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Age effect on the llama fleece structure and its relationship to fibre textile quality

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Age effect on the llama fleece structure and its relationship to fibre textile quality

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In this list, the variables are introduced in the sequence in which they were created through the successive activities carried out in the framework of this thesis. In this way, it serves as a guide to understand how each variable is built, particularly regarding the different types of mean fibre diameter (MD).

Within the abbreviated designation of a variable, the upper-case letters correspond to the variable designation itself, while the lower-case letters are used to describe and explain a variable aspect, for example, letter “w” when the TMD is weighed by weight.

Abbreviations ordered according to the sub-chapters:

This abbreviation list is ordered according to topics, sub-chapters and the different research activities carried out.		
Abbreviation	**Description**	**Unit**
Fleece type (FT):		
FT	Fleece type (DC, IC, SC, HL, L)	-----
DC	Double Coated fleece type	-----
IC	Intermediate Coated fleece type	-----
SC	Simple Coated fleece type	-----
HL	Hemi Lustre fleece type	-----
L	Lustre fleece type	-----
Fibre type (Medulla Type (MEDT)):		
MEDT	Medulla Type (A, F, I, C and G)	-----
A	Non-medullated fibre (A, for the Spanish word for non-medullated: **a**medulada)	-----
F	Fragmented medullated fibre	-----
I	Interrupted medullated fibre	-----
C	Continuous medullated fibre	-----
G	Large (lattice) medullated fibre (G, for the Spanish word for large or coarse: **g**ruesa)	-----
Fibre Groups (FG) as a result of the Three Group Dissection:		
FG	Fibre group (FG1, FG2 and FG3)	-----
FG1	FG of coarse fibres	-----
FG2	FG of intermediate fibres	-----

FG3	FG of fine fibres	-----
Crimp groups (CG): according to Crimp Groups for Llama Fibre (Figure 3)		-----
CG	Crimp group (CG1, CG2, CG3, CG4, CG5, CG6 and CG7)	-----
CG1	Crimp group 1	-----
CG2	Crimp group 2	-----
CG3	Crimp group 3	-----
CG4	Crimp group 4	-----
CG5	Crimp group 5	-----
CG6	Crimp group 6	-----
CG7	Crimp group 7	-----
Other abbreviations:		
KW	Kruskal–Wallis test	-----
R	Rest (Three Group Dissection)	-----
AM2	Name of the Industrial dehairing machine	-----
SUPPRAD	Small Ruminant Productive Sustainability in less favoured Areas Programme (SUPPRAD, for its acronym in Spanish: Sustentabilidad Productiva y Promoción de Áreas Desfavorecidas)	-----
UCC	Catholic University of Córdoba, Argentina (UCC, for its acronym in Spanish: Universidad Católica de Córdoba)	-----
LAFTA	Animal Textile Fibre Analysis Laboratory (LAFTA, for its acronym in Spanish: **L**aboratorio de **A**nálisis de **F**ibras **T**extiles **A**nimales)	-----
Generic variables: The term "generic variable" refers to a variable that involves several specific variables at the same time, for example, MD involves all the variables related to the mean diameter, such as TMDv, TMDw, TMDn, MD1, MDA, etc.		
MD	Mean fibre diameter (MD is equal to MFD in Brodtmann et al. (2018))	µ
TMD	Total Mean fibre diameter: MD of a complete staple, “T” means “total”, that is to say including all fibres within a staple. The TMD can be measured from a fleece staple (TMDv and TMDvo) or it can be weighed through the 3 FGs forming a complete	µ

	staple (TMDw and TMDn). (TMD is equal to TMFD in Brodtmann et al. (2018).)	
SD	Standard deviation	µ
W	Absolute weight	g
W%	Relative weight	%
N	Absolute fibre frequency (or absolute number of fibres)	quantity
N%	Relative fibre frequency	%
NA	Absolute fibre frequency of non-medullated fibres	quantity
NF	Absolute fibre frequency of fragmented medullated fibres	quantity
NI	Absolute fibre frequency of interrupted medullated fibres	quantity
NC	Absolute fibre frequency of continuous medullated fibres	quantity
NG	Absolute fibre frequency of large (lattice) medullated fibres	quantity
N%A	Relative fibre frequency of non-medullated fibres	%
N%F	Relative fibre frequency of fragmented medullated fibres	%
N%I	Relative fibre frequency of interrupted medullated fibres	%
N%C	Relative fibre frequency of continuous medullated fibres	%
N%G	Relative fibre frequency of large (lattice) medullated fibres	%
CF	Crimp frequency (crimps/cm)	crimps/cm
CG	Crimp Group according to the Crimp Group Diagram for Llama Fibre (CG1, CG2, CG3, CG4, CG5, CG6 and CG7)	-----
L	Fibre length	cm
Lower-case letters or numbers (describing a variable characteristic):		
v	MD of a staple taken from a fleece, that is to say from the complete staple taken directly from the animal (Sub-chapter 1) (v, stands for the Spanish word for fleece: **v**ellón)	-----
w	MD weighed according to the relative weight (**W**%)	-----
n	MD weighed according to the relative fibre frequency (**N**%)	-----
With no lower-case letter	Variable corresponding to the experimental database (Sub-chapter 1)	-----
c	Variable corresponding to the **c**omplete experimental flock (Sub-chapter 1)	-----
o	Variable corresponding to the **o**bservational database (= big database) (Sub-chapter 1)	-----
d	Variable corresponding to the **d**ehairing product (Sub-chapter 2)	-----
s	Variable corresponding to the dehairing **s**ubproduct	-----

	(Sub-chapter 2) (Not to mistake the lower-case letter ´s´ as when used as plural of a variable, such as for ´FTs´, ´FGs´, ´MDs´ and ´CGs´.)	
e	Variable corresponding to the study related to the fleece structure (Sub-chapter 3) (e, for the Spanish word for structure: **e**structura.)	-----
1	Variable corresponding to FG**1**	
2	Variable corresponding to FG**2**	
3	Variable corresponding to FG**3**	
Sub-chapter 1 **Age effect on llama fleece structure**		
* The variables identified with an asterisk are present in the database and are used to create another variable, but they are not mentioned in the text. They are only expressed through a table or a graph.		
A) Variables measured after the implementation of the Three Group Dissection, based on the 3 fibre groups formed:		
A1) Variables measured for a FIBRE GROUP (FG)		
MD1, MD2 and MD3, and the related variables (Equation 4, Figure 5): Experimental database		**Division 1.1**
FG1:		
MD1	Mean diameter measured for FG1	µ
MDA1	Non-medullated fibres MD of FG1	µ
MDF1	Fragmented medullated fibres MD of FG1	µ
MDI1	Interrupted medullated fibres MD of FG1	µ
MDC1	Continuous medullated fibres MD of FG1	µ
MDG1	Large (lattice) medullated fibres MD of FG1	µ
N%A1	Non-medullated fibres N% of FG1	%
N%F1	Fragmented medullated fibres N% of FG1	%
N%I1	Interrupted medullated fibres N% of FG1	%
N%C1	Continuous medullated fibres N% of FG1	%
N%G1	Large (lattice) medullated fibres N% of FG1	%
FG2:	Analogous variables to FG1, replace “1” with “2”	
FG3:	Analogous variables to FG1, replace “1” with “3”	

Relative weight (W%):		**Division 1.1**
W%1	W% of FG1	%
W%2	W% of FG2	%
W%3	W% of FG3	%
Relative fibre frequency (N%):		**Division 1.1**
N%1	N% of FG1 fibres	%
N%2	N% of FG2 fibres	%
N%3	N% of FG3 fibres	%
A2) Variables measured for 3 INDIVIDUAL FIBRES of each FG		
Crimp frequency (CF):		**Division 1.3**
CF1	CF average of 3 fibres out of FG1, randomly selected	crimps/cm
CF2	CF average of 3 fibres out of FG2, randomly selected	crimps/cm
CF3	CF average of 3 fibres out of FG3, randomly selected	crimps/cm
Absolute fibre frequency according to CG:		**Division 1.4**
FG1, FG2 and FG3: **(The following variables describing the CG exist for each of the three fibre groups.)**		
NCG1*	Absolute fibre frequency of CG1 fibres	quantity
NCG2*	Absolute fibre frequency of CG2 fibres	quantity
NCG3*	Absolute fibre frequency of CG3 fibres	quantity
NCG4*	Absolute fibre frequency of CG4 fibres	quantity
NCG5*	Absolute fibre frequency of CG5 fibres	quantity
NCG6*	Absolute fibre frequency of CG6 fibres	quantity
NCG7*	Absolute fibre frequency of CG7 fibres	quantity
Fibre length (L):		**Division 1.5**
L1	L of FG1	cm
L2	L of FG2	cm
L3	L of FG3	cm
B) WEIGHED VARIABLES based on MD1, MD2 and MD3, and based whether on N%1, N%2 and N%3, or on W%1, W%2 and W%3:		
TMDn and the related variables (Equation 3, Figure 5): **Experimental database**		**Division 1.1**
TMDn	Total mean diameter weighed by fibre frequency (N%)	µ

MD1	Mean diameter measured for FG1	μ
MD2	Mean diameter measured for FG2	μ
MD3	Mean diameter measured for FG3	μ
N%1	N% of FG1	%
N%2	N% of FG2	%
N%3	N% of FG3	%
TMDw and the related variables (Equation 2, Figure 5): Experimental database		**Division 1.1**
TMDw	Total mean diameter weighed by weight (W%)	μ
The variable TMDw is analogous to TMDn; it is only weighed by weight rather than fibre frequency, thus having the letter “w” at the end of the abbreviation. It is created based on equivalent variables: MD1, MD2 and MD3, W%1, W%2 and W%3		
C) CALCULATED VARIABLES for each fibre type (medulla) based on the variables measured during the projection microscope method		
MDA, MDF, MDI, MDC and MDG, and the related variables (Equation 5, Figure 5): Experimental database		**Divisions 1.2 and 1.6**
MEDT A:	**Med**ulla **T**ype A (Non-medullated fibre) (A, for the Spanish word for non-medullated: **a**medulada)	
MDA	Mean diameter of all non-medullated fibres	μ
MDA1	Non-medullated fibres MD of FG1	μ
MDA2	Non-medullated fibres MD of FG2	μ
MDA3	Non-medullated fibres MD of FG3	μ
N%A1	Non-medullated fibres N% of FG1	%
N%A2	Non-medullated fibres N% of FG2	%
N%A3	Non-medullated fibres N% of FG3	%
MEDT F:	Variables analogous to MEDT A, replace “A” with “F”	
MEDT I:	Variables analogous to MEDT A, replace “A” with “I”	
MEDT C:	Variables analogous to MEDT A, replace “A” with “C”	
MEDT G:	Variables analogous to MEDT A, replace “A” with “G”	
N%A, N%F, N%I, N%C and N%G, and the related variables (Figure 5): Experimental database		**Division 1.2**
MEDT A:	**Med**ulla **T**ype A (Non-medullated fibre) (A, for the Spanish word for non-medullated: **a**medulada)	

N%A	Relative fibre frequency (N%) of non-medullated fibres	**%**
N%A1	Non-medullated fibres N% of FG1	%
N%A2	Non-medullated fibres N% of FG2	%
N%A3	Non-medullated fibres N% of FG3	%
MEDT F:	Variables analogous to MEDT A, replace “A” with “F”	
MEDT I:	Variables analogous to MEDT A, replace “A” with “I”	
MEDT C:	Variables analogous to MEDT A, replace “A” with “C”	
MEDT G:	Variables analogous to MEDT A, replace “A” with “G”	
D) Variables measured for a staple taken from a FLEECE:		
TMDv and the related variables (Equation 1, Figure 5): **Experimental database** (v, for the Spanish word for fleece: **v**ellón)		**Divisions 1.1 and 1.6**
TMDv	Total mean diameter measured for a staple taken from a fleece (20 experimental animals tested annually)	µ
TMDvc	Total mean diameter measured for a staple taken from a fleece (complete experimental flock)	µ
MDAv	MD of non-medullated fibres	µ
MDFv	MD of fragmented medullated fibres	µ
MDIv	MD of interrupted medullated fibres	µ
MDCv	MD of continuous medullated fibres	µ
MDGv	MD of large (lattice) medullated fibres	µ
N%Av	N% of non-medullated fibres	%
N%Fv	N% of fragmented medullated fibres	%
N%Iv	N% of interrupted medullated fibres	%
N%Cv	N% of continuous medullated fibres	%
N%Gv	N% of large (lattice) medullated fibres	%
TMDvo and the related variables (Equation 1, Figure 5): **Observational database** (lower-case letter “o” for observational database)		**Division 1.6**
TMDvo	Total mean diameter measured for a staple taken from a fleece, observational information	µ
The TMDvo is equivalent to TMDv; it only describes information about the observational database, thus having the letter “o” at the end of the abbreviation. It is created based on equivalent variables: MDAvo, MDFvo, etc.		
E) Variables measured on the ANIMAL:		
Thoracic perimeter (PERIMc and PERIMo):		**Divisions**

		1.1 and 1.6
PERIMc	Thoracic perimeter (experimental animals, complete flock)	cm
PERIMo	Thoracic parameter (organizational database)	cm
Sub-chapter 2 **Dehairing effect on llama fibre structure**		
* The variables identified with an asterisk are present in the database and are used to create another variable, but they are not mentioned in the text. They are only expressed through a table or a graph.		
A) Variables measured after the implementation of the Three Group Dissection, based on the 3 fibre groups formed:		
A1) Variables measured for a FIBRE GROUP (FG)		
MD1d, MD2d and MD3d, and the related variables (Equation 4, Figure 5):		**Divisions 2.1 and 2.6**
FG1:		
MD1d	Mean diameter measured for FG1	µ
MDA1d	Non-medullated fibres MD of FG1	µ
MDF1d	Fragmented medullated fibres MD of FG1	µ
MDI1d	Interrupted medullated fibres MD of FG1	µ
MDC1d	Continuous medullated fibres MD of FG1	µ
MDG1d	Large (lattice) medullated fibres MD of FG1	µ
N%A1d	Non-medullated fibres N% of FG1	%
N%F1d	Fragmented medullated fibres N% of FG1	%
N%I1d	Interrupted medullated fibres N% of FG1	%
N%C1d	Continuous medullated fibres N% of FG1	%
N%G1d	Large (lattice) medullated fibres N% of FG1	%
FG2:	Analogous variables to FG1, replace “1” with “2”	
FG3:	Analogous variables to FG1, replace “1” with “3”	
Relative weight (W%):		**Divisions 2.1 and 2.7**
W%1d	W% of FG1	%
W%2d	W% of FG2	%
W%3d	W% of FG3	%

Relative fibre frequency (N%):		**Divisions 2.1 and 2.7**
N%1d	N% of FG1	%
N%2d	N% of FG2	%
N%3d	N% of FG3	%
A2) Variables measured for 3 INDIVIDUAL FIBRES of each FG		
Crimp frequency (CF):		**Division 2.3**
CF1d	CF average of 3 fibres out of FG1, randomly selected	crimps/cm
CF2d	CF average of 3 fibres out of FG2, randomly selected	crimps/cm
CF3d	CF average of 3 fibres out of FG3, randomly selected	crimps/cm
Absolute fibre frequency according to CG:		**Division 2.4**
FG1, FG2 and FG3: **(The following variables describing the CG exist for each of the three fibre groups.)**		
NCG1d*	Absolute fibre frequency of CG1 fibres	quantity
NCG2d*	Absolute fibre frequency of CG2 fibres	quantity
NCG3d*	Absolute fibre frequency of CG3 fibres	quantity
NCG4d*	Absolute fibre frequency of CG4 fibres	quantity
NCG5d*	Absolute fibre frequency of CG5 fibres	quantity
NCG6d*	Absolute fibre frequency of CG6 fibres	quantity
NCG7d*	Absolute fibre frequency of CG7 fibres	quantity
Fibre length (L):		**Division 2.5**
L1d	L of FG1 of the dehairing product	cm
L2d	L of FG2 of the dehairing product	cm
L3d	L of FG3 of the dehairing product	cm
L1s	L of FG1 of the subproduct	cm
L2s	L of FG2 of the subproduct	cm
L3s	L of FG3 of the subproduct	cm
B) WEIGHED VARIABLES based on MD1d, MD2d and MD3d, and based whether on N%1d, N%2d and N%3d, or on W%1d, W%2d and W%3d:		
TMDnd and the related variables (Equation 3, Figure 5):		**Divisions 2.1 and 2.7**
TMDnd	Total mean diameter weighed by fibre frequency (N%)	µ
MD1d	Mean diameter measured for FG1	µ
MD2d	Mean diameter measured for FG2	µ

MD3d	Mean diameter measured for FG3	μ
N%1d	N% of FG1	%
N%2d	N% of FG2	%
N%3d	N% of FG3	%
TMDwd and the related variables (Equation 2, Figure 5):		**Division 2.1**
TMDwd	Total mean diameter weighed by weight (W%)	μ
The TMDwd is analogous to TMDnd; it is only weighed by weight rather than fibre frequency, thus having the letter "w" at the end of the abbreviation. It is created based on equivalent variables: MD1d, MD2d, MD3d, W%1d, W%2d and W%3d		
C) CALCULATED VARIABLES for each fibre type (medulla) based on the variables measured during the projection microscope method		
MDA, MDF, MDI, MDC and MDG, and the related variables (Equation 5, Figure 5):		**Division 2.2**
MEDT A:	**Medulla Type A**	
MDAd	Mean diameter of all non-medullated fibres	μ
MDA1d	Non-medullated fibres MD of FG1	μ
MDA2d	Non-medullated fibres MD of FG2	μ
MDA3d	Non-medullated fibres MD of FG3	μ
N%A1d	Non-medullated fibres N% of FG1	%
N%A2d	Non-medullated fibres N% of FG2	%
N%A3d	Non-medullated fibres N% of FG3	%
MEDT F:	Variables analogous to MEDT A, replace "A" with "F"	
MEDT I:	Variables analogous to MEDT A, replace "A" with "I"	
MEDT C:	Variables analogous to MEDT A, replace "A" with "C"	
MEDT G:	Variables analogous to MEDT A, replace "A" with "G"	
N%A, N%F, N%I, N%C and N%G, and the related variables (Figure 5):		**Division 2.2**
MEDT A:	**Medulla Type A**	
N%Ad	Relative fibre frequency (N%) of non-medullated fibres	**%**
N%A1d	Non-medullated fibres N% of FG1	%
N%A2d	Non-medullated fibres N% of FG2	%
N%A3d	Non-medullated fibres N% of FG3	%
MEDT F:	Variables analogous to MEDT A, replace "A" with "F"	

