre values of each fibre for each category criteria compared to each animal fibre.

5. Conclusion

This report outlined the benefits of blending alpaca fibre with other natural fibres. After extensive research, we have provided a thorough analysis on fibres that will mix well with alpaca fibres including cotton, merino, lyocell, cashmere, qiviut, bamboo, seacell, and hemp, as well as an analysis on alpaca fibres. Alpaca fibres have been included in this report to highlight its properties and benefits when using this fibre independently in addition to when other fibres are used to create different textiles. We analyzed the source of the fibre, weighed the advantages and disadvantages of their qualities, process procedures, and how they relate to alpaca fibres. The focus for this fibre analysis was primarily on producing apparel. Further, this report also includes two phase diagrams one for plant and one for animal fibres evaluating their qualities. The purpose for these diagrams is to provide the reader with the chance to see which fibre, plant or animal, works well with alpaca fibre and which is most desirable to the reader's needs. This allows a reader to verify if some fibres are stronger in certain aspects than others, leaving it up to the reader to judge which ones they deem most important.

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