CHARACTERIZATION AND EVALUATION OF THE MECHANICAL PROPERTIES OF BLENDED OF YARNS BASED ON ALPACA AND MILK PROTEIN FIBERS

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ABSTRACT

Purpose: The purpose of this study was to characterize and evaluate the mechanical strength of individual yarns as a blend of alpaca fiber and milk protein fiber. In addition, to obtain a product with a comfort factor suitable for textile applications.

Method: Different alpaca fiber diameters were used, such as alpaca huarizo fiber (AHF), alpaca superfine fiber (ASF) and alpaca baby fiber (ABF), and then mixed with milk protein fiber (MPF) to perform tests and methods, including the optical fiber diameter analyzer 4000 (OFDA 4000), tensile strength testing, scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX) and Fourier transform infrared spectroscopy (FTIR).

Results and Discussion: In SEM observation, MPF showed a smooth morphology with areas of irregular grooves and protrusions, while AHF, ASF and ABF fibers showed a smooth surface with thin flakes. EDAX analysis revealed a chemical composition of C, N, O, Na and Si for MPF, while AHF, ASF and ABF presented C, N, O and S. By FTIR, specific chemical groups were identified. MPF showed amide I groups at 1647 cm⁻¹ and amide II group at 1540 cm⁻¹, confirming the presence of protein. AHF, ASF and ABF fibers presented at 1624 cm⁻¹ the amide I band due to contributions from the C=O stretching vibration of the peptide skeleton, and at 1514 cm⁻¹ the amide II group, arising from N-H bending and C-N stretching vibrations. The results of the comfort factor (CF) of AHF is significantly lower than that of MPF. Specifically, the CF of AHF was 38.15%, while that of MPF reached 99.69%. This indicates that, in terms of comfort, AHF does not equal MPF. Furthermore, when combining these fibers, the addition of MPF increases the CF, while reducing the diameter and the variability of the coefficient of variation (CV). Finally, in single yarn tensile strength tests, AHF demonstrated higher tensile strength, with a value of 63.3±4.9 MPa and a % strain of 6.98±1%, compared to ASF and ABF. However, MPF exhibited a maximum tensile stress of 67.2±4.9 MPa and a % strain of 11.71±1.3%, far exceeding AHF. In mixtures, the MPF-50%_AHF-50% combination showed a maximum tensile stress of 64.9±4.8 MPa, but with a low % strain, compared to the MPF-70%_AHF-30% mixture, which had a % strain of 10.39±1%.

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Research Implications: The synergy between both fibers (alpaca yarns, blended with other natural fibres) not only seeks to improve the tactile experience of the garment, but also to contribute to the manufacture of more sustainable and environmentally friendly garments.

Originality/Value: This study contributes to the field of the textile industry by providing an alternative to the processing of textile fibers from the mixture of milk protein fibers and alpaca fibers, offering important knowledge for industry and academia.

Keywords: Alpaca Huarizo, Alpaca Superfine, Alpaca Baby, Milk Protein Fiber, Comfort Factor.

CARACTERIZAÇÃO E AVALIAÇÃO DAS PROPRIEDADES MECÂNICAS DE MISTURA DE FÍOS À BASE DE FIBRAS DE ALPACA E PROTEÍNA DE LEITE

RESUMO

Objetivo: O objetivo deste estudo foi caracterizar e avaliar a resistência mecânica de fios individuais como uma mistura de fibra de alpaca e fibra de proteína do leite. Além disso, obter um produto com fator de conforto adequado para aplicações têxteis.

Método: Diferentes diâmetros de fibra de alpaca foram utilizados, como fibra de alpaca huarizo (AHF), fibra superfina de alpaca (ASF) e fibra de bebê de alpaca (ABF), e depois misturados com fibra de proteína de leite (MPF) para realizar testes e métodos, incluindo a fibra óptica analisador de diâmetro 4000 (OFDA 4000), teste de resistência à tração, microscopia eletrônica de varredura (SEM), espectroscopia de energia dispersiva de raios X (EDAX) e espectroscopia de infravermelho com transformada de Fourier (FTIR).