MEDT I:	Variables analogous to MEDT A, replace “A” with “I”	
MEDT C:	Variables analogous to MEDT A, replace “A” with “C”	
MEDT G:	Variables analogous to MEDT A, replace “A” with “G”	
Other abbreviations:		
TFD	Total follicular density	
Sub-chapter 3 **Evaluation of classing and dehairing on textile quality**		
* The variables identified with an asterisk are present in the database and are used to create another variable, but they are not mentioned in the text. They are only expressed through a table or a graph.		
** The variables identified with two asterisks are present in the database and are used to create another variable, but they are not mentioned in the text, nor are they graphed.		
A) Variables measured after the implementation of the Three Group Dissection, based on the 3 fibre groups formed:		
A1) Variables measured for a FIBRE GROUP (FG)		
MD1e, MD2e and MD3e, and the related variables (Equation 4, Figure 5):		**Division 3.8**
FG1:		
MD1e	Mean diameter measured for FG1	µ
MDA1e**	Non-medullated fibres MD of FG1	µ
MDF1e**	Fragmented medullated fibres MD of FG1	µ
MDI1e**	Interrupted medullated fibres MD of FG1	µ
MDC1e**	Continuous medullated fibres MD of FG1	µ
MDG1e**	Large (lattice) medullated fibres MD of FG1	µ
N%A1e**	Non-medullated fibres N% of FG1	%
N%F1e**	Fragmented medullated fibres N% of FG1	%
N%I1e**	Interrupted medullated fibres N% of FG1	%
N%C1e**	Continuous medullated fibres N% of FG1	%
N%G1e**	Large (lattice) medullated fibres N% of FG1	%
FG2:	Analogous variables to FG1, replace “1” with “2”	
FG3:	Analogous variables to FG1, replace “1” with “3”	
Relative weight (W%):		
W%1e**	W% of FG1	%

W%2e**	W% of FG2	%
W%3e**	W% of FG3	%
Relative fibre frequency (N%):		
N%1e**	N% of FG1	%
N%2e**	N% of FG2	%
N%3e**	N% of FG3	%
A2) Variables measured for 3 INDIVIDUAL FIBRES of each FG		
Crimp frequency (CF):		**Division 3.3**
CF1e*	CF average of 3 fibres out of FG1, randomly selected	crimps/cm
CF2e*	CF average of 3 fibres out of FG2, randomly selected	crimps/cm
CF3e*	CF average of 3 fibres out of FG3, randomly selected	crimps/cm
Absolute fibre frequency according to CG:		**Division 3.4**
FG1, FG2 and FG3: **(The following variables describing the CG exist for each of the three fibre groups.)**		
NCG1e*	Absolute fibre frequency of CG1 fibres	quantity
NCG2e*	Absolute fibre frequency of CG2 fibres	quantity
NCG3e*	Absolute fibre frequency of CG3 fibres	quantity
NCG4e*	Absolute fibre frequency of CG4 fibres	quantity
NCG5e*	Absolute fibre frequency of CG5 fibres	quantity
NCG6e*	Absolute fibre frequency of CG6 fibres	quantity
NCG7e*	Absolute fibre frequency of CG7 fibres	quantity
Fibre length (L):		**Division 3.5**
L1e*	L of FG1	cm
L2e*	L of FG2	cm
L3e*	L of FG3	cm
B) WEIGHED VARIABLES based on MD1, MD2 and MD3, and based whether on N%1, N%2 and N%3, or on W%1, W%2 and W%3:		
TMDne the related variables (Equation 3, Figure 5):		**Divisions 3.6 to 3.9**
TMDne	Total mean diameter weighed by fibre frequency (N%)	µ
MD1e	Mean diameter measured for FG1	µ
MD2e	Mean diameter measured for FG2	µ

MD3e	Mean diameter measured for FG3	µ
N%1e**	N% of FG1	%
N%2e**	N% of FG2	%
N%3e**	N% of FG3	%
TMDne< 31 and the related variables (Equation 3, Figure 5):		**Divisions 3.6 to 3.9**
TMDne<31	Total mean diameter weighed by fibre frequency (N%), only of fleeces with a TMDne lower than 31 µm	µ
MD1e<31	Mean diameter measured for the FG1, only of fleeces with a TMDne lower than 31 µm	µ
MD2e<31	Mean diameter measured for the FG2, only of fleeces with a TMDne lower than 31 µm	µ
MD3e<31	Mean diameter measured for the FG3, only of fleeces with a TMDne lower than 31 µm	µ
N%1e<31**	N% of FG1, only of fleeces with a TMDne lower than 31 µm	%
N%2e<31**	N% of FG2, only of fleeces with a TMDne lower than 31 µm	%
N%3e<31**	N% of FG3, only of fleeces with a TMDne lower than 31 µm	%
TMDne< 28 and the related variables (Equation 3, Figure 5):		**Divisions 3.6 to 3.9**
TMDne<28	Total mean diameter weighed by fibre frequency (N%), only of fleeces with a TMDne lower than 28 µm	µ
MD1e<28	Mean diameter measured for the FG1, only of fleeces with a TMDne lower than 28 µm	µ
MD2e<28	Mean diameter measured for the FG2, only of fleeces with a TMDne lower than 28 µm	µ
MD3e<28	Mean diameter measured for the FG3, only of fleeces with a TMDne lower than 28 µm	µ
N%1e<28**	N% of FG1, only of fleeces with a TMDne lower than 28 µm	%
N%2e<28**	N% of FG2, only of fleeces with a TMDne lower than 28 µm	%
N%3e<28**	N% of FG3, only of fleeces with a TMDne lower than 28 µm	%

Abbreviations in alphabetical order:

*** For all variables related to non-medullated fibres that contain an "A" in their abbreviation (A, for the Spanish word of non-medullated: **a**medulada), analogously, also exist these variables for the fragmented, interrupted, continuous and large medullated fibres. In order to name them, the letter "A" is replaced by "F", "I", "C" and "G", respectively (G, for the Spanish word for large or coarse: **g**ruesa).		
1	"1" for being a variable corresponding to FG**1**	-----
2	"2" for being a variable corresponding to FG**2**	-----
3	"3" for being a variable corresponding to FG**3**	-----
A	Non-medullated fibre (A, for the Spanish word for non-medullated: **a**medulada)	-----
AM2	Name of the Industrial dehairing machine	-----
c	Variable corresponding to the **c**omplete experimental flock (Sub-chapter 1)	-----
C	In an abbreviation, a "C" may stand for "continuous" as well as for "crimp" or "coated". A "c" stands for "complete".	-----
C	**C**ontinuous medullated fibre	-----
CF	**C**rimp **f**requency (crimps/cm)	crimps/cm
CF1	CF average of 3 fibres out of FG1, randomly selected (Sub-chapter 1, experimental)	crimps/cm
CF1d	CF average of 3 fibres out of FG1, randomly selected (Sub-chapter 2, dehairing product)	crimps/cm
CF2	CF average of 3 fibres out of FG2, randomly selected (Sub-chapter 1, experimental)	crimps/cm
CF2d	CF average of 3 fibres out of FG2, randomly selected (Sub-chapter 2, dehairing product)	crimps/cm
CF3	CF average of 3 fibres out of FG3, randomly selected (Sub-chapter 1, experimental)	crimps/cm
CF3d	CF average of 3 fibres out of FG3, randomly selected (Sub-chapter 2, dehairing product)	crimps/cm
CG	**C**rimp **g**roup (CG1, CG2, CG3, CG4, CG5, CG6 and CG7) according to Crimp Groups for Llama Fibre (Figure 3)	-----
CG1	Crimp group 1	-----
CG2	Crimp group 2	-----
CG3	Crimp group 3	-----
CG4	Crimp group 4	-----
CG5	Crimp group 5	-----

CG6	Crimp group 6	-----
CG7	Crimp group 7	-----
d	“d” for being a variable corresponding to the **d**ehairing product (Sub-chapter 2)	-----
DC	**D**ouble **C**oated fleece type	-----
e	Variable corresponding to the study related to the fleece structure (Sub-chapter 3) (**e**, for the Spanish word for structure: **e**structura.)	-----
F	In an abbreviation, a “F” may stand for “fibre” as well as for “fragmented”, “frequency” or “fleece”.	-----
F	**F**ragmented medullated fibre	-----
FG	**F**ibre **g**roup (FG1, FG2 and FG3)	-----
FG1	FG of coarse fibres	-----
FG2	FG of intermediate fibres	-----
FG3	FG of fine fibres	-----
FT	**F**leece **t**ype (DC, IC, SC, HL, L)	-----
G	Large (lattice) medullated fibre (G, for the Spanish word for large or coarse: **g**ruesa)	-----
HL	**H**emi **L**ustre fleece type	-----
I	**I**nterrupted medullated fibre	-----
KW	Kruskal–Wallis test	-----
L	In an abbreviation, a “L” may stand for “lustre” as well as for “length” and “laboratory”.	
L	**L**ustre fleece type	-----
L	Fibre **l**ength	cm
L1	L of FG1 (Sub-chapter 1, experimental)	cm
L1d	L of FG1 (Sub-chapter 2, dehairing product)	cm
L1s	L of FG1 (Sub-chapter 2, subproduct)	cm
L2	L of FG2 (Sub-chapter 1, experimental)	cm
L2d	L of FG2 (Sub-chapter 2, dehairing product)	cm
L2s	L of FG2 (Sub-chapter 2, subproduct)	cm
L3	L of FG3 (Sub-chapter 1, experimental)	cm
L3d	L of FG3 (Sub-chapter 2, dehairing product)	cm
L3s	L of FG3 (Sub-chapter 2, subproduct)	cm
LAFTA	Animal Textile Fibre Analysis Laboratory (LAFTA, for its acronym in Spanish: **L**aboratorio de **A**nálisis de **F**ibras **T**extiles **A**nimales)	-----

MD	**M**ean fibre **d**iameter (MD is equal to MFD in Brodtmann et al. (2018))	µ
MD1	Mean diameter measured for the FG1 (Sub-chapter 1, experimental)	µ
MD1d	Mean diameter measured for the FG1 (Sub-chapter 2, dehairing product)	µ
MD1e	Mean diameter measured for the FG1(Sub-chapter 3)	µ
MD1e<28	Mean diameter measured for the FG1, only of fleeces with a TMDne lower than 28 µm	µ
MD1e<31	Mean diameter measured for the FG1, only of fleeces with a TMDne lower than 31 µm	µ
MD2	Mean diameter measured for the FG2 (Sub-chapter 1, experimental)	µ
MD2d	Mean diameter measured for the FG2 (Sub-chapter 2, dehairing product)	µ
MD2e	Mean diameter measured for the FG2 (Sub-chapter 3)	µ
MD2e<28	Mean diameter measured for the FG2, only of fleeces with a TMDne lower than 28 µm (Sub-chapter 3)	µ
MD2e<31	Mean diameter measured for the FG2, only of fleeces with a TMDne lower than 31 µm (Sub-chapter 3)	µ
MD3	Mean diameter measured for the FG3 (Sub-chapter 1, experimental)	µ
MD3d	Mean diameter measured for the FG3 (Sub-chapter 2, dehairing product)	µ
MD3e	Mean diameter measured for the FG3 (Sub-chapter 3)	µ
MD3e<28	Mean diameter measured for the FG3, only of fleeces with a TMDne lower than 28 µm (Sub-chapter 3)	µ
MD3e<31	Mean diameter measured for the FG3, only of fleeces with a TMDne lower than 31 µm (Sub-chapter 3)	µ
MDA***	Mean diameter of all non-medullated fibres (Sub-chapter 1, experimental)	µ
MDA1***	Non-medullated fibres MD of FG1 (Sub-chapter 1, experimental)	µ
MDA1d***	Non-medullated fibres MD of FG1 (Sub-chapter 2, dehairing product)	µ
MDA2***	Non-medullated fibres MD of FG2 (Sub-chapter 1, experimental)	µ
MDA2d***	Non-medullated fibres MD of FG2 (Sub-chapter 2, dehairing product)	µ

MDA3***	Non-medullated fibres MD of FG3 (Sub-chapter 1, experimental)	µ
MDA3d***	Non-medullated fibres MD of FG3 (Sub-chapter 2, dehairing product)	µ
MDAd***	Mean diameter of all non-medullated fibres (Sub-chapter 2, dehairing product)	µ
MDAv***	Non-medullated fibres MD (Sub-chapter 1, experimental)	µ
MDAvo***	Non-medullated fibres MD (Sub-chapter 1, observational)	µ
MEDT	**Med**ulla **T**ype (A, F, I, C and G) defining fibre type	-----
N	Absolute fibre frequency (or absolute **n**umber of fibres)	quantity
n	“n” for being a MD weighed according to the relative fibre frequency (**N**%)	-----
N%	Relative fibre frequency (or relative **n**umber of fibres)	%
N%1	N% of FG1 (Sub-chapter 1, experimental)	%
N%1d	N% of FG1 (Sub-chapter 2, dehairing product)	%
N%2	N% of FG2 (Sub-chapter 1, experimental)	%
N%2d	N% of FG2 (Sub-chapter 2, dehairing product)	%
N%3	N% of FG3 (Sub-chapter 1, experimental)	%
N%3d	N% of FG3 (Sub-chapter 2, dehairing product)	%
N%A***	Relative fibre frequency (N%) of non-medullated fibres (Sub-chapter 1, experimental)	**%**
N%A1***	Non-medullated fibres MD of FG1 (Sub-chapter 1, experimental)	%
N%A1d***	Non-medullated fibres MD of FG1 (Sub-chapter 2, dehairing product)	%
N%A2***	Non-medullated fibres MD of FG2 (Sub-chapter 1, experimental)	%
N%A2d***	Non-medullated fibres MD of FG2 (Sub-chapter 2, dehairing product)	%
N%A3***	Non-medullated fibres MD of FG3 (Sub-chapter 1, experimental)	%
N%A3d***	Non-medullated fibres MD of FG3 (Sub-chapter 2, dehairing product)	%
N%Ad***	Relative fibre frequency (N%) of non-medullated fibres (Sub-chapter 2, dehairing product)	**%**
N%Av***	Non-medullated fibres MD (Sub-chapter 1, experimental)	%
NA***	Absolute fibre frequency of non-medullated fibres	quantity
o	“o” for being a variable corresponding to the **o**bservational database (Sub-chapter 1)	-----
PERIMc	Thoracic **perim**eter (experimental animals, **c**omplete flock)	cm

PERIMo	Thoracic **perim**eter (**o**rganizational database)	cm
R	**R**est (Three Group Dissection)	-----
s	“s” for being a variable corresponding to the dehairing **s**ubproduct (Sub-chapter 2) (Not to mistake the lower-case letter ´s´ as when used as plural of a variable, such as for ´FTs, ´FGs´, ´MDs´ and ´CGs´.)	-----
SC	**S**imple **C**oated fleece type	-----
SD	**S**tandard **d**eviation	µ
SD1	SD of MD1 (Sub-chapter 1, experimental)	µ
SD2	SD of MD2 (Sub-chapter 1, experimental)	µ
SD3	SD of MD3 (Sub-chapter 1, experimental)	µ
SUPPRAD	Small Ruminant Productive Sustainability in less favoured Areas Programme (SUPPRAD, for its acronym in Spanish: Sustentabilidad Productiva y Promoción de Áreas Desfavorecidas)	-----
T	In an abbreviation, a “T” may stand for “type” as well as for “total”.	
TMD	Total Mean fibre diameter: MD of a complete staple, “T” means “total”, that is to say including all fibres within a staple. The TMD can be measured from a fleece staple (TMDv, TMDvc and TMDvo) or it can be weighed through the 3 FGs forming a complete staple (TMDw and TMDn). (TMD is equal to TMFD in Brodtmann et al. (2018))	µ
TMDn	Total mean diameter weighed by fibre frequency (N%) (Sub-chapter 1, experimental)	µ
TMDnd	Total mean diameter weighed by fibre frequency (N%) (Sub-chapter 2, dehairing product)	µ
TMDne	Total mean diameter weighed by fibre frequency (N%) (Sub-chapter 3)	µ
TMDne<28	Total mean diameter weighed by fibre frequency (N%), only of fleeces with a TMDne lower than 28 µm (Sub-chapter 3)	µ
TMDne<31	Total mean diameter weighed by fibre frequency (N%), only of fleeces with a TMDne lower than 31 µm (Sub-chapter 3)	µ
TMDw	Total mean diameter weighed by weight (W%) (Sub-chapter 1, experimental)	µ
TMDwd	Total mean diameter weighed by weight (W%) (Sub-chapter 2, dehairing product)	µ

TMDv	Total mean diameter measured for a staple taken from a fleece (Sub-chapter 1, 20 experimental animals)	µ
TMDvc	Total mean diameter measured for a staple taken from a fleece (Sub-chapter 1, complete experimental flock)	µ
TMDvo	Total mean diameter measured for a staple taken from a fleece (Sub-chapter 1, observational)	µ
TFD	Total follicular density	
UCC	Catholic University of Córdoba, Argentina (UCC, for its acronym in Spanish: Universidad Católica de Córdoba)	-----
v	"v" for being a MD of a staple taken from a fleece, that is to say from the complete staple taken directly from the animal (Sub-chapter 1) (v, for the Spanish word for fleece: **v**ellón)	-----
VC	**V**ariation **C**oefficient	-----
W	Absolute **w**eight	g
w	"w" for being a MD weighed according to the relative **w**eight (W%)	-----
W%	Relative **w**eight	%
W%1	W% of FG1 (Sub-chapter 1, experimental)	%
W%1d	W% of FG1 (Sub-chapter 2, dehairing product)	%
W%2	W% of FG2 (Sub-chapter 1, experimental)	%
W%2d	W% of FG2 (Sub-chapter 2, dehairing product)	%
W%3	W% of FG3 (Sub-chapter 1, experimental)	%
W%3d	W% of FG3 (Sub-chapter 2, dehairing product)	%
With no lower-case letter	Variables without a letter correspond to the experimental database (Sub-chapter 1)	-----

ABSTRACT:

The study of the llama fleece structure was carried out to determine if, from the point of view of textile quality, the ageing of the animal modifies unfavourably the fleece structure (micron blowout). Furthermore, the objective of the study aims to verify if a potential loss in textile quality is rectifiable with an industrial dehairing process. Thus, not only fleeces and its fleece structure were analysed but processed fibre lots too, which also form a certain fibre structure. The analysis was realized, on one hand, according to the three fibre groups, which result by implementing the Three-Group-Dissection (FG1, FG2 y FG3), and according to the five fibre types, on the other hand, which are determined in principle by its medulla (medulla types A, F, I, C, G).

The results showed that the animal ageing reduces the textile quality because the fleece structure is modified unfavourably and that micron blowout regarding the total mean fibre diameter (TMDn) has its origin in all fibre groups and all fibre types, but more so in the fibre type of large medulla (G, lattice), which is contained in the fibre group of the coarse fibres (FG1). In addition, it was confirmed that the processing step of dehairing modifies the fibre structure improving the textile quality and that the modification has its origin mainly in the separation of the coarse fibres out of the fibre lot, which is the main reason for the reduction of the total mean fibre diameter of the dehairing product (TMDnd). Also, it was verified that, although dehairing is an efficient measure in order to improve textile quality, it is not sufficient on its own, but needs of a previous fleece classing regarding fineness. As reason therefore was found that a high-quality dehairing product can be obtained only if the processed fleeces are of relatively reduced TMDn, given that only these contain the desired fine and super fine fibres. Furthermore, it was confirmed that classing regarding fineness also is an effective measure in order to improve textile quality, but on its own is not sufficient either because it does not allow to separate coarse or objectionable fibres, which are contained even in the fleeces of reduced TMDn. Implementing both measures, as to say, classing regarding fineness including fleeces of a TMDn of up to 28 or 31 μm, and thereafter dehairing, raw material of a TMDnd of 21.6 or 22.8 μm respectively is obtained. Finally, the need of implementing classing regarding fleece types previous to dehairing was determined, joining Double Coated (DC), Intermediate Coated (IC) and Simple Coated (SC) fleeces, on the one hand, and Hemi Lustre (HL) and Lustre (L) fleeces, on the other hand, because the separation according to fleece types leads to a unified behaviour of the processed fleeces, which allows a better adjustment of the dehairing machine. Also, this measure helps to assemble the most homogenous raw material regarding crimp frequency and crimp type and enhances a better behaviour of the fibre during the manufacturing process.