Resultados e Discussão: Na observação SEM, MPF apresentou morfologia lisa com áreas de sulcos e saliências irregulares, enquanto as fibras AHF, ASF e ABF apresentaram superfície lisa com flocos finos. A análise EDAX revelou composição química de C, N, O, Na e Si para MPF, enquanto AHF, ASF e ABF apresentaram C, N, O e S. Por FTIR foram identificados grupos químicos específicos. O MPF apresentou grupos amida I em 1647 cm⁻¹ e grupo amida II em 1540 cm⁻¹, confirmando a presença de proteína. As fibras AHF, ASF e ABF apresentaram em 1624 cm⁻¹ a banda amida I devido às contribuições da vibração de estiramento C=O do esqueleto peptídico, e em 1514 cm⁻¹ o grupo amida II, decorrente das vibrações de flexão NH e estiramento C==N. Os resultados do fator de conforto (FC) da AHF são significativamente inferiores aos do MPF. Especificamente, o CF do AHF foi de 38,15%, enquanto o do MPF atingiu 99,69%. Isto indica que, em termos de conforto, AHF não é igual a MPF. Além disso, ao combinar essas fibras, a adição de MPF aumenta o CF, ao mesmo tempo que reduz o diâmetro e a variabilidade do coeficiente de variação (CV). Finalmente, em testes de resistência à tração de fio simples, o AHF demonstrou maior resistência à tração, com valor de 63,3±4,9 MPa e % de deformação de 6,98±1%, comparado ao ASF e ABF. No entanto, o MPF exibiu uma tensão máxima de 67,2±4,9 MPa e uma % de deformação de 11,71±1,3%, excedendo em muito o AHF. Nas misturas, a combinação MPF-70%_AHF-30% apresentou tensão máxima de tração de 64,9±4,8 MPa, mas com baixa % de deformação, comparada à mistura MPF-70%_AHF-30%, que apresentou % de deformação de 10,39±1%.

Implicações da Pesquisa: A sinergia entre ambas as fibras (fios de alpaca, misturados com outras fibras naturais) procura não só melhorar a experiência táctil da peça, mas também contribuir para o fabrico de peças de vestuário mais sustentáveis e amigas do ambiente.

Originalidade/Valor: Este estudo contribui para o campo da indústria têxtil ao fornecer uma alternativa para o processamento de fibras têxteis a partir da mistura de fibras protéicas do leite e fibras de alpaca, oferecendo conhecimento importante para a indústria e a academia.


CARACTERIZACIÓN Y EVALUACIÓN DE LAS PROPIEDADES MECÁNICAS DE MEZCLAS DE HILOS A BASE DE FIBRAS DE ALPACA Y PROTEÍNA DE LECHE

RESUMEN

Objetivo: El propósito de este estudio fue caracterizar y evaluar la resistencia mecánica de hilos individuales como una mezcla de fibra de alpaca y fibra de proteína de leche. Además, obtener un producto con un factor de confort apto para aplicaciones textiles.
Método: Se utilizaron diferentes diámetros de fibra de alpaca, como fibra de alpaca huarizo (AHF), fibra de alpaca superfina (ASF) y fibra de alpaca baby (ABF), y luego se mezclaron con fibra de proteína de leche (MPF) para realizar pruebas y métodos, incluyendo el analizador de diámetro de fibra óptica 4000 (OFDA 4000), pruebas de resistencia a la tracción, microscopía electrónica de barrido (SEM), espectroscopía de rayos X de energía dispersiva (EDAX) y espectroscopía infrarroja por transformada de Fourier (FTIR).

Resultados y Discusión: En la observación SEM, MPF mostró una morfología suave con áreas de surcos y protuberancias irregulares, mientras que las fibras AHF, ASF y ABF mostraron una superficie lisa con escamas delgadas. El análisis EDAX reveló una composición química de C, N, O, Na y Si para MPF, mientras que AHF, ASF y ABF presentaron C, N, O y S. Mediante FTIR, se identificaron grupos químicos específicos. MPF mostró grupos amida I a 1647 cm\(^{-1}\) y grupo amida II a 1540 cm\(^{-1}\), confirmando la presencia de proteína. Las fibras AHF, ASF y ABF presentaron en 1624 cm\(^{-1}\) la banda amida I debido a las contribuciones de la vibración de estiramiento C=O del esqueleto peptídico, y en 1514 cm\(^{-1}\) el grupo amida II, que surge de las vibraciones de flexión N-H y de estiramiento C-N. Los resultados del factor de comodidad (FC) de AHF son significativamente más bajos que los de MPF. En concreto, el FC del AHF fue del 38,15%, mientras que el del MPF alcanzó el 99,69%. Esto indica que, en términos de comodidad, AHF no es igual a MPF. Además, al combinar estas fibras, la adición de MPF aumenta el CF, al tiempo que reduce el diámetro y la variabilidad del coeficiente de variación (CV). Finalmente, en pruebas de resistencia a la tracción de un solo hilo, el AHF demostró una mayor resistencia a la tracción, con un valor de 63,3±4,9 MPa y un % de deformación de 6,98±1%, en comparación con el ASF y el ABF. Sin embargo, MPF exhibió una tensión de tracción máxima de 67,2 ± 4,9 MPa y un porcentaje de deformación de 11,71 ± 1,3 %, superando con creces al AHF. En mezclas, la combinación MPF-50%_AHF muestra un esfuerzo de tracción máximo de 64,9±4,8 MPa, pero con un % de deformación bajo, en comparación con la mezcla MPF-70%_AHF-30%, que tuvo un % de deformación de 10,39±1%.

Implicaciones de la investigación: La sinergia entre ambas fibras (hilados de alpaca, mezclados con otras fibras naturales) no sólo busca mejorar la experiencia táctil de la prenda, sino también contribuir a la confección de prendas más sostenibles y respetuosas con el medio ambiente.

Originalidad/Valor: Este estudio contribuye al campo de la industria textil brindando una alternativa al procesamiento de fibras textiles a partir de la mezcla de fibras proteicas de leche y fibras de alpaca, ofreciendo conocimientos importantes para la industria y la academia.

Palabras clave: Alpaca Huarizo, Alpaca Superfina, Bebé Alpaca, Fibra De Proteína De Leche, Factor De Comodidade.

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1 INTRODUCTION

The world production of textile fibers in 2022 was 113 Mt, dominated by synthetic fibers since the mid-1990s, specifically by polyester with a world production of 60.5 Mt. The production market of natural fibers is dominated by cotton, with a world production of 24.7 Mt, considered as the second most important fiber. Fibers, such as jute, linen or hemp, have a production of 6%, while natural fibers of animal origin presented a world production of 1.6%. Among them, wool has a production of 1 Mt, while alpaca fiber has a production of 6000 tons. Of the total production of these fibers, only 14.8% is recycled (Textile Exchange, 2022).

Textile fibers have been an integral component of society until present day. Natural
fibers, such as cotton, wool and silk, were preferred for their comfort, versatility, softness, absorbency and dyeing properties (Uddin F., 2019).

The discovery of synthetic fibers, the industrial revolution and technology have made it possible to develop new textile materials with improved and specific properties. One of these techniques is the blending of fibers, which has given rise to products such as cut-resistant gloves, bulletproof vests, antibacterial and waterproof fibers, etc., and has led to the development of new materials with improved and specific properties (Wang L. et al., 2005). There are studies regarding blends of natural fibers. For instance, jute has been extensively blended with other natural fibres to achieve desired yarn quality at minimum cost (Basu G. & Roy A., 2008). Blended bamboo fiber based yarns have also been tested, finding significant effect of blend on all yarn properties (Sowmya R. et al., 2017; Ahsan R. & Akmal A., 2022). Milk protein fibers are stronger than wool, although showing lower crimpability (Bin Yang, 2012). Commercial fabrics from milk protein fiber, alone or blended, already exist in the market (for example, Duedilatte). The fibers that have been successfully blended include alpaca fiber, wool and polypyrrole, in order to observe changes in frictional and tensile properties (Wang L. et al., 2005). This focus on fiber blending has led to advances in the understanding and manipulation of textile properties, opening up new possibilities in the manufacture of textile products with specific and improved characteristics (Quispe et al., 2013).