Keywords:

Llama, fleece type, fleece structure, medulla, micron blowout, textile quality, dehairing, classing, dissection

RESUMEN:

El estudio de la estructura de vellón de llama se llevó a cabo con el objetivo de determinar si el envejecimiento del animal modifica la estructura de vellón desfavorablemente desde el punto de vista de la calidad textil ("micron blowout"). Asimismo, el objetivo apunta a verificar si una eventual pérdida de calidad textil es rectificable con el procesamiento de descerdado industrial. Por lo tanto, no se estudió solamente vellones y su estructura de vellón, sino también lotes de fibra procesados, los cuales también forman una estructura de fibra específica. El análisis se realizó, por un lado, según grupos de fibra, o sea diferenciando según los tres grupos de fibra que se forman al implementar la Disección Tripartita (FG1, FG2 y FG3), y por otro lado según los cinco tipos de fibra, los cuales están determinados en principio por su médula (tipos de médula A, F, I, C, y G). Se comprobó que el envejecimiento del animal produce una pérdida de la calidad textil, ya que se modifica la estructura de vellón desfavorablemente y que el engrosamiento del diámetro medio total de fibra (DMTn) se origina en todos los grupos de fibra y todos los tipos de fibra, aunque en mayor medida en el tipo de fibra de médula grande (G) que está contenido en el grupo de fibras gruesas (FG1). A su vez, se confirmó que el descerdado modifica la estructura de fibra mejorando la calidad textil y que la modificación fundamentalmente se origina en la separación de las fibras gruesas del lote de fibras, lo cual es la principal razón para la reducción del diámetro medio total del producto de descerdado (DMTnd). Asimismo, se comprobó que, si bien el descerdado como proceso para mejorar la calidad textil es efectivo, no es suficiente por sí solo, sino que una clasificación de los vellones según finura previa es necesaria. La razón para esto es que solamente se obtiene un producto de descerdado de alta calidad si los vellones procesados son de un DMTn relativamente reducido, porque solamente estos contienen las fibras deseadas superfinas y finas. Además, se determinó que la clasificación según finura también es una medida efectiva para mejorar la calidad textil, pero que, por sí sola, tampoco es suficiente, ya que no permite separar las fibras gruesas u objetables, las cuales están incluidas inclusive en los vellones de DMTn más reducido. Al implementar ambas medidas, una clasificación según finura, incluyendo a vellones de un DMTn de hasta 28 o 31 µm, y un descerdado posterior, se logra materia prima de un DMTnd de 21,6 o 22,8 µm respectivamente. Por último, se destacó la necesidad de implementar una clasificación según tipos de vellón antes del descerdado, juntando vellones Doble Capa (DC), Capa Intermedia (CI) y Simple Capa (SC) por un lado y vellones Hemi Lustre (HL) y Lustre (L) por otro, ya que la separación según tipos de vellón posibilita un comportamiento parecido de los vellones procesados, lo cual permite una mejor puesta a punto de la maquina descerdadora. Además, esta medida homogeniza la materia prima respecto a su frecuencia de ondulación y grupos de ondulación (rizo) y posibilita un mejor desempeño de la fibra en el proceso productivo.

Palabras clave:

Llama, tipo de vellón, estructura de vellón, médula, engrosamiento, calidad textil, descerdado, clasificación, disección

ZUSAMMENFASSUNG:

Die Untersuchung der Lama-Vliese diente dazu herauszufinden, ob das Altern der Lamas die Textilqualität beeinträchtigt („micron blowout“). Außerdem hatte die Untersuchung zum Ziel, zu klären, ob eine mögliche Reduzierung der Textilqualität durch das Entgrannen als Teil eines industriellen Spinnverfahrens korrigierbar ist. Deshalb wurde nicht nur die Struktur von Vliesen untersucht, sondern auch die Struktur von Faser-Chargen, die sich in der Verarbeitung befinden, und die auch eine ganz bestimmte Faserstruktur aufweisen. Zum einen wurden die drei verschiedenen Fasergruppen untersucht, die bei der Zerlegung einer Vliesprobe in ihre Einzelfasern entstehen (FG1, FG2 und FG3). Zum anderen die fünf Fasertypen, die im Prinzip durch ihre Medullation (Medullationstyp A, F, I, C, und G) definiert werden. Eine Beeinträchtigung der Textilqualität durch das Altern der Tiere wurde bestätigt, da die Vliesstruktur dadurch nachteilig beeinflusst wird und der Mittlere Durchmesser des gesamten Vlieses (TMDn) zunimmt. Dies ist durch Veränderungen bei allen Fasergruppen und bei allen Fasertypen bedingt, aber am meisten beim Fasertyp mit grober Medullation (G), der in der Fasergruppe der groben Fasern (FG1) enthalten ist. Es wurde bestätigt, dass das Entgrannen die Faserstruktur verändert und dadurch die Textilqualität verbessert wird. Diese Verbesserung erfolgt vor allem durch die Absonderung der groben Fasern, was die Hauptursache für die Reduzierung des Mittleren Durchmessers des Endprodukts des Entgrannens (TMDnd) ist. Obwohl eine Verbesserung der Textilqualität durch das Entgrannen belegt werden konnte, wurde festgestellt, dass diese Maßnahme allein nicht ausreicht, sondern dass davor eine Sortierung der Vliese nach Feinheit nötig ist. Der Grund dafür ist, dass beim Entgrannen nur dann ein Endprodukt hoher Qualität gewonnen werden kann, wenn die verarbeiteten Vliese einen relativ niederen TMDn haben, denn nur diese enthalten die gewünschten feinen und superfeinen Fasern. Die Untersuchung bestätigte außerdem, dass auch die Sortierung nach Feinheit der Vliese eine effektive Methode zur Verbesserung der Textilqualität ist. Dies reicht jedoch auch nicht als einzige Maßnahme aus, da dadurch das grobe Deckhaar, das heißt die Grannenhaare, die sogar in den feinsten Vliesen enthalten sind, nicht abgesondert werden. Durch Anwendung beider Methoden, genauer gesagt zuerst durch eine Sortierung der Vliese nach einem TMDn von bis zu 28 oder 31 μm, gefolgt vom Entgrannen, wird ein Rohstoff von jeweils 21,6 oder 22,8 μm TMDnd gewonnen. Abschließend wurde die Notwendigkeit einer Sortierung nach Vliestypen festgestellt, und zwar indem die Vliestypen Double Coated (DC), Intermediate Coated (IC) und Simple Coated (SC) von den Vliestypen Hemi Lustre (HL) und Lustre (L) getrennt werden. Die Trennung der Vliestypen erlaubt ein einheitliches Verhalten der Vliese bei ihrer Verarbeitung, wodurch die Apparatur für das Entgrannen besser justiert werden kann. Außerdem wird auf diese Weise der Rohstoff in Bezug auf die Crimp-Frequenz und den Wellentyp homogener, wodurch der Verarbeitungsprozess der Fasern verbessert wird

Schlüsselwörter

Lama, Vliestypen, Vliesstruktur, Medullation, „Micron Blowout“, Textilqualität, Entgrannen, Sortierung, Zerlegung einer Vliesprobe in ihre Einzelfasern

CHAPTER I. INTRODUCTION

A llama is a typically multi-purpose animal, with fibre and/or meat production being two important activities that have more or less weight, depending on the country and area. Both of them can be developed with an economic purpose and a potential to generate incomes for the less favoured areas where these animals are bred since it is feasible to breed them in very unfavourable conditions, for example, regarding the climate and the lack of abundant forage. However, the development of a formal market for llama meat is more complex, for example, because of the need for authorized slaughterhouses. In Argentina, llama meat is generally destined for the breeder's own consumption or for informal sale, while llama fibre has the possibility of being stockpiled and taken to a formal market. In addition, there is a perspective related to the production of fibre as a raw material due to its excellent textile behaviour. Textile quality is given by the mean diameter and its distribution, by the fleece types that constitute differentiable structures, and, to a lesser extent, by the colour of the fibre (Adot & Frank, 2015).

The price the producer receives per kilogram of fibre is mainly determined by its colour and its mean diameter (Vinella, 1994). This means that, if a producer sells white fleeces, the price they receive per kilogramme is different from the one they receive for coffee-coloured or black fleeces. It also means that if they sell fine fleeces, its price per kilogramme is differential, because the fibre is of better textile quality. According to McGregor (1997, 2006), a small total mean fibre diameter is the most important factor regarding the market value of alpaca fleeces in Australia. On the other hand, since a fibre producer sells the fibre in kilogrammes, this logically means that, depending on the amount of fibre sold, the producer's income varies. However, the price does not vary regarding the amount of fibre sold. This is because, for example, a producer who sells 10 kg of fibre of a certain quality obtains the same price (pesos/kg or dollars/kg) as a producer who sells 100 kg of fibre of the same quality.

In short, producers can improve their incomes by producing and selling more quantity and, at the same time, by improving the quality of the fibre. The latter one, as long as the better quality is reflected in a higher price. Undoubtedly, better fibre quality leads to a higher value for the consumer of a textile clothing, but this value does not automatically translate into a higher price for the raw material. In the practice of fibre production, this is reflected in the fact that a fleece from a young animal of superfine fibre can weigh between 1.5 and 1.7 kg approximately; while a fleece from an old animal of very coarse fibre can weigh 3 kg or more. Thus, if an animal produces a heavy fleece, on the one hand, this has the potential to increase the producer's income by selling more kilogrammes, but, on the other hand, if the fleece is heavy because it is coarse fibre, it may reduce the possibility of income due to obtaining a low price per kilogramme or, directly, not finding a buyer. Therefore, the debate of this thesis is framed in the dilemma between quantity (kg) and quality (reflected in pesos/kg or dollars/kg) of the fibre.

Factors affecting fibre production in South American Domestic Camelids (CSD, by its Spanish acronym), both in quantity and quality, can be strictly divided into specific environmental factors and genetic factors (Frank et al., 1995; Frank et al., 2006a). Specific environmental factors have been divided into permanent or internal, and temporary or external ones. While the environmental factors affect the general population (feeding and handling), the genetic ones affect the individual (sex, maternal effects, the animal's age, reproductive condition, etc.) (Turner & Young, 1969; Frank et al., 2006a). Additionally, the variation in fleece structure has a particular effect on the quality of the final product in most of the world's marketed wools (Wickham, 1984). This has also been extensively demonstrated in studies with the fibre of Argentine llamas and their different fleece types (Frank, 2001; Frank et al., 2007a; Idem, 2007c).

The external effects that modify the productive response in alpacas are the age of the animal, the age of the mother and, moreover, their year and day of birth (Bravo, 1973). For fleece weight, the number of shearings and the year of the shearing are significant (Ruiz de Castilla et al., 1992). In Argentine llama populations, significant differences among ages are found for mean diameter, coefficient of diameter variation, staple length and medullation degree (Frank et al., 1985). For fleece weight, the difference between areas and age is significant, but not for shearing type, while the mean diameter is affected by shearing type, staple length and age (Frank and Nuevo Freire, 1993).

Furthermore, it is important to differentiate between growth time of the fibre, which is equivalent to the time between one shearing and the next one (shearing gap), and the age of the animal. It is possible to speak of an interaction between the two effects, however, both ones can be confused with each other. While the age class undoubtedly increases year after year, the shearing is not necessarily every year, and there may be animals to which the first shearing is not done until they are three years old. When the shearing gap and the age of the animal are separated, it is verified that successive shearings over the years do not, by themselves, affect the diameter of the fibre. This happens up to such an extent that, by processing a staple into portions corresponding to different growth times (possibly a staple of several years of growth); a difference in diameter is verified, showing that this depends on age and not on the effect of successive shearings (Frank et al., 2006a).

The influence of age on fibre diameter in sheep is substantial. From an analysis of a large number of medium fibre diameter wool records in New South Wales, the fibre diameter in young rams increased by 0.3 µm per month during the period from 8 to 18 months old (Atkins & Semple, 1991). In one example, where a group of rams was measured on three different occasions, the mean fibre diameter increased by 1 µm in rams which were between 6 and 10 months old, and by further 3 µm over the following 6 months. Within the observations in two- and four-tooth rams, the fibre diameter generally increases by 2 µm. This is true for both free-range and shed breeding, what shows that the fact that animals are more sheltered from the cold does not prevent an increase in wool diameter and shows the age effect on diameter (Roberts, 1970).

Both fibre production and fleece characteristics are influenced by age. The fibre growth rate increases from birth to a maximum of 3 or 4 years old, after which it declines. The effect is similar in many breeds of sheep (Bigham et al., 1978; Brown et al., 1966, Idem, 1968; Hight et al., 1976), cashmere producing goats (Gifford et al., 1990) and Angora goats (Stapleton, 1978). There are several reports of age effects on fleece weight characteristics of Merinos. During the phase in which wool production declines, there is a progressive decrease in the density of active follicles and a reduction in fibre volume. Although mean fibre diameter increases, there is a relatively greater reduction in fibre length (Brown et al., 1968). The washing performance, colour, and "handle", that is to say, the tactile sensation related to hand contact with a fabric or clothing, also deteriorate (Mullaney et al., 1969); crimp frequency decreases (Brown et al., 1968) and "crimping" abnormalities increase (Chapman & Jackson, 1972). The published information regarding age trends and fleece weight characteristics of other breeds of sheep and goats are limited, but it suggests similar trends to those reported about Merinos. In New Zealand crossbred sheep, the influence of age on bulkiness and its components was studied, with the diameter increasing in direct relation to body weight gain up to the age of 3 years old (Sumner & Upsdell, 2001).

Also, it was found that the total follicular density decreases regarding the age and does not show modifications with the type of shearing, area, or fleece type, showing the same behaviour in the follicular density of secondary follicles; while the follicular density of primary follicles does not show differences of any kind. Among the follicular variables of vertical skin sections, the most affected ones by external effects are follicular length, follicular insertion angle and bulbar papilla area (Frank et al., 1993; Idem, 2006b).

In alpacas and llamas from Peru and in llamas from Argentina, it has been observed that the black phenotype has a smaller fibre diameter, less medullation and longer staple length than the white and coloured phenotypes (Valjalo Cepeda, 1964; Cardozo et al., 1981; Frank et al., 1985; Ruiz de Castilla & Olaguibel de Olivera, 1991). However, other authors described black fibre as the coarsest, white as the finest, and coffee-coloured and cream colours with intermediate fineness (Oria et al., 2009), or found no statistically significant differences for mean diameter between colours (Trejo, 1986; Renieri et al., 1991). However, Trejo (1986) finds statistically significant differences for colour in fibre length in Peruvian alpacas.

The fleece type shows significant differences in fleece weight, staple length, mean diameter and medullation in Argentine llamas (Frank et al., 1985), while for follicular variables significant differences are only found in the follicular insertion angle variable (Frank et al., 2006a) in animals of the same origin. Such effects can also be seen at the level of fibre and skin variables in other animal species: sheep, Angora goats, cashmere goats (Russel, 1994), Angora rabbits (Thébault & Allain, 1994) and guanacos (Moseley, 1995).

In an Australian study with Peruvian alpacas, the heritability of the micron blowout characteristic which is observed among different ages was found to be low (Munyard & Greeff, 2013). This study explains the difficulty of modifying the micron blowout problem through genetic means. Meanwhile, mechanical dehairing reduces the amount of coarse or objectionable fibres (primary follicles) and shortens fibre length (Batten, 2003). These two effects, the reduction of objectionable fibres and the shortening of the fibre, behave in the opposite direction regarding to what is desired, thus good dehairing must achieve the right balance between the two of them.

The aim of this thesis is to study possible measures through which more homogeneous fibre lots can be obtained and thus offer better quality raw material to the textile market. Dehairing is a production step that is designed to satisfy the need to homogenise animal fibre, particularly in cashmere (McGregor, 2018), but it has not been sufficiently studied in relation to llama fibre. Therefore, a general problem to which this thesis provides answers is a lack of knowledge that exists in relation to llama fibre as a textile raw material. In order to make the textile industry's interest in llama fibre increase, it is essential that its characteristics are thoroughly understood and, thus, that it can be put to the best possible use. In order to achieve this goal, it is necessary to generate an understanding of llama fibre which is able to explain its complexity.

In this context and in order to provide a concrete answer to the abovementioned problem, the following **GENERAL HYPOTHESIS** arises:

> In Argentine llamas, the increasing age of the animal modifies the fleece structure unfavourably from the point of view of textile quality, which is rectified by the dehairing process.

The general hypothesis includes three different topics which are intrinsically related to the textile quality of the llama fibre:

- The age effect of the animal on the fleece structure which modifies the fibre textile quality.
- The dehairing effect on the fibre structure within a fibre lot that improves its textile quality.
- The fibre characteristics which define the llama fleece structure and, at the same time, the effect of certain measures that can be implemented to modify the fibre structure within a fibre lot and, therefore, its textile quality.

The sequence chosen for the development of this thesis is to differentiate and break down these three topics from the general hypothesis and approach them in different specific hypotheses. In Sub-Chapter 1, the modification of the fleece structure due to the age effect is described. Then, in Sub-Chapter 2, the effect of dehairing on the fibre structure within a fibre lot is analysed. Finally, in Sub-Chapter 3, specific measures to improve the textile quality are evaluated, integrating previous inputs. This division into three sub-chapters is appropriate because the 3 topics are analysed through different materials, which respond to the specific need for analysis of each topic.

GENERAL OBJECTIVE:

> To study the fleece structure of a population of productively controlled llamas, to determine information related to the textile quality and the modifications produced by the increasing age and the fleece types, as well as to explore a possible solution to the loss of textile quality through the dehairing process.

In addition to the three topics already mentioned, there is a subject that is implicitly included in the general objective and which is related to the presence of objectionable fibres. This subject is included throughout the different sub-chapters in order to progress regarding its evaluation. Besides, an implicit intention within the general objective is to come up with recommendations to reduce the unfavourable age effect on the textile quality of the fibre produced by Argentine llamas and to be able to offer more homogeneous fibre to the market.

As stated in this thesis title, this research work is about the ‘llama fleece structure’, consisting of the way in which its fibres are arranged in the fleece. However, before the textile process begins, the fibres of various fleeces are mixed. Therefore, the fleece as an isolated unit disappears and so does its original structure. ´Llama fibre´ is then handled as raw material, that is to say, a fibre lot. And, in the same way that the llama fleece is a set of fibres of different types that are arranged in a specific structure, a specific structure of a set of fibres is also formed when, among many fleeces, a fibre lot is assembled to be used in the textile industry. Thus, it can be said that the set of fibres found within the textile process also has a certain ‘structure’ or ‘fibre structure’. This means that when the term ‘fibre structure’ is mentioned in this thesis, it does not refer to the structure of an individual fibre, but to the structure of a set of fibres included in a fibre lot before or during the textile process.