Regarding the alpaca fiber, not much research was done, although it is currently considered a luxury item for presenting unique and special properties, considered as the main producer Peru with 90% worldwide, followed by Bolivia, Argentina and Chile, these countries raise two breeds of Alpaca, being 95% Huacaya breed and 5% Suri breed, these differ in shape, size and especially the diameter of the fleece, as the diameter of the fleece decreases its cost is higher (Quispe et al., 2013). Alpaca fibres are more elastic than other natural fibres, as goat or sheep (Jankowska D. et al., 2021). While these fibers undeniably possess unique properties, they also exhibit some significant disadvantages. First, their high cost, attributable to their rarity and value, makes them quite expensive options. The maintenance of garments made from these fibers requires meticulous attention to preserve their softness and luster, as they tend to generate pilling or small beads on the surface of garments. In addition, their contact may cause sensitivity in susceptible skins, resulting in itching or irritation in some people when wearing them.

On the other hand, there is a growing interest in natural products, and natural fibers feature prominently in the eco-fashion movement. This movement seeks to create garments that are sustainable in every phase of their life cycle, from production to disposal, but not all natural fibers are ecological fibers.
In this context, milk protein fiber has attracted attention and interest in recent years due to its exceptional properties in the chemical, biological and technological fields. It is obtained from dairy residues, since more than 20% by weight of dairy products are lost or wasted during processing, distribution or consumption (Malacarne M. et al., 2002). Milk protein fiber has unique characteristics, such as antibacterial properties, high mechanical strength and superior softness to wool, making it suitable even for sensitive skin.

Although alpaca yarns, blended with other natural fibres, can be found, the possibility of combining alpaca fiber with milk protein fiber is proposed, with the aim of reducing the irritability that can be experienced when in contact with the skin, known as the Comfort Factor. This synergy between both fibers not only seeks to improve the tactile experience of the garment, but also to contribute to the manufacture of more sustainable and environmentally friendly garments.

2 EXPERIMENT

2.1 MATERIALS AND PROCESS

The alpaca fibers used were of the Huacaya breed, because this fiber is short, dense and fluffy. It has a woollen appearance and presents a natural crimp, that is to say, it has small undulations along the fiber strand. Moreover, it is abundant in Peru, which presents different types and diameters. Three of them were selected for this research (Huarizo, Superfine and Baby), which diameter is shown in Table 1. The milk protein fiber presented a yellowish color and soft to the touch, very similar to wool.

Table 1

<table>
<thead>
<tr>
<th>Fiber diameter and coding in the research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Alpaca Huarizo Fiber</td>
</tr>
<tr>
<td>Alpaca Superfine Fiber</td>
</tr>
<tr>
<td>Alpaca Baby Fiber</td>
</tr>
<tr>
<td>Milk Protein Fiber</td>
</tr>
</tbody>
</table>

To make the mixture of these fibers, different proportions of MPF were established (at 70, 50 and 30% by weight), combining these fibers with the different samples of alpaca fiber. To generate these yarns, the spindle tool was used. As a result of its application, the yarn was obtained, the blends were codified and presented in Table 2.
Table 2

Coding of the mixtures.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Sample code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MPF-70%_AHF-30%</td>
</tr>
<tr>
<td>2</td>
<td>MPF-70%_ASF-30%</td>
</tr>
<tr>
<td>3</td>
<td>MPF-70%_ABF-30%</td>
</tr>
<tr>
<td>4</td>
<td>MPF-50%_AHF-50%</td>
</tr>
<tr>
<td>5</td>
<td>MPF-50%_ASF-50%</td>
</tr>
<tr>
<td>6</td>
<td>MPF-50%_ABF-50%</td>
</tr>
<tr>
<td>7</td>
<td>MPF-30%_AHF-70%</td>
</tr>
<tr>
<td>8</td>
<td>MPF-30%_ASF-70%</td>
</tr>
<tr>
<td>9</td>
<td>MPF-30%_ABF-70%</td>
</tr>
</tbody>
</table>

2.2 CHARACTERIZATION

2.2.1 Characterization by Scanning Electron Microscopy (SEM)

The test was carried out in the ZEISS MA LS 10 equipment of the Zeiss brand, working with an electron beam of 10 keV to 50 keV. By means of this test, the morphology of the fibers was studied. For the preparation of the samples, fibers of approximately 1 mm were taken and then coated with a conductive layer of gold, then placed in a slide holder to take it to the SEM equipment. The images obtained were evaluated at 2000X.

2.2.2 Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR assay was performed on a Perkin Elmer equipment with a range of spectra 4000 - 400 cm⁻¹. In addition, the attenuated total reflection (ATR) Nicolet iZ10 technique and an adapter with a ZnSe crystal were used. This analysis was used to identify the chemical bonds of a molecule by producing an absorption spectrum. Prior to testing, the textile fibers were washed in 100% pure ethanol to remove excess grease from the fiber surface.

2.2.3 Fiber diameter optical analyzer

The Meltzer OFDA 4000 was used to evaluate fiber diameter, comfort factor (CF) and coefficient of variation (CV).

For this analysis, 1 g of sample in fleece form was required for both the original samples and the mixtures obtained. These samples were subjected to a muffle at 100 °C for 12 h to eliminate the moisture present, then the sample was cut with a guillotine and placed in the
sample holder and using a microscope with a light source and controlled by software. The images of each fiber were captured by a video camera.

2.2.4 Tensile test

This test was performed on the LY-1066A universal testing machine with a capacity of 20 kN. With this test, the maximum tensile strength (σmax) and maximum deformation (ɛmax) were measured, working at a load speed of 50 mm/min, following the parameters indicated in the ASTM D2256 standard.

3 RESULTS AND DISCUSSIONS

3.1 CHARACTERIZATION BY SCANNING ELECTRON MICROSCOPY

Figure 1A shows the morphology of MPF. These fibers present a longitudinal surface with irregular grooves and island-shaped protrusions. The irregularity in certain areas in the MPF morphology is due to the dehydration of the fiber surface during the spinning process and the rapid orientation of the fibers. But it is also because these fibers have excellent moisture absorption and permeability properties and have an important impact on the brightness and stiffness of the fibers (Xiurong & Zengge, 2012). The irregularity of the fiber surface and some micro convexity changes can alter the absorption, reflection and refraction of light. It has to be indicated that this milk protein has a certain curl, a slightly yellowish appearance and a soft feel.

The morphology for AHF, ASF and ABF, as seen in Figures 1B, 1C and 1D, presents a smooth longitudinal surface with thinner and denser scales to the wool (Sabir T, 2018; Liu X. et al., 2004). The alpaca fiber has a fine structure. Each fiber is surrounded by an outer layer of flattened cuticular cells that provide protection to the internal cortical cells. The cortical cells are formed by exocuticula rich in sulfur and an epicuticle membrane. On the surface, it can be observed a set of superficial scales that are oriented from the root to the tip, being the cuticular cells that form the scales that are very small and barely visible. Because of this, the fibers have little filtering power (Cook J., 2001).
Figura 1

SEM Morphology of A) MPF, B) AHF, C) ASF and D) ABF

3.2 CHARACTERIZATION BY ENERGY DISPERSIVE X-RAY SPECTROSCOPY

While the EDX spectrum, as shown in Figure 2A, shows more pronounced peaks, they correspond to elements such as carbon, oxygen, nitrogen and sulfur. These elements are the main components of casein, the protein found in MPF (Van Devenen et al., 2018).

Alpaca fibers are composed mainly of keratin proteins. Hence, their chemical composition usually contains nitrogen (16 -17%), sulfur (3.2-3.7%), ash (0.38-0.42%) which includes calcium (0.09-0.12%) and phosphorus (0.017-0.023%) and a small amount of sodium (McGregor, 2018). The rest of the fiber is approximately 27% oxygen, 47% carbon and hydrogen. This keratin is composed of 19 amino acids whose proportions have not been definitely determined. But cystine is considered to be the main component because of the presence of strong disulfide bonds and because it is found in the greatest quantity.

Figures 2B, 2C and 2D show the EDX spectra of alpaca fibers. The most pronounced peaks in these plots correspond to carbon, oxygen, nitrogen and sulfur. These elements are the main components of keratin, the protein found in alpaca fibers.
In general, EDX spectra show that milk protein fiber and alpaca fibers have a similar elemental composition. However, there are some differences. Milk protein fiber has a higher nitrogen and sulfur content than alpaca fibers. This is because casein contains more nitrogen and sulfur than keratin.

Differences in the elemental composition of the fibers can have an impact on their properties. For example, the higher nitrogen and sulfur content of milk protein fiber may contribute to a higher tensile strength.