1. Age effect on llama fleece structure

Studies confirm that the quality of llama fibre decreases with the increasing age of the animal because the fibre underlies coarsening (Frank et al., 2006b). This increase in the mean fibre diameter is also known in relation to other species and is referred to as "micron blowout". However, in relation to other fibre characteristics, the age effect has not yet been studied and it has not yet been determined how the llama fleece structure is affected. It remains to be seen how fine fibres, on the one hand, and coarse fibres, on the other hand, change with increasing age, being evaluated as separate groups.

In order to perform a more detailed analysis of the age effect, in this research work, the Three Group Dissection is implemented, which provides an observation according to the fibre groups that are separated in the dehairing process (Singh, 2003). Through the Three Group Dissection, the group of the finest fibres is separated from the staple, which allows evaluating how fine they really are. And, at the same time, the group of coarser fibres is separated and it becomes possible to evaluate how many of these fibres are included in the staple.

In Sub-chapter 1, the main method of this thesis is introduced which is the Three Group Dissection whose implementation procedure is described in detail. When implementing this dissection, one starts from a single staple and forms three fibre groups (FG1, FG2 and FG3). Thus, a description of the llama fleece structure according to fibre groups (FG) emerges and it is revealed in which way the fleece can be described and analysed according to what enables this type of dissection. The three FGs are, on the one hand, the group with the coarsest fibres of a sample (FG1), on the other hand, one with the intermediate fibres (FG2) as well as a third group with the finest fibres (FG3).

Information about fibre characteristics is provided for each group separately and this reveals characteristics related to the textile quality that is different for each group. In this way, the llama fleece structure can be described in an innovative way and specific information is provided that can be used in decision making for the agricultural sector when producing llama fibre as well as for further textile processes. In addition, the aim is to evaluate whether the implementation of the Three Group Dissection to dissect a llama fibre sample provides consistent information that is useful to evaluate certain characteristics related to the textile quality of the sample.

The heterogeneity of the llama fleece and the age effect are not only shown through a variation in coarseness, but also in the variation of other parameters of the fibre morphology. The fibre characteristics that define the textile quality are multiple. In this work, the mean fibre diameter (MD) is evaluated as the main characteristic, which includes the analysis of fibre type (defined by its medulla type (MEDT)). In addition, this analysis is accompanied by the evaluation of the crimp frequency (CF) and the crimp group (CG) as characteristics that also have an important influence on fleece structure. Furthermore, these characteristics are fundamental in relation to the discussion related to objectionable fibres.

1st SPECIFIC HYPOTHESIS:

> From the point of view of textile quality, the increasing age of the animal modifies the fleece structure unfavourably in relation to the mean fibre diameter (MD) and the relative fibre frequency (N%).

1st SPECIFIC OBJECTIVE:

> To study the fleece structure of a population of productively controlled llamas regarding fibre groups and fibre types as well as the modifications produced by age and to determine information related to textile quality.

The first specific hypothesis refers to a modification of the fleece structure and, therefore, to a modification of textile quality that includes other variables, besides the total mean diameter (TMD). It is essential to complete the discussion on the MD with the relative fibre frequency (N%) of the different fibre groups and fibre types, as specified in the 1° specific hypothesis. MD and N% are generic denominations that include different variables, that is to say, MD and N% of different fibre groups and of different fibre types.

2. Dehairing effect on llama fibre structure

The aim of this thesis is to determine possible improvements in the textile quality of llama fibre and, eventually, to come up with recommendations for the fibre production sector as well as for the beginning of textile process. Therefore, it is not limited to describing the age effect, but it investigates possible solutions for textile quality improvement. In this regard, a dehairing trial was carried out, since dehairing modifies the llama fibre structure profoundly and it can be hypothesised that its implementation rectifies the unfavourable age effect on fleece quality.

The trial was carried out with an industrial dehairing machine, with which trials had been carried out prior to this thesis, but, until now, a dehairing trial such as the one carried out as part of this research work has not been documented or analysed. Just as in the first sub-chapter, the mean fibre diameter (MD) is evaluated as the main trait including the analysis of the fibre type (defined by its medulla type (MEDT)) and, in addition, this analysis is complemented by the evaluation of the crimp frequency (CF) and crimp group (CG) as characteristics that also have an important influence on the fibre structure.

2nd SPECIFIC HYPOTHESIS:

> From the point of view of textile quality, the dehairing textile process modifies the fibre structure favourably in relation to the mean fibre diameter (MD), the relative weight (W %) and the relative fibre frequency (N%).

2nd SPECIFIC OBJECTIVE:

> To study the llama fibre structure during the dehairing textile process regarding fibre groups and fibre types as well as the modifications produced by this process and to determine information related to textile quality.

The 2° specific hypothesis refers to a modification in a fibre lot that has a certain fibre structure, thus to a textile quality modification. As in the first sub-chapter, the analysis and discussion about the MD are completed by the relative fibre frequency (N%) of the different fibre groups and fibre types. In the second sub-chapter, the dehairing effect on the coarser fibre group is analysed in particular depth, as these coarser fibres are intrinsically related to the objectionable fibres and therefore to the textile quality.

3. Effect of classing and of dehairing on fibre textile quality

This sub-chapter accomplishes the evaluation according to fleece types, being this part of the general objective. In this sub-chapter the age of the animal is not evaluated, but the analysed samples are representing a set of fleeces from animals of all ages equivalent to a commercial textile raw material lot from a breeder of llamas productively controlled.

Furthermore, Sub-chapter 3 provides a framework for the textile quality of llama fibre, which is a central topic of this thesis. The measure to provide a solution for textile quality that was proposed to be analysed in Sub-chapter 2 is the implementation of dehairing in an industrial plant, that is to say, testing the dehairing in practice. It turned out to be convenient to complete this analysis with an evaluation of the theoretical potential of the dehairing in order to establish a frame of reference. Furthermore, the analysis of the dehairing was complemented by an analysis of the potential of fleece classing, since classing and dehairing are two measures aiming at the same goal of improving the textile quality of llama fibre as a raw material through homogenisation.

Both measures, classing and dehairing, are considered and analysed due to the problem caused by the high heterogeneity of llama fibre as provided by primary production and the need to determine measures capable of homogenising it. These measures can be applied in fleece lots before they are supplied to the industrial sector, that is to say, as part of the shearing and the stockpile, or within the industrial sector, at the beginning of the textile process.

Sub-chapter 3 explores the potential of such measures on a theoretical and conceptual level, which provides further insight into the nature of the raw material structure offered by a fibre lot as well as the possibilities to modify that structure favourably. The aim is to explore whether the separation of different fleece types (classing) and/or different fibre types contained in a fleece (dehairing) offers potential for increasing the homogeneity and the textile quality of the fibre. Furthermore, the aim is to make descriptions and graphs related to llama fleece structure that facilitate the reliable identification of the different fleece types.

The analysis focuses especially on verifying the morphological characteristics of the fine fibre group that corresponds to the textile product obtained by means of the dehairing process, as well as the information regarding the objectionable fibres that are mainly associated with the coarse fibre group within the textile jargon. The mean fibre diameter (MD) is evaluated as the main characteristic and, in addition, the crimp frequency (CF) and crimp group (CG) as characteristics that also have an important influence on the structure of the different fleece types.

3rd SPECIFIC HYPOTHESIS:

The classing of fleeces regarding fineness and/or fleece type as well as the dehairing offer potential for modifying the fibre structure and increasing its textile quality in relation to the mean fibre diameter (MD).

3rd SPECIFIC OBJECTIVE:

To evaluate the fleece structure of a population of productively controlled llamas regarding fibre groups and fleece types as well as to determine whether the classing of fleeces regarding fineness and/or fleece type plus the dehairing offers potential for increasing textile quality in relation to mean fibre diameter (MD).

CAPÍTULO II. BIBLIOGRAPHICAL REVIEW

Chapter II includes a reference and knowledge framework that goes beyond what is strictly necessary in relation to the most important citations that support this research work. Its purpose is to function as a description of the "state of the art" related to the main aspects covered in this thesis, for example, the fleece structure, the coarsening of the fibre, the textile quality and the dehairing. This seemed to be convenient due to the fact that this work is situated at a hinge point in the production chain, specifically between the agricultural sector and the textile industry, and is therefore highly complex.

Camelid fibre:

Fibres coming from camelids and goats are called by different names: special fibres, rare fibres, exotic fibres, noble fibres or, more commonly, luxury fibres. A thorough speculative analysis concludes that Merino wool does not generally meet all the characteristics of a luxury fibre, but it does have some characteristics that could elevate it to that category if the marketing is done correctly. Any marketing strategy requires a thorough knowledge of the characteristics of the product to be promoted and marketed (McGregor, 2002).

The characteristics and features that give added value to the luxury fibres have been summarised by Watkins & Buxton (1992) as: softness, brightness, scarcity or rarity, high price, mysterious, romantic, elegant and exclusive nature, being softness and brightness or "lustre" the only characteristics that depend only on the raw fibre itself. The other characteristics have a cultural or socio-cultural nature and are not subject to possible modifications in the production process which are what concerns us in this thesis.

Research carried out in Australia showed that the difference in softness favouring the alpaca could be 12 µm in relation to the wool, which means that a 27 µm alpaca could be as soft as 15 µm wool (Wang et al., 2003). However, the accuracy of this determination is low as the coefficient of determination, regarding wool (R^2=0.56) and alpaca fibre (R^2=0.38), show that factors other than mean diameter are important in explaining fibre tensile strength, which is an indirect measure of softness.

More recently, it was confirmed that the tactile sensation or “handle” places 26 µm alpaca fibre at equal height to conventional Merino wool of 18 µm. This was verified regarding tops: when these fibres were spun and woven, the panellists failed to distinguish the 26 µm alpaca fabric from a woollen fabric of equal fineness, determining that the quality of the yarn obtained would have been the reason of the "interference" in the softness of the alpaca fabric (Hillbrick, 2012).

Diameter distribution:

The fineness determination of animal fibres is complex due to the great variability of fibres found in a fleece. Two parameters are defined in order to determine the wool fineness, the mean diameter and the variation coefficient (VC). By analysing wool tops from 20 to 24 µm mean diameter, it was concluded that the fibre diameter distribution (FDD) is very close to a normal distribution and conforms to a lognormal distribution. This means that the coarse edge of the analysed wool can be adequately predicted using a Gaussian distribution or, even better, a lognormal distribution (Naylor et al., 1995).

The FDD is important to determine the quality due to the effect on the product appearance and comfort as well as the effect on the fibre behaviour during the textile process (Mayo et al., 1994). According to Gilmour & Atkins (1992), the FDD in Merino wool can be adjusted to a combination of normal distributions, therefore, in mixed fleeces (camelid and goat) with much greater variation in fibre types (McGregor, 2007; Frank et al., 2007c; Idem, 2007a), the end on the right of the frequency distribution graph is much broader. It is this end which reflects the fibre frequency of fibres coarser than 30 µm and determines the so-called “coarse edge”, for which the relationship with the prickle effect on the skin has been clearly proven (Bow et al., 1992). Additionally, the distinguishable aspect that some fibres show in comparison to others as well as the a priori impression that these fibres are difficult to dye, and that they have an effect on the tactile sensation (handle), on the stiffness and prickle effect, have led to designate fibres with this appearance as “objectionable or observable fibres” for all types of animal fibres (Smuts & Hunter, 1987; Balasingam, 2005).

The llama fleece FDD also fails to have a normal distribution, but it is more lengthened towards the high diameters (positive bias) as well as being different for the different fleece types. In addition to this, the fine and coarse fibres can differ in its morphology, that is to say that they show another kind of crimp, brightness and medullation degree. Therefore, the stiffness and tactile sensation of the llama fibre, when used in textiles, differ due to not only a fineness change, but also a different fibre morphological structure (Frank et al., 2007a; Idem, 2011a; Idem, 2014).

Although there is the possibility of reducing the distribution by means of selection (Taylor & Atkins, 1997), and this response to selection could interfere with the mean diameter reduction (according to this work on sheep and anecdotal evidence on alpacas), there is also another possibility to be analysed that is the mechanical dehairing or separation of different fibre types (Batten, 2003; McGregor & Butler, 2008b). In this regard, the development of dehairing technology by the SUPPRAD programme (Small Ruminant

Productive Sustainability in less favoured Areas), a technology called AM2, raises an interesting set of questions about the use of the first or second alternative, making it necessary at least to initially assess the physical consequences of such process on the structure of the mixed fleeces of domestic and wild camelids, cashmere goats and creole sheep (Frank et al., 2017a). This poses the dilemma of whether to modify the fibre quantity and quality from the genetic point of view and/or from the mechanical point of view (dehairing), for which the knowledge currently available about structural changes by both means is too limited to be able to predict the consequences of each or both actions at the same time.

The fibre analysis equipment available on the market are the Projection Microscope, the Air Flow Method, the OFDA (Optical Fibre Diameter Analyser), the Wool View, the Sirolan Laserscan and the technology recently provided by NIT (Near Infrared Reflectance) (Gishen & Cozzolino, 2007). These devices were developed to analyse sheep wool, but they are also used for the analysis of camelid fibre, producing good results for mean diameter measuring. However, their uses are not so clear for other situations. For example, the OFDA has the possibility of measuring the brightness or opacity of white wool, which is naturally non-medullated. When measuring fine fibres with continuous medullation, as the ones included in the llama fleece, they are qualified as kemp fibres. This is due to the fact that the medullated fibres display different properties to non-medullated fibres, for example, they scatter light differently (Wood, 1998). This type of measurement is misleading because, regarding the textile quality, the presence of kemp is more serious than fibres with only continuous or fragmentary medullation (Hunter et al., 1990). Therefore, more information is required to make use of this instrument successfully. Equipment recently developed in Peru by a local company, which is also based on image analysis (Fibre Electronic Characterizer, Fibre-EC equipment), managed to overcome the measurement difficulties of the previous equipment and, being less expensive, it offers an excellent possibility to evaluate the quality of the llama fibre (Quispe et al., 2017).

Fleece types:

Even though wild camelid fibre (guanacos and vicunas) is not homogeneous, it has greater uniformity than llama fibre because all animals have only one fleece type. This is typical for the wild animal and corresponds to the Double Coated type in llamas. However, the llama fleece can come from five different fleece types. The greater uniformity of wild camelid fibre has the advantage of a simpler textile process. Whereas the llama fibre as a textile raw material is characterised by a high degree of heterogeneity in relation to the fibre type, which results in a more complex textile process. This can be interpreted as a disadvantage, but, on the other hand, the high degree of variability of llama fibre develops a great potential because fibres with different characteristics can cover a wider range of different uses (Frank et al., 2007a; Adot & Frank, 2015).

The classing into fibre types for sheep and camelid wool as well as for animals which do not produce fibre, such as pets or wild animals, led to different ways of classing depending on the context and the applied criteria. An extensive bibliographical review is described in Frank (2001) and states that existing classing up to that time did not cover the high variability in llama fleece. Frank (2001) created a new classing for Argentine llamas using objective criteria that are based on measurable fibre characteristics. This resulted in the identification of five fleece types named Double Coated (DC), Intermediate Coated (IC), Simple Coated (SC), Hemi Lustre (HL) and Lustre (L), which specify different fleece structures (Frank, 2001; Frank et al., 2007a). Through macroscopic observation, the five fleece types can be differentiated by making use of only four fibre morphological characteristics: length, coarseness, crimp type and opacity/lustre degree, with no need to differentiate other fibre properties (Frank, 2001; Frank et al., 2007a). A more consistent statistical analysis leads to summarising the fleece types as Double Coated, Simple Coated (including the before mentioned Intermediate Coated) and Lustre (including the before mentioned Hemi Lustre) (Frank et al., 2019a).

The definition of fleece types shows high repeatability in different environments and in successive shearings (Frank, 2001, Frank et al., 2007a). They can be identified in a precise and objective way. This justifies its use to classify fleece types in animals of all ages (Frank et al., 2008). Moreover, the fleece type can be noted in the livestock as well as in the fleece after the shearing.

While the classing of the fleece types is clear, there are still unstudied details of the llama fleece that are relevant to its quality and therefore of textile interest. The different fleece types are verified by the presence of certain more representative fibre types, but the importance of the frequency of the different fibre types is still open as a criterion to be studied (Frank, 2001). One study concludes that, although the fleece types are differentiated by certain types of representative fibres, their frequency is considered to be of little importance in defining each fleece type. On the other hand, it is important which fibre groups are found in a fleece as these are typical for characterising it. For example, two of the five fibre groups that constitute the DC fleece have short fibres. These short fibres are found in two fibre groups, depending on whether they are fine or very fine, and depending on their crimp and lustre type, and were only identified in the DC fleece. However, the other fleece types have medium and long fibres which led to different fibre groups depending on the combination of certain types of crimp and lustre (Frank et al., 2007a). This was definitively demonstrated by using 23 different variables, measured over a group of 960 fibres which were dissected and studied individually. By means of the multivariate statistics, it was shown that the fleece types are undoubtedly identifiable and can be regrouped Intermediate Coated (IC) together with Simple Coated (SC), and Hemi Lustre (HL) together with Lustre (L), thereby obtaining 3 fleece types: Simple Coated, Double Coated and Lustre (Frank et al., 2019a).

The easy and correct classing regarding fleece type is essential in practice, both for breeder selection and for commercial classing in the textile industry (Frank et al., 2007a; Idem., 2019a), in addition to other classing criteria of greater or lesser importance depending on the context of use. For example, they can be classified regarding body sites as part of the shearing process (Frank et al., 2007b), they can be classified regarding colour and fineness for marketing, etc., everything for practical purposes such as price setting or delivery of more homogeneous raw material to the textile process (Adot & Frank, 2015).

Fleece structure and its modification due to increasing age:

A heterogeneous structure regarding diameter and medullation is described in Bolivian llamas. A mean diameter of 31.6 µm with a VC of 17% was determined as well as a coarse fibre diameter of 40.8 µm and a fine fibre diameter of 25.5 µm. The medullated fibre percentage was established in 43.1% (Martínez et al., 1997). There is no specification regarding the fleece type from which the samples were taken.

A study on Argentine llamas also reveals a large heterogeneity of fibres. The data found differ significantly from those mentioned in the previous paragraph, which emphasises the large variability of fibres present in llama fleece. The mean diameter determined for Argentine llamas was 22.91±1.55 µm with a VC of 26.39±4.34%, as well as a primary follicles fibre diameter of 35.5±4.27 µm and a secondary follicle fibre diameter of 19.92±3.82 µm. The total percentage of the medullated fibre was established in 28.3±4.7% and showed an increase with the increasing age. The samples analysed came from the five fleece types (Frank et al., 2006a).

The coarsening of camelid fibre due to the age increase is discussed in several bibliographical sources and confirms the related problem, being this a reduction in textile quality. The increase in mean diameter due to increasing age was determined in Australian alpacas (McGregor & Butler, 2002) and alpacas from New Zealand (Wuliji et al., 2000). Coarser diameters of older animals were described in Bolivian llamas (Iñiguez et al., 1998) and the increasing age was seen as an important factor for the fibre coarsening in Argentine guanacos (Bacchi et al., 2010). In Bolivian llamas, an important increase in the mean diameter and the medullation was found in animals with advanced age (Martínez et al., 1997). An increase in the mean fibre diameter was documented in Argentine llamas during the first 5 to 6 years after their birth and a reduction after that age (Frank et al., 2006a).