**Figura 2**

EDX of fiber samples. A) MPF, B) AHF, C) ASF and D) ABF

![EDX spectra images](image_url)

3.3 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

The threads were characterized to identify the chemical groups. The spectra can be visualized in Figure 3, where it is observed that the MPF presents an absorption peak at 1647 cm$^{-1}$ that represents the C=O structure in the amide I bond, while the peak at 1540 cm$^{-1}$...
represents a strong amide II bond that is formed due to the N-H bond of the C-N-H group (Xiurong & Zengge, 2012) this confirms the presence of protein. Finally, there are absorption peaks at 1450 cm\(^{-1}\) (related to the C-N bond present in the amide III bond) and the peak at 1036 cm\(^{-1}\) is related to the S-O vibration.

For the absorption peaks of AHF, ASF and ABF samples shown in Figure 3, it can be seen at 3227 cm\(^{-1}\) a superposition of the N-H region of amide hydrogen and O-H region, while peak 2920 cm\(^{-1}\) at can correspond to the C=H saturated and C-H unsaturated groups; at 1624 cm\(^{-1}\), the amide I band is mainly due to contributions from the C=O stretching vibration of the peptide backbone. At 1514 cm\(^{-1}\), the amide II group arises from the N-H bending and C-N stretching vibrations (amide III band) of the backbone, and finally at 1230 cm\(^{-1}\) the C-O group and at 1043 cm\(^{-1}\) S-O vibrations peaks can be found.

**Figure 3**

*FTIR of MPF, AHF, ASF and ABF*

### 3.4 OPTICAL FIBER DIAMETER ANALYSIS

According to Quispe et al., 2013, in the apparel industry, a fleece whose diameter exceeds 5% in fibers larger than 30 µm may be uncomfortable to wear due to the itchy skin sensation experienced by the consumer. Therefore, fibers with a CF equal to or greater than 95% are considered to be more suitable for application in the textile industry. In addition, a
fleece with a low CV exhibits greater uniformity in fiber diameter. In other words, fleeces that exceed 24% CV fail to provide optimum textile performance (Quispe et al., 2013).

Table 3 shows the data related to fiber diameter, as well as the CV and CF, both for the original fibers and for the blends made. Alpaca Huarizo Fiber (AHF) exhibits a remarkably high diameter and CV, together with a considerably low CF, registering 38.15%. These results coincide with previous findings indicating a CF of 44.42% (Liu X. et al., 2004). In contrast, Lupton reported a higher CF, reaching 68.39% (Jankowska D. et al., 2021). These data were given controlling some factors that should be controlled such as breed, age, feeding, sex, etc.

In other investigations (Quispe et al., 2013), significant data have been revealed on the CF, reaching 93.67% in white alpacas of the Huacaya breed. It is highlighted that this factor is intrinsically related to the age and year of the alpaca, indicating that as the age increases, an increase in the fleece weight and in the diameter of the fibers is observed (Cook J., 2001). The young alpacas produce less heavy fleeces than the adult ones, because they have a smaller body surface. However, they produce fleeces with finer fibers, because the shearing has the effect of increasing the follicular functioning. The shearing is done between the months of October to November. The profile of the diameter from the base to the tip is increasing, while in fibers sheared in the months of March to April the diameter from the base is decreasing and then almost from the middle part is increasing. Therefore, the best month for shearing is in November, since this helps the growth of the fibers and with the help of the warm temperature and the first rains make the slaughter favorable, so that the sheared animals are not exposed to the intense cold of winter and the growth of fresh grass allows to cover the energetic wear to grow new fiber (Quispe et al., 2009).

In comparison, MPF exhibits reduced diameter and CV, along with a CF above 95%, which qualifies it as suitable for the apparel industry. In the context of blends, it is observed that, as the percentage of MPF increases, the CF exceeds 95%, simultaneously decreasing the diameter and CV.

Table 3

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Diameter (µm)</th>
<th>CV (%)</th>
<th>CF (%)</th>
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<tr>
<td>AHF</td>
<td>34.99</td>
<td>31.15</td>
<td>38.15</td>
</tr>
<tr>
<td>ASF</td>
<td>25.74</td>
<td>28.9</td>
<td>78.68</td>
</tr>
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<td>ABF</td>
<td>21.34</td>
<td>28.26</td>
<td>93.21</td>
</tr>
<tr>
<td>MPF</td>
<td>17.67</td>
<td>17.03</td>
<td>99.69</td>
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<td>MPF-30%_AHF-70%</td>
<td>22.46</td>
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<td>MPF-50%_AHF-50%</td>
<td>20.37</td>
<td>36.43</td>
<td>90.32</td>
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<tr>
<td>MPF-70%_AHF-30%</td>
<td>18.94</td>
<td>30.83</td>
<td>95.41</td>
</tr>
</tbody>
</table>
3.5 TENSILE TEST OF INDIVIDUAL YARNS AND MIXTURES OF MILK PROTEIN FIBER WITH ALPACA FIBER

The results shown in Table 4 reveal that the σmax value of MPF sample yarns of 67.2 ± 4.9 MPa (7.5±0.5 cN/tex) with a ɛmax of 11.7%. In previous studies, diverse results have been obtained, such as: 72-87 MPa (8-9.7cN/tex) (Cook, J., 2001, McGregor B & Butler K., 2004), 119.97 MPa (13.33cN/tex) at a feed rate of 500 mm/min [Sowmya R. et al., 2017], values in the range of 252-369 MPa (28-41 cN/tex) at a feed rate of 10 mm/min have also been recorded (Bin Yang, 2012; Tasnim N., 2019). In relation to the deformation, the results are very close to 15.3% (Xu G. & Yu J., 2013). Other studies have reported a deformation of up to 22.8% (Bin Yang, 2012), as well as a wider range of 25 - 35% (Tasnim N., 2019; Chauahn et al., 2018). These results are compared with wool, since they present very similar values in terms of tensile strength and elongation (Tasnim N., 2019).

Regarding alpaca yarns, the values of σmax and ɛmax for AHF indicate a σmax of 63.3±4.9 MPa (7.0±0.5 cN/Tex), with a ɛmax of 7.0%. On the other hand, ASF presents σmax of 58.6 MPa (6.5 cN/Tex) and ɛmax of 5.6% while ABF presents σmax 58.7±3.2 MPa (6.5 cN/Tex) and ɛmax 6.13%. These results have been contrasted with previous investigations, such as those of Lupton (2006), which showed σmax results in the range of 27-50 MPa (3-5.5 cN/tex) (Cook, J., 2001). In New Zealand, values ranging from 8.6 to 68.4 MPa (3-7.6 cN/tex) were found (Quispe et al., 2009). As for the strain, data ranging from 46% to 51% have been observed at a feed rate of 10 mm/min (Cook, J., 2001), as well as values of 33%, which show remarkable similarities with the elongations characteristic of Kashmir (Jankowska D., 2021).

In relation to the mixtures made with different fiber diameters and different proportions of MPF, the results obtained stand out. For AHF, the optimum combination was MPF-50%_AHF-50% reaching a σmax 64.9 MPa, but a low % ɛmax was obtained, compared to the combination of MPF-70%_AHF-30%, with a value of 10.4%. In the combination with ASF, the best results of σmax and ɛmax were obtained in the mixture of MPF-70%_ASF-30% with a value of 63 MPa and 10.5%, respectively. Finally for the mixture with ABF, the best σmax and ɛmax was in the MPF-50%_ABF-50% mixture with a value of 75.5 MPa and 9.9%.
These results present significant comparisons with other blends involving various fibers, whether vegetable, animal, protein or synthetic. For example, the combination of protein fiber with cotton (30% milk protein fiber and 70% cotton) showed a tensile strength of 127.89 MPa or 14.21 cN/tex and an elongation % of 17% (Xu G. & Yu J., 2013). In the biomedical field, milk protein fibers were developed through the use of nitric acid, improving tensile properties up to 110 MPa and an elongation of 13.6%. Combinations of alpaca fiber with polyacrylonitrile (PAN) were also investigated, concluding that the mixture with 10% alpaca and 90% PAN achieved a tenacity of 10.94 ± 0.31 cN/tex and an elongation of 6.95 ± 0.21% (Xu G. & Yu J., 2013). Finally, mixtures of alpaca fiber with palm kernel and polypropylene (PP) were made, obtaining tensile strength values of 62 MPa for a combination of 15% alpaca, 20% kernel and 65% PP (Vinoth N. et al., 2021).