The increase in age is described as the external factor of greatest influence on the gain in weight of llama fleece, noting that at the same time the fibre length decreases and the diameter increases. Therefore, the increase in fleece weight is mainly due to the increase in its coarsening, which has a very negative influence on the textile quality and selling price (Frank, 2001). This was confirmed in a subsequent fibre analysis of llamas from the Jujuy Altiplano, in Argentina (Frank et al., 2006a).

The relationship of primary and secondary fibre diameters (RPSFD) shows significant differences within the different fleece types of Argentine llamas. This is a noteworthy aspect as it shows that the llama fleece visual examination is linked to the RPSFD and it can be a useful indicator (Frank et al., 2006a). This leads to the use of a manual dissection method that defines fibre groups through the visual examination as proposed in the work to be developed in this thesis (Frank et al., 2007a).

From what has been described so far, it can be concluded that there is still limited knowledge about the change in llama fleece structure which takes place during the animal's growth and bears textile relevance. It remains to be detected how the fine and coarse fibres change as separate groups regarding length, mean diameter, medullation degree, etc., which is important to determine how much the textile value changes respectively. This distinguishing change would be based on the fact that the different fibre types are produced by different follicle types, which in this regard are classified embryologically into: central primary, lateral primary, epidermal or original secondary and derived secondary (Frank, 2001).

Fibre coarsening due to age increase - "micron blowout":

There is an English term, "micron blowout", which literally means "burst or leak of microns" and is used in connection to wool. Within the context of this thesis, it is defined as the fibre diameter increase that can be seen as the animal grows older and is used as a general term. Apart from that, the use of the term can be confusing because it depends on the context in which it is implemented and because it does not mean the same to everyone. It can refer to a sheep that at a certain age shows more fibre micronage than the average of the flock to which it belongs. For a commercial wool producer who bought a ram, it can mean that between the time of the young animal purchase and when the analysis is made two or three years after that, the fibre micronage has increased. And for the herd owner, it can mean a complex combination of the two meanings mentioned above. In any case, an influence of age on wool diameter is confirmed, more noticeably in rams than in mother ewe, which can have a difference from 2 to 4 fibre microns (Atkins, 1996).

According to other authors, the fibre diameter increase due to the change in the animal age, called “micron blowout”, is determined when this change occurs faster in a specific animal than in the average of the group being studied, which generally creates uncertainty about the validity of the mean diameter measured at a young age (Olivier & Olivier, 2010). This phenomenon has been described in all fibre-producing species, in Merino wool (Atkins, 1996), in mohair (Van Der Westhuysen et al., 1985; Martin et al., 1998) and in cashmere (McGregor & Butler, 2008a). In Chilean alpacas, a significant change was determined among age groups for TMD and total follicular density (TFD) with an increase in TMD and a decrease in TFD, with TMD and TMF having a negative and significant correlation (Crossley et al., 2014). Within camelids, Butler & McGregor (2002) determined a mean diameter modification of 7.5±7.5 µm in alpacas due to age. This implies that the coarsening variation among animals is very significant. While some animals’ fibre does not experience any coarsening, in others, it can be of up to 15 µm. The maximum coarsening occurs at 7.5 years old and the correlation between 1.5-to-2-year-old animal diameter and that of older animals was much higher than correlations with younger animals. Within Argentine llamas, Frank et al. (2006a) determined that the age is the external effect that produces the greatest change in the diameter. They studied the MD increase due to the age increase and found that the MD increase and the animal´s growth develop equivalently. Possibly, this is explained by the follicular density reduction as the animal grows older. A similar analysis performed Hill et al. (1999) in Merino sheep, from the genetic point of view.

The evaluation of the aspects and criteria supporting the camelid fleece structure has been reviewed in Frank (2001) and applied in Frank et al. (2007a). However, the aspects related to morphology changes through a dynamic process (age) have not yet been clearly established, therefore, it is necessary to address topics developed in other studies. It has been shown that the mean diameter can be handled with the feeding conditions in sheep, but with a food constraint that produced a reduction of 0.6 µm, it also produced an effect of "tenderness" or fibre strength reduction (Mata et al., 2002).

The micron blowout heritability in alpacas aged between 1 and 2 years old (group of age one to two) resulted in a value of 0.13±0.08; between 2 and 3 years old, a value of 0.05±0,07, and between 3 and 4 years old, a value of 0.06±0.11. In general, high environmental and phenotypic correlations were estimated between the micron blowout and the fibre diameter in all age group categories. But a high genetic correlation was only estimated between the fibre diameter at two years old and the micron blowout of the one-to-two-year-old age group. Very low genetic correlations were estimated between the fibre diameter and the micron blowout of the age group of two to three years old and three to four years old (Munyard & Greeff, 2013). These results show that it would be difficult to obtain an improvement quickly through the animal selection in favour of a reduced micron blowout.

Group of coarse fibres (objectionable fibres):

The term "objectionable" is born regarding the objective of producing fine textiles that do not prickle on the skin. However, if a fibre lot is intended to be used to produce carpets, the term "objectionable" does not make sense because it is precisely these rigid fibres contained in the llama fleece that have great textile value for carpet production. This is the case particularly for wall-to-wall carpet production as the rigid and coarse llama fibres are very resilient after having been pressed down (Mcloughlin & Sabir, 2017).

Another issue to be evaluated regarding fleeces with a high number of coarse fibres and which are meant for the carpet industry is if there is a possible reason to implement the dehairing even in this case, as the dehairing process improves the textile quality and therefore enhances the subsequent textile process because it separates the felted or tangled parts as well as the vegetable matter (anecdotal reference). Likewise, it was observed that dehaired alpaca fibre is cleaner, smoother, bulkier and more suitable to be used as a filling material for quilts (Wang et al., 2008).

Three Group Dissection:

The Three Group Dissection is central to this thesis, and consists in dissecting a staple according to fibre type, forming three different groups. The fibres included in these groups are clearly distinguishable by the human eye. This dissection method was developed in the Animal Textile Fibre Analysis Laboratory (LAFTA, for its acronym in Spanish). It is performed according to what was established by Frank (2001), who observed and quantified the main morphological characteristics of separated fibres found in llama fleeces. The original idea of this approach is based on the study of lamb fleeces, in which is observed that the fleece’s structure is formed according to the fibres with which they are composed (Dry, 1975).

Furthermore, this dissection method was developed out of the appearance given by the fibres after being laid out over a piece of cloth, regarding the procedure called Baer Diagram (Onions, 1962). This method implies the separation of all fibres contained within a staple in such a way that they lie parallel and side by side, arranged in order from the longest to the shortest ones. This practice is quick and very useful to get a general idea about the fibre types included in a fibre sample, because the length distribution of fibres present in a staple is shown. The Baer Diagram is a commonly-used method to evaluate mean fibre length, called hauteur, in tops or carded staples. Figure 1 shows the fibres of a staple placed on a velvet cloth in accordance with a Baer Diagram.

Figure 1: DC staple fibres placed on a velvet cloth in accordance with Baer Diagram (Onions, 1962).

The method of arranging the fibres contained in a staple according to their length is used in the staple comb method for cotton (comb sorter diagram) in order to measure fibre length and its distribution, as described in the German Standard DIN 53 806 (1970) and the corresponding British Standard BS 4044 (1989).

As well as the methods described in the preceding paragraphs, the Three Group Dissection is based on the idea of separating fibre types according to a particular variable as, for instance, the fibre length. When using the Three Group Dissection the diameter and the crimp type are also considered. In fact, these last two fibre characteristics are the ones given the most importance in determining which group every fibre belongs to. This dissection method is performed only by visual examination of the fibres, without the use of a microscope, thus it is based on the fibre macroscopic characteristics. The crimp type is clearly visible and also the differences regarding the diameter of different fibres can be detected visually. According to studies carried out by Lang (1947), the human eye is capable of distinguishing fineness differences among separated fibres by 2.5 microns or more.

When looking closely at Figure 1 about the Baer Diagram, it can be seen that, on the right, where most of the fibres are fine, there are coarse fibres which are intermingled. Therefore, it is not useful to tell the textile value of the staple because it does not fully reveal it by not separating different fibre types more thoroughly. The Three Group Dissection goes a step further towards that aim.

Prickle effect:

Within the textile context, the expression "soft" is commonly recognised as the tactile sensation or handle, and combines in itself information related to several characteristics at once: skin comfort (prickle), stiffness, smoothness, softness (De Boos et al., 2002; Frank et al., 2014). The term “prickle”, which implies itching or pruritus, is only applied to garments used in contact with the skin, directly or indirectly, and it has become increasingly significant. Several studies have shown that the prickle sensation comes from the coarse fibres of the right end of the diameter distribution, the so-called "coarse edge” (Garnsworthy et al., 1988; Naylor, 1992b). The prickle is produced because the fibres push on the skin’s surface with so much force as to activate nerve cells (Kenins, 1992). Naylor (1992b) has determined that the percentage of fibres coarser than 30 µm is a good predictor of prickle sensation in knitted fabrics and much more accurate in plain-weave fabrics. However, this 30 µm cut-off point can be argued because it can be altered by several factors and it could be said to fluctuate between 26 and 35 µm, for which further experimental evidence is required (Frank et al., 2017b).

Moreover, it must be considered that not only does the diameter determine whether a fibre prickles or not, but also its stiffness has a crucial impact, what is influenced by the fibre medulla type (Frank et al., 2014). Historically, the emphasis on the fibre’s capacity to prickle has been directed to the percentage of fibres whose diameter is greater than 30 µm. However, a recent work concludes that much finer fibres, up to a fineness of only 20 µm, are capable of triggering the prickle sensation if the fibre length protruding out of the fabric surface is sufficiently short. And, it is considered that some spinning characteristics probably are influencing the incidence of fibre triggering prickle within the cloth too, e.g., the torsion, also may affect the tendency of textiles to trigger prickle. Differences were also observed regarding the knitted fabrics and the plain-weave fabrics (Naebe et al., 2015). This means that with the fineness of a fibre lot there remains more to be said regarding a possible prickle effect, thus other technical data defined during the process within the textile industry will have to be taken into account, e.g., if the spinning is combed or carded, what the spinning torsion is, if a knitted fabric or a plain-weave fabric is produced, etc. According to such situations, the coarser and stiffer fibres are placed in different ways on the textile structure and its surface, and may differ in their ability to trigger prickle. An investigation related to superfine sheep wool as well as sheep wool/cashmere blend spinning confirmed that the fibre characteristics significantly affecting the comfort properties are TMD and the medullated fibre frequency (Naebe & McGregor, 2013).

Naylor (1992b) established that the prickle effect is directly correlated to the Euler's theory about the bending or buckling of a beam or wire, according to which the force to buckle a round structure is equal to the Young's modulus multiplied by the diameter to the fourth and divided by the length squared (Ramsay et al., 2012). Furthermore, it shows that this is not only true for wool but also for an artificial fibre, thus it is true regardless the fibre used. Should this be so, it must be verified what happens with camelid fibres in which, for example, the stiffness modulus (Young) has been proven to be greater than in sheep wool, therefore, the load or force to achieve the fibre bending is expected to be greater or the diameter should be smaller to reach the same stiffness (Liú et al., 2005).

The magnitude of the effect of fibres which are protruding in different length and the deformation type of camelid fibre has been calculated to reach the 75 mfg required to trigger prickle sensation according to Eq1 (Naylor, 1992b) and Eq2 (Ramsay et al., 2012). These data were determined based on the length of 1-3 mm protruding fibres and the frequency at which they occur in a knitted fabric of llama fibre, and were obtained from Frank et al., (2012b). The two equations provide the mean diameter that an isolated fibre should have to reach the level of the buckling load required to reach the 75 mfg.: when protruding 1 mm: Eq1=18.9-20.3 µm; Eq2=N/D; when protruding 2 mm: Eq1=25.8-28.9 µm; Eq2=31.9-34.4; when protruding 3 mm: Eq1=32.8-35.4 µm; Eq2=43.1-46.6 µm and the average of the fibre protruding length corrected by frequencies is Eq1=28.3 µm; Eq2= 29.97 µm (Frank et al., 2014). For the yarn or fabric, this effect is determined by the protruding fibre ends structure more than by the total yarn structure, although the protruding fibre ends effect is generally determined with high accuracy by the mean diameter and total yarn diameter dispersion (De Boos et al., 2002). The protruding fibre diameter is 2 - 3 µm larger than the yarn TMD (Naylor, 1992a; Frank et al., 2014).

If the "coarse edge" in the diameter distribution is what causes the prickle effect problem, two possible solutions can be thought of: reduce the mean diameter (shift to the left of the normal curve with the corresponding "coarse edge") or decrease the range in fibre diameter (shift to the left only the "coarse edge", leaving the mean unchanged) (Naylor et al., 1995). This could be achieved either by dehairing or by genetic selection. Anecdotal information exists for the first situation and experimental information for the second one (Frank et al., 2008; Idem, 2017b).

The fabric comfort, as well as the physical characteristics of the fibre, is closely related to its physicochemical properties and fundamentally to its capacity for retaining heat and water. The former property may be good in some cases and not so good in others, but the latter one is one of the most advantageous properties (Holcombe, 1986). The wool has long been known to be able to absorb up to 35% of its weight in water without draining and this triggers fibre swelling and a concomitant heat loss (Watt & D´Arcy, 1979). This absorption is closely related to the water concentration in the air (relative humidity) and there is a certain asymmetry between the absorption curve and the discharge curve called hysteresis (Burgman, 1965). In relation to this property, no trials have been carried out so far on luxury fibres, however, humidity is a very important issue for the dehairing (Batten, 2003; Adot, O., com. per).

During one experiment, the prickle sensation triggered by textiles produced with two different wool groups was compared. The textiles produced with the wool group of higher mean diameter, 23.2 µm, triggered less prickle sensation than the ones produced with wool of 21.5 µm. This was due to the fact that the VC of the coarser wool was lower, 16.4%, and the VC of the finer wool was higher, 21.7%, thus producing different "coarse edges", 3.6% and 5.0% respectively. This 1.4% difference in the content of fibres with diameter higher than 30 µm could be detected by consumers as a difference in the prickle sensation level caused by the textiles (Dolling et al., 1992).

The cut-off variables (thresholds) that panellists can detect regarding yarn and fabric made with dehaired fibre evoking significantly less prickle than regarding yarn and fabric without dehairing were: total fibre diameter (1.01 µm in yarn and 1.55 µm in fabric surface), the diameter variation coefficient turned out to be significant in yarn only (5.31%), percent of fibres > 30 µm (7.66% in yarn and fabric surface), coarse fibre by weight/fibre total weight (3.23% in yarn and 4.57% in fabric surface), and coarse mean fibre diameter (3.5 µm in yarn and 3.2 µm in fabric surface). These threshold differences were mainly explained by the following fibre variables identified by medulla types: lattice fibre diameter (8.2 µm in yarn and 6.5 µm in fabric surface), non-medullated fibre diameter (0.67 µm in fabric surface only) and lattice fibre frequency (1.6% in fabric surface only). (Frank et al., 2014).

An important aspect of the llama fleece is that this fibre shows a higher heterogeneity since, apart from a coarseness variation, it also includes the variation of other parameters of its morphological structure such as crimp and medullation. The stiffness varies with these parameters and also influences the fibre capacity for evoking prickle. Therefore, for llama fibre, it is essential to define the objectionable fibres not only regarding its coarseness (Frank et al. 2007a; Idem, 2014).

Dehairing or purification:

As explained above, the curve of fibre diameter distribution (FDD) has approximately a normal distribution. This FDD is formed by the sum of the FDDs of the primary fibres on the one hand and, on the other hand, by the FDDs of the secondary fibres. On average, secondary follicle fibres are finer than those of the primary follicle fibres. But, given to the either side end of the normal distribution, both FDDs overlap. This means that the right end or "coarse edge" of the secondary fibres is intermingled with the finer primary fibres. Or, in other words, within a llama fleece, there are some secondary fibres that are coarser than some primary fibres. And, in the same way, it can be stated that there are some primary fibres that are finer than some secondary fibres within a llama fleece. This is a phenomenon that is more or less strongly marked, depending on the fleece type because the FDD is wider in some fleece types than in others (Frank, 2001). This is why different fleece types react differently to the dehairing. The Double Coated fleece type is the best one for being dehaired and Lustre types are the least responsive to this step of the textile process (Frank, 2001; Frank et al., 2010). This can be explained due to the relationship between the mean diameter of primary and secondary fibres: in a Double Coated fleece, the difference between the primary mean fibre diameter and the secondary mean fibre diameter differs much more than in a Lustre fleece (Frank et al., 2006a).

The implementation of the dehairing or purification at the beginning of the textile process results in a structure modification of the fibre as textile raw material since it extracts the coarsest, longest and straightest fibres, the so-called objectionable fibres, what has an effect on the rest of the textile process. The purification yield in Double Coated fleeces is lower due to a high number of coarse fibres. In Double Coated fleeces, the prickle effect was reduced significantly, in Simple Coated fleeces, the reduction was less significant and in Lustre fleeces, no effect was detected. An important implication of these findings is that the classing regarding the fleece type is a fundamental requirement to be performed before, as to say at the beginning of, the textile process since different fleece types require to be treated differently during the purification (Frank et al., 2011a). Also, the ethno-zootechnical study of llama populations in the province of Jujuy, in Argentina, confirmed the need to carry out a classing process in order to obtain homogeneous commercial lots (Hick et al., 2013).

To test the efficiency of the purification process, trials with guanaco, llama, alpaca and cashmere goat fleeces were carried out, and it was concluded that, in order to determine the reduction of undesirable fibres (objectionable fibres), the weight-to-weight ratio is the most appropriate (Frank et al., 2009). By means of trials performed with guanaco and llama Double Coated fleeces, the purification technology is confirmed to be available for its use with fibres of wild camelids (guanaco) and domestic camelids (llama) (Hick et al., 2003).

The dehairing or separation of different fibre types by mechanical means is the alternative to be analysed (Batten, 2003). The dehairing technology development (SUPPRAD Programme) raises this alternative, establishing the physical consequences of such process (Frank et al., 2012b). Dehairing carried out by hand has shown its feasibility (Cochi, 1999), although the process is only efficient with the Double Coated and Intermediate Coated fleece types, as a not very effective separation of coarse fibres is achieved in Simple Coated and Lustre fleeces (Frank, 2001). Even so, it is shown that the performance of fine fibre per person and per hour is 9.9 ± 1.1 g/person/h, which makes it totally unfeasible economically speaking (Quispe et al., 2015).

As a result of a dehairing trial of alpaca fibre carried out in Australia, it is concluded that only a relatively small number of coarse fibres can be removed. Furthermore, the dehairing shortens the alpaca fibre length considerably, therefore, this is unlikely to be a viable practice if the only aim is to reduce the fibre diameter and it is only useful to reclassify the dehaired fibre into a finer quality. The real benefit of the dehairing should be the quality improvement of the alpaca final products (Wang et al., 2008). Meanwhile, a dehairing trial of baby alpaca top carried out using the Argentine technology AM2 produced a high product yield (83.5%), with a 10% reduction of the average length and little difference in diameter since the top fineness was low (22.4 μm). In conclusion, the product obtained is feasible to be processed by the combing system (worsted) without any problems, what justifies the process (Frank et al., 2019b).

The traditional dehairing machines were designed to dehair guanaco and vicuna fibre, which show a different behaviour when being dehaired since their primary and secondary fibres, regarding their morphology, differ a lot from each other and, moreover, fibres are short. These machines produce less satisfactory results regarding llama fibre (Adot & Frank, 2015), what led to the design of a new dehairing machine, called AM2, and to implement it for the textile industry.

The adjustment of an initial module of this dehairing technology made it possible to launch the first commercial products based on camelid and caprine (cashmere) fibre (Frank et al., 2009). One work evaluates the reduction of coarse or objectionable fibre frequency, the reduction of the fibre length, effect of the reduction of objectionable fibres upon mean diameter of fine fibres and total mean diameter of the product obtained (“down”) in fibre produced by regional creole goats, llamas, alpacas and guanacos. This dehairing yield was obtained: 20-40% cashmere, 50-70% guanaco and Double Coated llama; 70-85% for non-double-coated alpaca and llama. Among the variables examined to analyse the coarse fibres, weight/weight was chosen when the model included the total mean diameter as concomitant variable. A higher coarse fibre reduction is observed in cashmere, followed by guanaco, llama and alpaca ($p<0.05$). The reduction of coarse fibre is generally related to the total mean diameter ($R^2=0.42$). The weight/weight ratio is the most appropriate measure to determine the reduction of undesirable fibres and the reduction of fine fibre length is only partly explained by the reduction process of coarse fibre frequency (Frank et al., 2009). It can be also stated that the relationship between diameter and prickle factor is similar for alpaca and llama fibre, and it adjusts to a potential distribution, showing a break point of 21.67-22.3 µm, as the prickle factor is constant before the break point and increases significantly after it. Practically all fibre (>96%) lays beyond the threshold required for fine garments, while only the 3.5% and 3.8% is below it regarding alpaca and llama respectively; thus, most of it requires dehairing (Frank et al., 2012a).

A dehairing trial used an alpaca top of 22.4 µm of average fineness, having a VC of 23.5%, objectionable fibre weight/weight: 6.8%, fibre of >30 µm: 6.6% and average fibre length (down + guard hair: Baer Diagram): 111.8 mm. A dehaired/down product was obtained (Pass IV): 21.9 µm of average fineness, having a VC of 24.0%; objectionable fibre weight/weight: 2.2%; fibre of >30 µm: 3.6% and average fibre length (down: Baer Diagram): 83.0 mm (reduction: 6.9 - 21.2%), having a yield of 83.5% and the product is processed by the worsted system (combing) (Frank et al., 2018). When the objectionable or coarse fibre frequency exceeds the 3%, consumers identify the prickle in the fabric. The dehairing is a possible solution to this problem, but the fibres are shortened with the successive passes. The textile quality of the South American Camelids' fibre seems to be very promising if the problem of the presence of undesirable or objectionable fibres is solved, by reducing them to a frequency tolerable by consumers (<3 %). The fundamental problem affecting the efficiency of the dehairing is the way in which the fleeces are placed on the entrance tray of the laboratory dehairing machine. This can be calculated by means of laboratory trials with a dehairing machine (alpaca and llama), which calculates the percentage of coarse fibre dropped per pass, the shortening per pass and the dehairing yield (Flores Gutiérrez, A., com. per.). A problem in establishing the dehairing efficiency arises in the laboratory due to its complexity and the dependence on the operator when implementing the traditional methods used on velvet boards.

In a consumer study, it can be concluded that the dehairing reduces the prickle, mainly in fabrics made of Double Coated fleeces, being less noticeable with Simple Coated fleeces and having no detected effect at all with the Lustre fleeces. The preferred samples were the softer ones, with a more moderate "prickle factor". The classing regarding the fleece type is a fundamental pre-requisite for the textile process, due to the different dehairing needs for the different fleece types of Argentine llama fibre (Frank et al., 2009). Finally, the fibre commercialisation could improve and strengthen the profitability of domestic camelid breeding, as a result of this product which includes classing (Frank et al., 2019b).

CHAPTER III. MATERIALS AND METHODS

In order to proceed with the different topics included in this research, it was necessary to use different materials, that is to say, different sample groups. Therefore, it was essential to divide the work into different sub-chapters. The materials used were whole llama fleeces as well as different groups of llama fibre samples. The fleeces were used for being processed in the industrial dehairing trial. The fibre samples were taken from the llama fibre found in that textile process or in the country from the fleece of the free-range live animal. According to this, different databases were produced. Thus, in each sub-chapter, the material and databases used vary, having been selected specifically to proceed with the research of the corresponding topic. The fibre samples were analysed in the Fibre Laboratory of the Faculty of Agricultural Sciences of the UCC.

1. Age effect on the llama fleece structure

The materials used to study the age effect were obtained by monitoring an experimental llama flock, through an annual collection of fibre samples. The resulting data were referred to as "experimental data". In addition, samples from the observation of different llama flocks and their respective routine analyses were analysed as they entered the Fibre Laboratory during the years prior to the development of this thesis. This database includes a large number of animals of different ages and the resulting data were called "observational data".

Experimental data:

The annual sampling of the experimental flock was implemented during 9 years, from 2008 to 2016. Fibre samples were taken from animals being up to 11 years old. These animals were sampled year after year, shortly before shearing. Therefore, the shearing gap is one year. The only exception to this is the first sample taken from some animals, as they were purchased and included in the flock. In this case, the shearing gap may be different because it was not possible to know when the previous shearing had been done.

The time of sampling was in December of each year. 20 animals were sampled annually, that is to say, 20 sample series were obtained. These series include samples from 5 to 9 successive years, depending on the animal. Animals of different fleece types were chosen in order to obtain 4 series of each fleece type. In total, 150 samples were taken. For the individual identification of each animal, an ear tag with the identification number was placed in one ear and, for greater security in case the ear tag was lost, a button with the same number was placed in the other ear. The fibre samples were taken from the animal's flank, from the area of the last rib, with mechanical shearing scissors. It is assumed that the genetic structure of the population was not modified during the years of sampling.

Figure 2 shows a series of staples taken annually from the same animal, being each staple prepared for the Three Group Dissection. The first sample was taken when the animal was one year old, corresponding to the first shearing, and subsequent samples were taken annually.

Figure 2: Samples series taken annually from a SC fleece animal.

The samples come from the llama breeder of the Piedra del Agua Ranch, located in the Sierras Centrales of San Luis Province, Argentina. This breeder develops management control and, therefore, has a population of productively controlled llamas, which includes annual shearing and the implementation of a regular health plan, so that the fleece does not show signs of felting. On the establishment, an individual llama identification register is kept for the identification of each animal's age class. The crias (baby llamas) born in the establishment are registered every summer and, at the moment of the first sampling, they show a certain variety in relation to age, between 10 and 14 months old. Therefore, the first shearing staple length varies more than in successive shearings. With the purchased animals, data from a register given by the selling establishment was used. Variables arising from the experimental database are named without a lower-case letter at the end of their abbreviation in order to indicate which database they come from (e.g., TMDv, TMDn, MDA, MD1 or W%1). In contrast, observational animal variables are identified with an "o" at the end of the abbreviation (e.g., TMDvo, PERIMo or MDAo).

Observational data:

This database includes data from 2164 animals, which are up to 9 years old and have all fleece types, coming from three different observational flocks from the Provinces of Buenos Aires and La Pampa, in Argentina. In general, there is no annual follow-up of the same animal in this database, except in some cases in which the same animal was sampled for two or three years in a row (mean repeatability of 2.9 years). Fibre samples were taken from the animal's flank, from the area of the last rib.

The shearing gap for these samples is annual, except for the first samples, for which there may be different shearing gaps. The age of the animal was determined using a dental chart that allows age differentiation with an error of approximately 3 months (Frank, E.N., unpublished). The age category of each animal is defined by means of the gaping, through which the development of the dentition is identified, that is to say, according to the presence and quantity of the different types of teeth and tooth wear. The observational database includes 75 variables determined on fibre and skin respectively, which are part of this thesis and various publications (Frank, 2001; Frank et al., 2011a; Idem, 2011b).

Variables used in Division 1.1 and 1.6 within Sub-chapter 1 come from this database and are identified with the letter "o" at the end (Figures 25 to 27: Variables PERIMo, TMDvo, MDAo, MDFo, MDIo, MDCo and MDGo). In addition, this database is used for the development of Sub-chapter 3, using data from animals of age categories from 1 to 3 only. These variables are identified with the letter "e" at the end.

Statistical analysis and graph production:

Regarding the statistical analysis of the data referring to the mean diameter (MD), it should be taken into account that this is a non-normal variable since the normality and homogeneity of variance of the MD distribution is not stated. The data were processed with Infostat statistical analysis software and a Kruskal Wallis test (KW) was used. The KW according to ranges is a non-parametric method to test whether samples originate from the same distribution. It is used to compare two or more independent samples of equal or different size. A significant KW indicates that at least one sample stochastically dominates, at least, one of the other samples (Siegel, 1988). The test does not identify where the stochastic dominance occurs or for how many two-sample groups the stochastic dominance is obtained. Dunn's test helps to analyse two-sample groups specifically in *post hoc* tests (Dunn, 1964).

The determination of the mean fibre diameter (MD) and the counting of the fibre types was done on a sample basis and this estimation can be more or less accurate according to statistical theory if the number of fibres measured per sample is modified. This number (n) was set according to a required amplitude in terms of percentage of the mean of 5%, that is to say, that amplitude would be 1 µm for a mean of 20 µm. The usual equation of $\mathrm{n} = \frac{(2*1.96*\mathrm{SD})}{(0.05*\mathrm{MD})}$, was applied where SD is sample standard deviation and MD is mean fibre diameter. This equation is applicable even for approximate variable confidence gaps for the mean of a non-normal random variable distribution, whilst the assumptions of the central limit theorem are met and for a sufficiently large *n* (Casanoves et al., 1998).

Infostat was used to create the dot plots for Sub-chapters 1 and 2. The standard error was used to express variation as most of the variables do not have a normal distribution. Smoothing (LOWESS) was implemented for all variables (Kelmansky, 2010), except for the thoracic perimeter plot, where a polynomial quadratic regression was used (PERIMc and PERIMo in Figure 25). The bandwidth of the smoothing was set to 50%. The graphs in Sub-chapter 3 were created in Excel spreadsheets.

Fleece types:

The identification of fleece types was made according to what was determined in Frank (2001). Furthermore, the differentiation of fleece types is described in Frank et al. (2007a), and complemented in Brodtmann et al. (2018) and through a multivariate statistical analysis (Frank et al., 2019a).

Three Group Dissection:

The Three Group Dissection was used as the main method of this thesis since it was used for all 3 sub-chapters. Thus, a large part of the conducted evaluations was carried out according to fibre groups (FG1, FG2 and FG3), which are defined through the implementation of the Three Group Dissection. Its implementation is described in the following paragraphs and was published in Brodtmann et al. (2018). It was taken into account what was expressed for the cashmere dehairing theory (Singh, 2003).

The flow chart in **¡Error! No se encuentra el origen de la referencia.** shows the steps to i mplement this dissection method. For dissection, a staple of approximately 0.2 g is separated from the fibre sample and its length is measured in such a way that the staple is placed straight on a velvet cloth, but without having stretched it. A weighing balance with an accuracy of 0.001 g is used to weigh the staple. Dissection is done by hand and by visual examination. The fibres are separated into three fibre groups (FG1, FG2 and FG3). FG1 integrates the coarsest and the most visible fibres, FG2 the intermediate fibres and FG3 the finest ones.

It is important to note that in this context "fine" and "coarse" are relative expressions because the finest fibres of a very coarse fleece are not fine. This means that in the Three Group Dissection, the fibres are not separated according to different diameters with absolute values, but according to different fibre diameters relative to each other. Therefore, when starting the dissection, it is important and very useful to establish the range of fibre types that are present in the sample. For this, a small part of a staple from 30 to 50 fibres is separated and its fibres are placed on a velvet cloth. Through this, the operator determines from the beginning what fibres are typical for each fibre group and what is the approximate diameter range included in FG2 and which is the observed crimp. Accordingly, coarser fibres of a certain crimp type belong to FG1 and finer fibres with another specific crimp type belong to FG3.

The designation of each FG with "1", "2" and "3" results from the Three Group Dissection practice, which starts by separating the fibres that stand out visually by their coarseness, crimp type and, possibly, their length. These fibres are therefore designated with number "1". At the end of the dissection, after having removed the coarse and intermediate fibres from the sample, the finest fibres, in this sense the "third" group, remain. The numbers "1" to "3" do not imply any hierarchy.

Dissection begins with removal of the coarsest and most visible fibres from the entire staple. They are removed from the staple and placed on a velvet cloth to form FG1. Then, less coarse fibres are separated from the staple to form FG2 and placed elsewhere on the cloth. Finally, the finer fibres corresponding to FG3 are separated and also placed on another place on the cloth. This last step is only done to a certain extent due to the large quantity of fine fibres. The rest (R) of the fine fibres are retained in a remaining bunch of fibres. The three fibre groups are weighed separately as well as R. R is then joined with the other fine fibres that had been placed on the cloth and, together, they form FG3. The absolute weight of each FG (W1, W2 and W3) is recorded and then the relative weight (W%1, W%2 and W%3) is calculated.

The fibres in FG1 and FG2 are counted one by one and the absolute fibre frequency of these two FGs (N1 and N2) is obtained. In addition, the fibres of FG3 that had been placed on the cloth are counted and then the number of fibres contained in R is calculated by extrapolation according to the weight of R and the fine fibres that were counted. Therefore, it is very important to ensure that the fibres of FG1 and FG2 were completely removed from the bunch of fine fibres. The absolute fibre frequency of FG3 (N3) is obtained by adding the fibres of FG3 and R. The relative fibre frequency corresponding to each FG (N%1, N%2 and N%3) is then calculated.

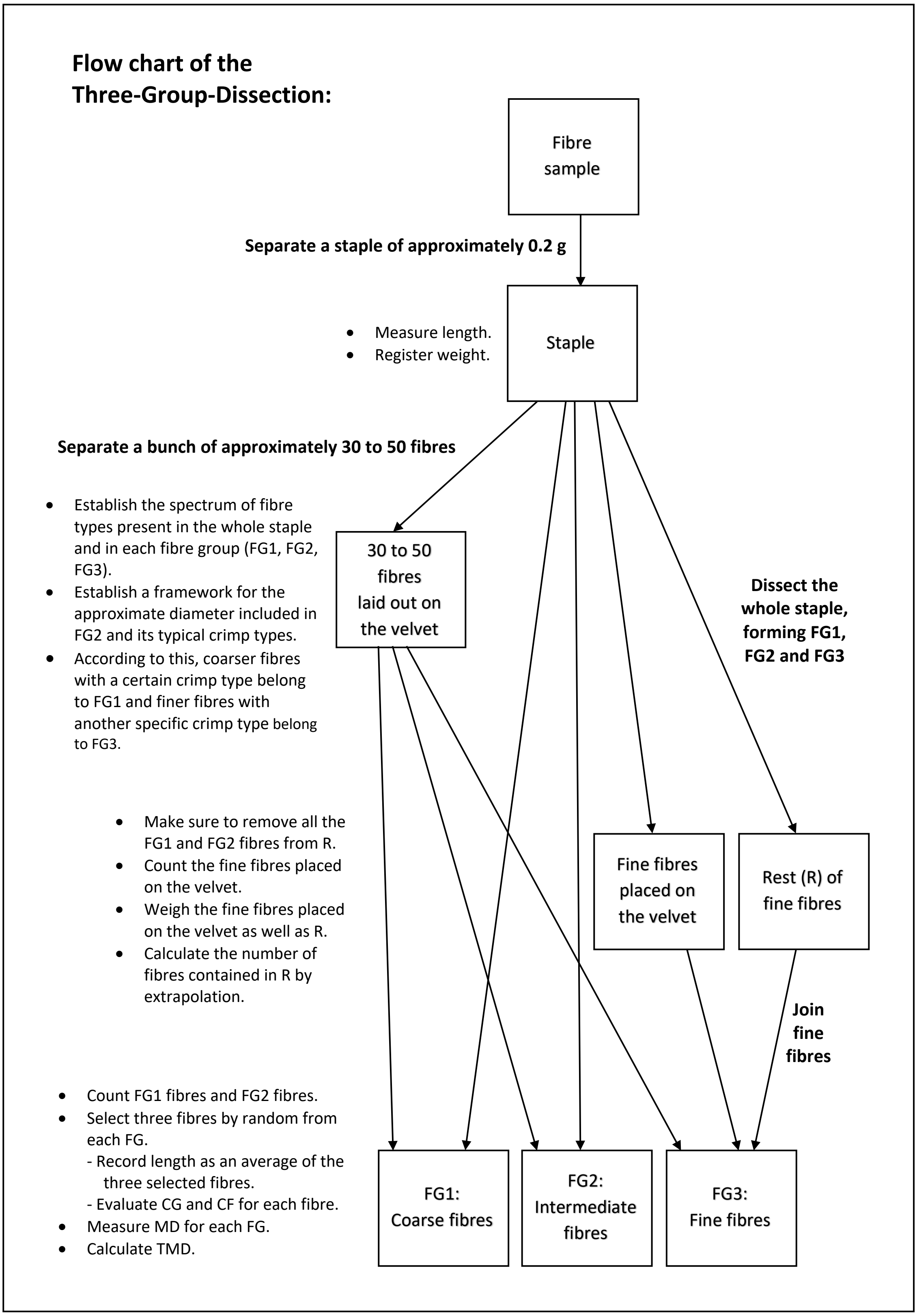


Figure 3: Three Group Dissection Flow chart.

Then, 3 fibres are randomly selected from each FG and analysed regarding their crimp frequency (CF), crimp group (CG) and length (L). These variables are described in divisions 1.3, 1.4 and 1.5. CF and CG are recorded for each fibre, while length is recorded as an average of the 3 selected fibres. Subsequently, the MD is measured for each of the three FGs that were formed.