Table 4
Summary of the tensile test.

<table>
<thead>
<tr>
<th>Sample</th>
<th>σ_{max} (MPa)</th>
<th>% ɛ_{max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPF</td>
<td>67.2±4.9</td>
<td>11.7±1.3</td>
</tr>
<tr>
<td>AHF</td>
<td>63.3±4.9</td>
<td>7.0±1.1</td>
</tr>
<tr>
<td>ASF</td>
<td>58.6±3.8</td>
<td>5.6±1.2</td>
</tr>
<tr>
<td>ABF</td>
<td>58.7±3.2</td>
<td>6.1±1.2</td>
</tr>
<tr>
<td>MPF-30%_AHF-70%</td>
<td>53.8±4.5</td>
<td>9.6±1.1</td>
</tr>
<tr>
<td>MPF-50%_AHF-50%</td>
<td>64.9±4.8</td>
<td>8.4±0.4</td>
</tr>
<tr>
<td>MPF-70%_AHF-30%</td>
<td>60.7±6.1</td>
<td>10.4±1.1</td>
</tr>
<tr>
<td>MPF-30%_ASF-70%</td>
<td>57.7±4.8</td>
<td>6.3±1.2</td>
</tr>
<tr>
<td>MPF-50%_ASF-50%</td>
<td>54.0±3.5</td>
<td>7.0±1.1</td>
</tr>
<tr>
<td>MPF-70%_ASF-30%</td>
<td>63.1±8.0</td>
<td>10.5±1.9</td>
</tr>
<tr>
<td>MPF-30%_ABF-70%</td>
<td>44.4±3.4</td>
<td>5.9±0.5</td>
</tr>
<tr>
<td>MPF-50%_ABF-50%</td>
<td>75.5±5.8</td>
<td>9.9±0.7</td>
</tr>
<tr>
<td>MPF-70%_ABF-30%</td>
<td>52.3±4.8</td>
<td>7.5±0.7</td>
</tr>
</tbody>
</table>

4 CONCLUSION

Regarding the morphology of the alpaca and milk fibers, it was determined that the alpaca fiber presents a smooth longitudinal surface with thin flakes, while the milk protein fiber presents a longitudinal surface with irregular grooves and island-shaped protrusions that are due to the dehydration of the fiber surface during the spinning process and the rapid orientation of the fibers.

The functional groups, detected with FTIR, and EDX chemical analysis confirm the keratine structure of milk protein and alpaca fibres.

Comfort factor of blended yarns diminishes when compared to that of plain milk protein fibre yarns. However, for all tested blended yarns, there can be found combinations promoting
CF greater than 95%, suitable for textile applications. Diameter and CV increases in blended yarns. Further selection of alpaca fibres could enhance those values.

Finally, the results of the tensile test showed that the alpaca huarizo fiber presented a higher tensile strength with a value of 63.3±4.9MPa and an elongation of 6.98±1%, the superfine alpaca showed a tensile stress of 58.59±3.8MPa and an elongation of 5.55±1.2%, the baby alpaca obtained a value of 58.68±3.2MPa of maximum tensile strength and an elongation of 6.13±1.2%, while the milk protein fiber showed a maximum tensile strength of 67.21±4.9MPa and an elongation of 11.71±1.3%. While for the mixtures with huarizo, the MPF-50%_AHF-50% combination showed a maximum tensile strength of 64.9±4.8 MPa, but a low elongation, compared to the MPF-70%_AHF-30% mixture with a value of 10.39±1% elongation. For the mixture with superfine showed a higher tensile strength the combination of MPF-70%_ASF-30% with a value of 63.11±8 MPa and with a higher elongation of 10.51±1.9% and finally the mixture with baby presenting the highest tensile strength the combination of MPF-50%_ASF-50% with a value of 75±5.8 MPa and an elongation of 9.88±0.7%.

Alpaca fibres are less strong and less ductile than milk protein fibres. Blended yarns show mechanical properties between both of its components.

**ACKNOWLEDGEMENTS**

Optional section, where the author can thank the funding agencies, or other applicable thank you.

**REFERENCES**