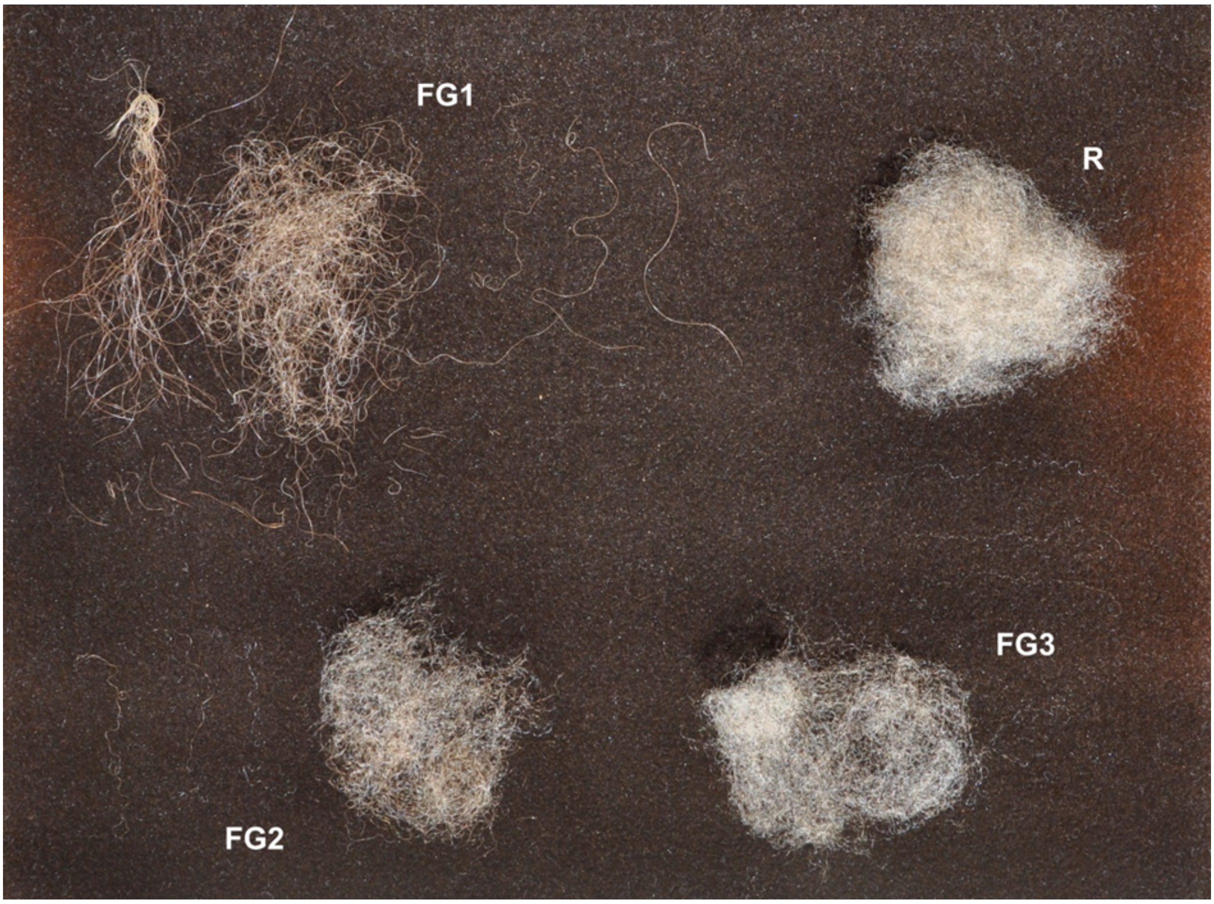


Figure 4: Fibres of a DC staple placed on a velvet cloth after implementing Three Group Dissection.

Figure 4 shows the fibres placed on a velvet cloth after having been dissected according to the Three Group Dissection, demonstrating the three resulting FGs and R. Next to each FG, the 3 randomly selected fibres can be observed.

1.1. Total mean diameter and mean diameter according to fibre groups (FGs)

In Division 1.1, the different variants used to express the total mean diameter (TMD) are described. TMD variables that were measured from a staple taken from a fleece of the animals in the observational flocks and from the 20 animals in the experimental flock are named with a "v" at the end of the abbreviation (TMDvo and TMDv (v, for the Spanish word for fleece: **v**ellón)), and TMD weighted regarding weight or fibre frequency from the three FGs resulting from the Three Group Dissection are named with a "w" or "n" at the end (TMDw and TMDn, only for the 20 experimental animals). The variables TMDv, TMDn and TMDw as well as other variables referring to these 20 experimental animals are not supplemented with an additional letter to indicate the origin of the sample, as they constitute the vast majority of the variables in this sub-chapter.

To measure the different mean fibre diameters (MDs), either for a fleece or for a FG, a projection microscope method was used, the same method for this whole research, except only for the TMD measured for the complete experimental flock (TMDvc). TMDvc is defined identically to TMDv, with the difference that the database includes the complete experimental flock, so the variable receives a "c" at the end of the abbreviation, while TMDv describes only the fibre of the 20 animals selected for annual monitoring. So, TMDvc was not measured year after year, but was sampled only once, in December 2018, and it was measured with the MiniFiber EC.

The projection microscope method is based on measuring the diameter of a certain number of fibres and recording the fibre frequency (N) of each fibre type (defined by its medulla type). N results from the same fibres of which the diameter is measured since the fibres are also counted according to their medulla type at the same time. This is a slightly modified version of the one of the IWTO (IWTO-8, 1961), a projection microscope method described in Frank et al. (1985) which takes into account suggestions for alpacas (Lamb, 1998). By applying this method, the MD is recorded according to the fibre types observed under the microscope (Lanameter), as well as their respective absolute fibre frequencies (NA, NF, NI, NC and NG). The relative fibre frequencies (N%A, N%F, N%I, N%C and N%G) are then calculated, that is to say the percentage value of the number of fibres in relation to the total analysed staple. In this context, fibre type is synonymous with medulla type, which is discussed more deeply in Division 1.2. The fibres to be measured in the Lanameter are 2- or 3-mm long fibre pieces that are spread on a glass microscope slide, mounted with glycerine and placed on the projection microscope. To obtain a representative blend of the fibre sample, a random staple is separated, bent and a few fibres are cut from it. This process of bending and cutting is repeated a few times to ensure the obtention of bits of the different fibre types present in the sample as well as bits extracted from different places along the same fibre. The latter is important due to the fact that the same fibre can have different diameters depending on which part of the fibre is involved.

The TMDv is weighted through the variables measured with the projection microscope method, which are the MD measured for fibres of different medulla types (MDAv, MDFv, MDIv, MDCv and MDGv) and their respective absolute frequencies (NAv, NFv, NIv, NCv and NGv) or relative frequencies (N%Av, N%Fv, N%Iv, N%Cv and N%Gv). In the following equation, both absolute and relative fibre frequencies can be used interchangeably, just like in the other equations used to calculate a MD.

Equation 1:

$$TMDv = \frac{(MDAv \cdot N\%Av) + (MDFv \cdot N\%Fv) + (MDIv \cdot N\%Iv) + (MDCv \cdot N\%Cv) + (MDGv \cdot N\%Gv)}{N\%Av + N\%Fv + N\%Iv + N\%Cv + N\%Gv}$$

The construction of the variable TMDvo is identical to TMDv, the only difference is that the data used to calculate it came from observational data, so the variable name is supplemented with an "o" at the end of the abbreviation. Figure 5 shows from which variables each MD is constructed. The measurement of MDAvo, MDFvo, MDIvo, MDCvo and MDGvo is identical to the variables MDAv, MDFv, MDIv, MDCv and MDGv mentioned in the previous paragraph.

From the same fibre sample from which a staple was separated to measure TMDv, a further staple was separated for which the measurement of the other two TMD variants arises, both at the same time, TMDw for the W% weighted variable and TMDn for the N% weighted variable, whereby these variables are given the letters "w" or "n". While TMDv is measured directly for the staple extracted from a fleece, that is to say from the complete staple, TMDw and TMDn were not measured for the staple in its complete original state, as it was extracted from the fleece, but they are calculated from the FGs formed after the Three Group Dissection has been implemented. In the case of TMDw and TMDn, first the MD of each FG (MD1, MD2 and MD3) is measured and W% as well as N% of each FG (W%1, W%2 and W%3; N%1, N%2 and N%3) are recorded. TMDw and TMDn are then weighted using equations 2 and 3.

Equation 2:

$$TMDw = \frac{(MD1 \cdot \mathrm{W}\%1) + (MD2 \cdot W\%2) + (MD3 \cdot W\%3)}{W\%1 + W\%2 + W\%3}$$

Equation 3:

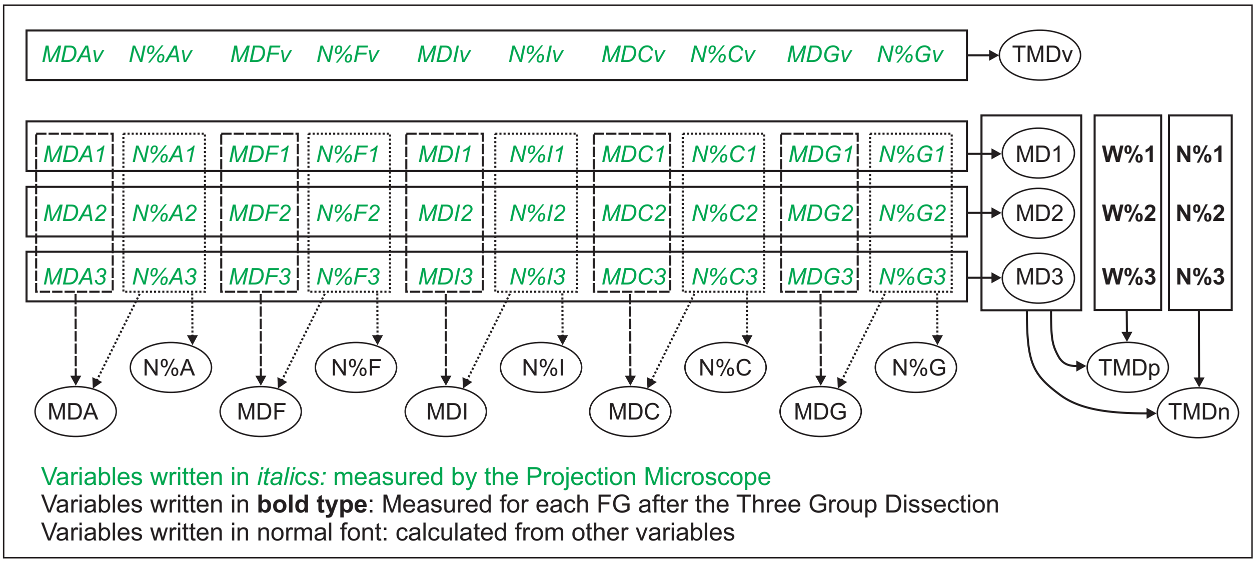
$$TMDn = \frac{(MD1 \cdot N\%1) + (MD2 \cdot N\%2) + (MD3 \cdot N\%3)}{N\%1 + N\%2 + N\%3}$$

The mean diameter of FG1 (MD1) and its standard deviation (SD1) result from the projection microscope method, during which the MDs of each fibre type were measured. For example, the MD of the non-medullated fibres within FG1 is named MDA1. To calculate the MD of the whole FG, then, the measured MDs for each fibre type and their respective N% are used according to the following equation.

Equation 4:

$$MD1 = \frac{(MDA1 \cdot N\%A1) + (MDF1 \cdot N\%F1) + (MDI1 \cdot N\%I1) + (MDC1 \cdot N\%C1) + (MDG1 \cdot N\%G1)}{N\%A1 + N\%F1 + N\%I1 + N\%C1 + N\%G1}$$

For the MDs of FG2 and FG3 (MD2 and MD3), and their respective standard deviations (SD2 and SD3), the variable names are analogous to FG1, replacing the digit "1" by "2" and "3" respectively. For PERIMc and PERIMo variables, see Division 1.6.



Variables written in *italics:* measured by the Projection Microscope
Variables written in **bold type**: Measured for each FG after the Three Group Dissection
Variables written in normal font: calculated from other variables

Figure 5: Variables used to build the different MDs.
(For variable abbreviation explanation see points A1), B), C) and D) of the list of the abbreviations ordered according to the sub-chapters)

1.2. Mean diameter according to fibre type

Fibre types are defined by their medulla, which are differentiated as non-medullated fibres (A, for its acronym in Spanish: fibra amedulada) as well as fragmented (F), interrupted (I), continuous (C) or large (G, for its acronym in Spanish: gruesa) medulla fibres (Frank, 2001). In microscopic observation, the fibre type is in principle determined by the medulla type, as its main morphological characteristic (Frank, 2001; Frank et al., 2007a).

The mean diameter measured for fibres with different medulla types for FG1 (MDA1, MDF1, MDI1, MDC1 and MDG1) as well as their respective relative fibre frequencies (N%A1, N%F1, N%I1, N%C1 and N%G1) arise from the projection microscope method. For FG2 and FG3, the variable names are analogous to FG1, replacing the digit "1" by "2" and "3" respectively.

The mean diameter of the non-medullated fibres (MDA) is weighted from the MD of the non-medullated fibres of each FG (MDA1, MDA2 and MDA3) and the relative fibre frequencies of the non-medullated fibres of each FG (N%A1, N%A2 and N%A3), as shown in Figure 5 and Equation 5. For the fibre MD of the other fibre types (MDF, MDI, MDC and MDG), the variable denominations are analogous to the non-medullated fibres, replacing the letter "A" by "F", "I", "C" and "G" respectively.

Equation 5:

$$MDA = \frac{(MDA1 \cdot N\%A1) + (MDA2 \cdot N\%A2) + (MDA3 \cdot N\%A3)}{N\%A1 + N\%A2 + N\%A3}$$

The relative fibre frequency of the non-medullated fibres (N%A) is calculated by weighting the N%A of the three FGs (N%A1, N%A2 and N%A3) according to the relative fibre frequencies of the fibres within each FG (N%1, N%2 and N%3), as shown in Figure 5 and Equation 6. For the fibre N% of the other fibre types (N%F, N%I, N%C and N%G), the variable denominations are analogous to the non-medullated fibres, replacing the letter "A" by "F", "I", "C" and "G" respectively.

Equation 6:

$$N\%A = \frac{(N\%A1 \cdot N\%1) + (N\%A2 \cdot N\%2) + (N\%A3 \cdot N\%3)}{N\%1 + N\%2 + N\%3}$$

1.3. Crimp frequency

The crimp frequency (CF) is defined by the number of "valleys" or "summits" shown by the fibre crimp within the length of one centimetre, that is to say, what corresponds to the period of a sinusoidal wave. The measured section within the fibre length is randomly chosen. In the case of the fibres of crimp group 4 (CG4), which are almost straight, a value of 0.5 crimps/cm is recorded as a generic expression for fibres with half a crimp per centimetre or less as well as for fibres including a sharp bend somewhere along their length, but which are otherwise almost straight.

1.4. Crimp groups

The crimp type is determined by comparing each individual fibre with the Llama Fibre Crimp Chart (modified from Frank, 2001; Brodtmann et al., 2018) in Figure 6. In Frank (2001), 23 different crimp types are distinguished while, with the Three Group Dissection, this is simplified by assigning these crimp types to seven different crimp groups (CG1 to CG7). Fibres within one of these groups show a similar pattern regarding their crimp. To form the crimp groups, the follicles are not taken into account. This modification is made taking into account what is defined by McGregor (2007) for cashmere fibre crimp. Here, crimp groups were established according to typical crimp patterns of different fibres.

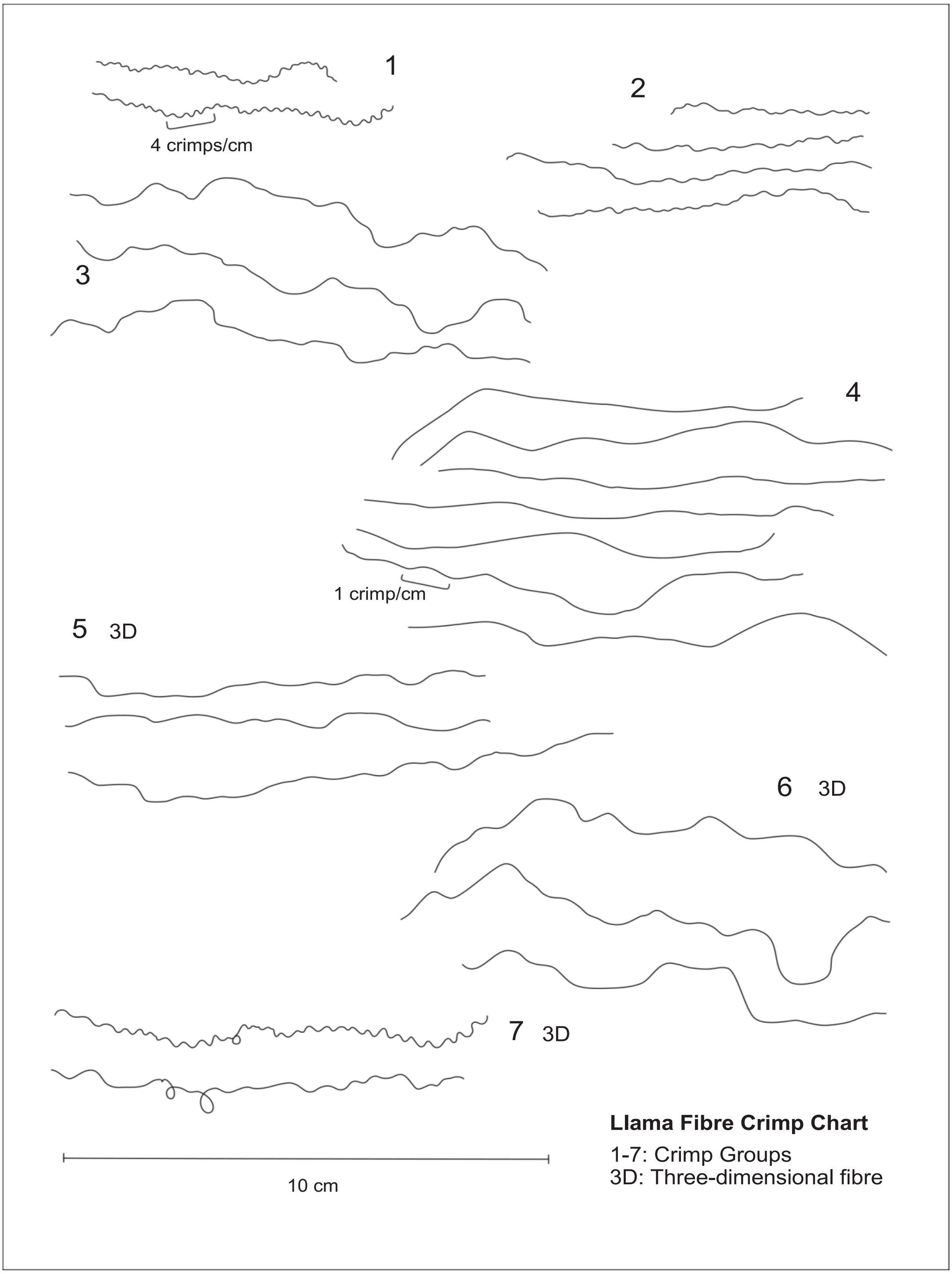


Figure 6: Llama Fibre Crimp Chart (modified from Frank, 2001; Brodtmann et al., 2018).

In the Llama Fibre Crimp Chart, the fibres are drawn in size one by one. A typical pattern of a llama fibre can be a short, regular crimp as well as a long, irregular crimp. It may also include curled fibres showing a three-dimensional (3D) shape. CG1 fibres are always very fine, those belonging to CG2 and CG3 increase in diameter. CG4 fibres, in general, are coarse or very coarse, excepted for fibres from Lustre and HL fleece types which may have fine CG4 fibres. CG5, CG6 and CG7 fibres may have different diameters. Fibres which form a marked loop at a certain point along their length are included in CG7.

1.5. Fibre length

The fibre length (L) is measured by placing the fibre along a straight line, allowing the fibre to lie in its natural shape, without stretching it. Only if the fibre shape includes a 180-degree turn, which is sometimes the case for CR4 fibres, the fibre is opened up a little without stretching it all the way.

1.6. Consistency of experimental and observational databases

In order to evaluate the possible consistency between the experimental database and the observational one, an evaluation of the results of both was undertaken. The variables evaluated are some of those described in the previous divisions, with the addition of the thoracic perimeter (PERIM) described in Frank et. al., (2011b).

- PERIMc - experimental data, complete flock
- PERIMo - observational data
- TMDv: See Division 1.1
- TMDvo: See Division 1.1
- MDA, MDF, MDI, MDC and MDG: See Division 1.2
- MDAvo, MDFvo, MDIvo, MDCvo and MDGvo: See Division 1.1

What for experimental data is the age class in years, for observational data is the age category. Both variables can be taken as equivalent. The only difference is the way of defining the animal age, which is based on a birth register on the one hand, and on the gaping and dental check on the other hand (see Division 1.1).

The thoracic perimeter of the experimental flock of the lama breeder of the Piedra del Agua Ranch (PERIMc) was not measured year after year, but only once, in January 2019. And it was not measured only for the 20 animals with annual follow-up, but for the complete flock of the establishment, which is why a "c" is added at the end of this variable.

2. Dehairing effect on llama fibre structure

The materials used for the industrial dehairing trials were 16 llama fleeces obtained from the shearing of breeding animals from an establishment in Tres Arroyos, Province of Buenos Aires. Two of the 16 fleeces belonged to the DC fleece type, 6 to the IC one, 6 to the SC one and 2 to the L fleece type. The availability of fleeces was limited to the ones the establishment could provide, so only one fleece of type L could be provided and also one

HL fleece type was used to represent the lustre fleeces, which is supported by the similarity of HL and L described in Frank et al. (2019a). Of each fleece type, half had an annual shearing gap and the other half had a biannual shearing gap. Some of the fleeces had felted parts, which were discarded and were not used for the trial.

In this sub-chapter, the taken and analysed samples belong to the fibre which was passing the dehairing process, thus the dehairing effect on the llama fleece structure is verified. Fibre samples were taken after each step of the textile process, that is to say, the resulting product from the Fearnaught was sampled, the dehairing product after each pass through the AM2 as well as the subproduct.

For the sampling, the grid method was used on the extended fibre, obtaining a staple from different sites until the sample was complete, 30 g in total. The grid consists of a plastic object and is shaped like a net, with holes sized approximately 3 cm by 7 cm. Its function is to help during sampling in order to take the sample in a balanced way from different parts of the complete fibre.

The essential aspect to determine is how the dehairing product is modified after each pass and how many passes are needed to achieve a product of the desired quality. At the same time, it is necessary to verify how many passes are indicated to achieve a satisfactory removal of objectionable fibres (Frank et al., 2009; Idem, 2018).

The method used for the dehairing trial was implemented in the framework of the existing industry in Argentina and it was carried out with an industrial dehairing machine. The process of the fleeces was carried out in the dehairing plant of the textile entrepreneur *Lic.* Diego G. Seghetti Frondizi. This plant is belonging to the SUPPRAD Programme and is equipped with machines for industrial dehairing of animal fibre using AM2 technology (Seghetti Frondizi, 2014).

Each fleece was processed separately. During the trial, the fibre was processed without being pre-washed and was prepared in the same way as commonly done on a daily basis in the plant. First, it is passed through the Fearnaught, which is a process implemented at the beginning of the textile chain and which has the function of opening up the matted and felted parts of a fleece. Therefore, the Fearnaught is also referred to as an "opener". The parts of a fleece that were so matted that they could not be disentangled after the pass through the Fearnaught were set aside and were not dehaired. The fibre was then humidified for at least 24 hours before being processed in the AM2. During dehairing, an antistatic product was applied to the fibre and a certain humidity was maintained in the air to improve the dehairing process.

The pass named "0" (zero) corresponds to the pass through the Fearnaught, that is to say, the fleece before being dehaired. In order to achieve a complete dehairing, several passes are made through the dehairing machine. The first pass is numbered '1' and the successive passes are numbered '2', '3' and so on. The dehairing trial includes 10 passes altogether, where the product of each pass is the raw material for the next pass. On the other hand, the subproduct of the successive passes was not processed further, as shown in Figure 7.

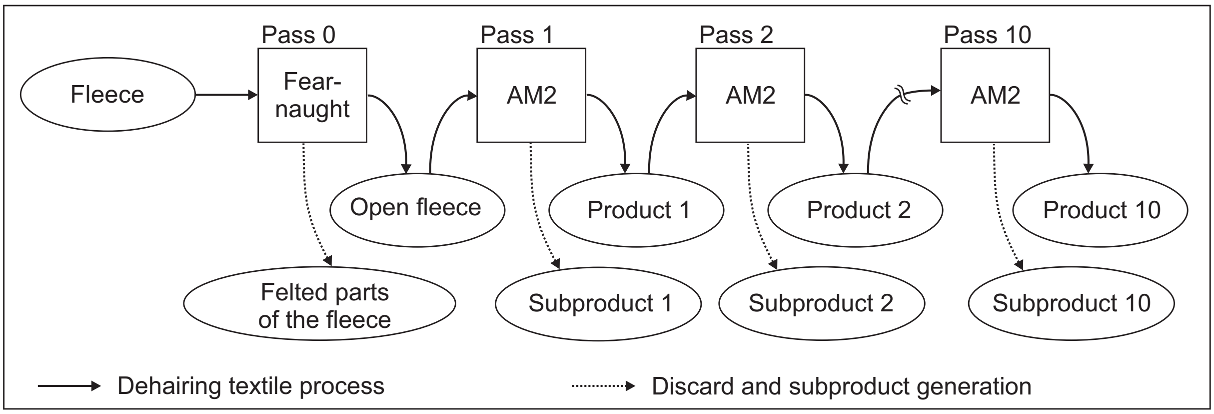


Figure 7: Flow chart of the dehairing trial.

From one pass to the next one, the fibre was left to stand for at least 24 hours in the humidification room. Before and after each pass, the product and the subproduct were weighed. The latter includes vegetable matter, soil dust, etc., which are extracted from the product through the dehairing. The so-called machine "sweeping" was also weighed, including the fibre rest remaining in the pipes, through which the fibre is taken to the AM2. After each pass, all three sections (product, subproduct and sweeping) were removed from the machine to ensure that the fibres from the different fleeces were not mixed. Each sample and section were stored in a nylon bag, identifying the fleece and pass number.

The characteristic used to define the yield is the weight of the dehairing product in relation to the weight of the complete fleece (Frank et al., 2009).

The variables of Sub-chapter 2 are identical to those of Sub-chapter 1, that is to say that everything described in the first sub-chapter regarding the variables, the Three Group Dissection and the statistical analysis also apply to the second sub-chapter. To the abbreviated denomination of the variables used, a letter "d" was added at the end of it, which stands for "dehairing" and is used for the product. An "s" is used for the "subproduct". The variables corresponding to the "0" (zero) pass also have a "d" added to them even though they do not represent data for a dehaired product, but are still describing the complete fleece. This follows the logic that the fleece, after being opened in the Fearnaught machine, becomes the raw material for the further process in the AM2, just like the product of each pass through the AM2 becomes the raw material for the next pass. That is why, also in the graphs, the data of the "0" pass is always integrated into the smoothed curve of the product which is identified with the letter "d".

2.1. Total mean diameter and mean diameter according to fibre groups (FGs)

See Division 1.1.

For the dehairing evaluation (Table 3), regarding the reduction of objectionable fibre percentage (W%1, W%2, W%3 or N%1, N%2, N%3) per pass, it was fitted to a polynomial square regression model, as used in Frank et al. (2018). Furthermore, with this square regression model, it is obtained the number of passes (1 to 10) for which the variable (W% and N%) has its minimum value (for FG2 and FG3) or maximum one (for FG3). This was done by calculating the first derivative of the square function and equalling this derivative to zero:

$$Y = a + b_1X + b_2X^2$$

(*Y* = W%1, W%2, W%3 or N%1, N%2, N%3; *X* = Number of passes through the AM2)

The first derivative was calculated as follows:

$$\frac{dY}{dX} = \frac{\lim}{\Delta X \rightarrow 0}\left(\mathbf{b}_1 + 2\mathbf{b}_2 X + \mathbf{b}_2 \Delta X\right) = \mathbf{b} + 2\mathbf{b}\mathrm{X}$$

$$\text{if } \mathbf{b}_1 + 2\mathbf{b}_2 = \mathbf{0}$$

$$\textit{then}: \quad X = \frac{\mathbf{b}_1}{2\mathbf{b}_2}$$

The value of the variable *Y* (W%) is calculated for the given pass that will have the minimum/maximum value of W%. And with the regression function corresponding to that pass, the minimum value of W% that can be obtained is calculated (Stewart, 2012). This function derivation is recommended for the case of doses or time series (Di Rienzo, 2015) and it had been used to determine the number of passes in cashmere fibre dehairing (Frank et al., 2018).

Since for FG1 and FG2, b_1 is negative, but b_2 is positive, this value is a maximum and, therefore, by replacing in the equation the value of *X* generated by the derivative=0 and rounding up (e.g., 5.56~6), the magnitude of that value (*Y*) can be established, when *X* being at its maximum. In the case of FG3, b_1 is positive and b_2 is negative and that is why it is a minimum value. This mathematical function allows extrapolating the value even when the derivative places the minimum/maximum values outside the real range of values of *X*, but care must be taken that the square figure is not too far from zero (Di Rienzo, 2015).

2.2. Mean diameter according to fibre type

See Division 1.2.

2.3. Crimp frequency

See Division 1.3.

2.4. Crimp group

See Division 1.4.

2.5. Fibre length

See Division 1.5.

3. Effect of classing and of dehairing on fibre textile quality

The logic of the graphs in Sub-chapter 3 changes in relation to the first two sub-chapters because the studied variables move from the Y-axis to the X-axis in the graphs. In the X-axis, the animal age is not differentiated, but the distribution of the samples is differentiated according to ranges of each variable. The Y-axis shows the percentage of samples within each range. Thereby, the fleece structure is displayed in an innovative way and different types of mean diameter (MD), crimp frequency (CF), crimp group (CG) and length (L) are investigated.

3.1. Schematic and conceptual description of the FTs

A large, unrecorded number of randomly separated llama fibre samples were used as materials for the schematic and conceptual description of the structure of the fleece types (FTs). This was done, on the one hand, before implementing the Three Group Dissection from the complete staple, especially with regard to the typical shape it shows. On the other hand, it was done during the implementation of the Dissection by observing the particularities of the fibres of each fibre group.

The method used is visual examination, through which typical characteristics of the different fibres were detected as well as of the staples of the different fleece types. Based on what was observed, a schematization and conceptualisation of the typical staples were carried out, highlighting specific differences. In addition, certain characteristics of the fibres and/or the fleece as opposites were described.

3.2. FT differentiation according to opposite characteristics

See Division 3.1.

3.3. Crimp frequency according to FT

The materials used for Divisions 3.3 to 3.9 are samples that were stored in the Fibre Laboratory and they are part of the observational database mentioned in the first sub-chapter. A total of 252 samples were selected out of a total of more than 2000, only fibre samples from young animals in the age categories of 1, 2 and 3 years. Among the 252 samples included in the analysis, 101 samples belong to the DC fleece type; 50, to the IC fleece type; 19, to the SC fleece type; 46, to the HL fleece type, and 36, to the L fleece type. The total number of samples was limited by the existing database in the Laboratory and cannot represent the whole llama population, but it does represent, in a valid way, a possible fibre lot.

The methods described in Sub-chapter 1 regarding the variables, the fleece types, the Three Group Dissection as well as the statistical analysis also apply to Sub-chapter 3. In order to differentiate the abbreviated denomination of the variables used, a letter "e" was added at the end of it. The letter "e" was chosen, for “estructura”, which means “structure” in Spanish, because the third sub-chapter is especially dedicated to describing llama fleece structure and highlighting differences according to the fleece types.

What was said in Division 1.3 about Crimp Frequency (CF) also applies here. The graphs related to CF were made with the three main fleece types, that is to say, DC, SC and L. Within these fleece types, fleeces of all diameters, coarse as well as fine, were included. The range established for the CF analysis is 1 crimp/cm. The CF for each FG is calculated as an average of the measured CF of three randomly separated fibres.

3.4. Crimp groups according to FT

What was said in Division 1.4 about Crimp Groups (CGs) also applies here. The graphs related to the CGs were made with the three main fleece types, that is to say, DC, SC and L, what means that the graphs do not include data about IC and HL fleeces. Within these fleece types, fleeces of all diameters, coarse as well as fine, were included.

3.5. Fibre length according to FT

What was said in Division 1.5 about fibre length (L) also applies here. For the graph related to fibre length, all fleece types were included and ranges of 2 cm were established. The fibre length for each FG is calculated as an average of the measured lengths of three randomly separated fibres.

3.6. Mean diameter according to FT

What was said in Division 1.1 about MD1, MD2 MD3 also applies here. Likewise, what was specified in Sub-chapter 1 about the statistical analysis and Kruskal–Wallis test use is also applied.

3.7. Mean diameter according to FT with and without classing and/or dehairing

What was said in Division 1.1 about MD3 also applies here. Likewise, what was specified in Sub-chapter 1 about the statistical analysis and Kruskal–Wallis test use is also applied.

As mentioned above, only samples from animals up to three years old were included in the analysis described in Sub-chapter 3. So, this implemented method implies a simulation of a basic field classing in favour of fleeces with a higher probability of being fine. Furthermore, due to the fact that the sampling area is located on the animal's flank, a fibre classing regarding body sites is simulated, in which claws and other coarse fibre parts are removed during or after shearing (Frank et al., 2007b).

However, apart from what was mentioned in the previous paragraph, the fleeces did not go through a classing as such, that is to say, the fleeces are not evaluated fleece by fleece in order to separate them according to their fineness. This type of classing was simulated by evaluating the data through successive separation of the fleeces according to their coarseness. The initial classing is simulated by excluding 26% of the fleeces from the analysis, including only fleeces with an TMD<31µm in the analysis. A second, slightly more rigorous classing was simulated by including only fleeces with an TMD<28µm, which meant excluding 50% of the fibre samples from the analysis.

Through the use of the Three Group Dissection, fine and coarse fibres are allocated to different FGs. In that way, a dehairing process is simulated and therefore yields on the dehairing can be calculated as well as changes related to fibre characteristics among the complete fleece on the one hand, and between the product and subproduct on the other hand. As a general rule, it can be said that FG3 is equivalent to the dehairing product and the FG1 to the subproduct, while FG2 takes an intermediate position. As an approximate value, one can take FG3 as a reference for the yield of dehairing. This means that the yield mentioned here is not the result of a dehairing process, but it is a value that is calculated from the results of the Three Group Dissection and can only be taken as a reference value.

The characteristic used to define the yield is the weight of FG3 in relation to the weight of the complete staple that was dissected (Frank et al., 2009).

3.8. Mean diameter with/without classing and/or dehairing

What is described in Division 1.1 about TMDn, MD1, MD2 and MD3 also applies here, likewise what is said in the first sub-chapter about statistical analysis and the use of the Kruskal-Wallis test. In addition, what is described in Division 3.7 regarding the simulation of classing and dehairing also applies to this division.

For the production of the MD related graphs, 3 µm ranges were established to create a histogram of fibre diameters and thus show the distribution of mean diameters. Table 1 shows that, according to the fineness ranges defined in Frank (2001), the range called "23.5 µm" corresponds to fine fibres; the range called "20.5 µm", to superfine fibres, and the fibres in the range "<19 µm" correspond to ultrafine (Baby) ones. For the production of the graph related to MD, all fleece types were included.

Table 1: Mean fibre diameter (MD) ranges.

Ranges used in this thesis		**Ranges used in Frank (2001)**	
MD ranges (µm)	Name	MD ranges (µm)	Name
16.00 – 18.99	< 19	< 19	Ultrafine (Baby)
19.00 – 21.99	20.5	19 – 21.9	Superfine
22.00 – 24.99	23.5	22 – 24.9	Fine
25.00 – 27.99	26.5	25 – 29.9	Medium
28.00 – 30.99	29.5	25 – 29.9 / > 30	Medium / Coarse
31.00 – 33.99	32.5	> 30	Coarse
Successive ranges from 34.00 to 69.99	Successive ranges from 35.5 to 68.5	> 30	Coarse
>= 70.00	>= 70	> 30	Coarse

(MD: Mean fibre diameter)

3.9. Classing and dehairing potential

What is described in Division 1.1 about TMDn, MD1, MD2 and MD3 also applies here, likewise what is said in the first sub-chapter about statistical analysis and the use of the Kruskal-Wallis test. In addition, what is described in Division 3.7 regarding the simulation of classing and dehairing also applies to this division.

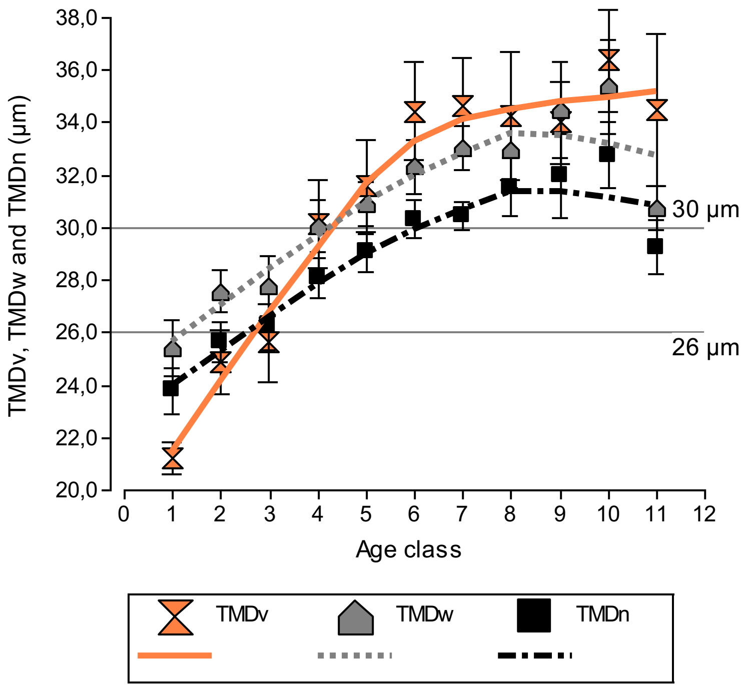
CHAPTER IV. RESULTS

1. Age effect on llama fleece structure

1.1. Total mean diameter and mean diameter according to fibre groups (FGs)

Figure 8 shows that the total mean diameter (TMD) is low for young animals and changes as age increases; the older the animal is, the higher the TMD becomes. The TMD reaches the threshold of 30 µm at age class 4, but it still continues increasing until age 5, according to the Kruskal Wallis (KW) test results.

The smoothed curves in Figure 8 could not be fitted to a linear function, but they show a curvilinear behaviour. When fitting TMDv to a second-degree polynomial (R^2=0.30), its first derivative equalled to zero gives a maximum of 8.8 years, and those ones regarding TMDw and TMDn, a maximum of 10.0 and 10.3 respectively. However, for the variable TMDv, the maximum level of significant difference in diameter with respect to age class 1 (KW) is already reached in age class 5, and for variables TMDn and TMDw, in age class 6. This shows a clear relationship with the animal's growth, which is represented by the thoracic perimeter (PERIMc and PERIMo). Figures 9 and 10 show the high correlation between PERIM and TMDv which exist for both experimental and observational animal flocks.

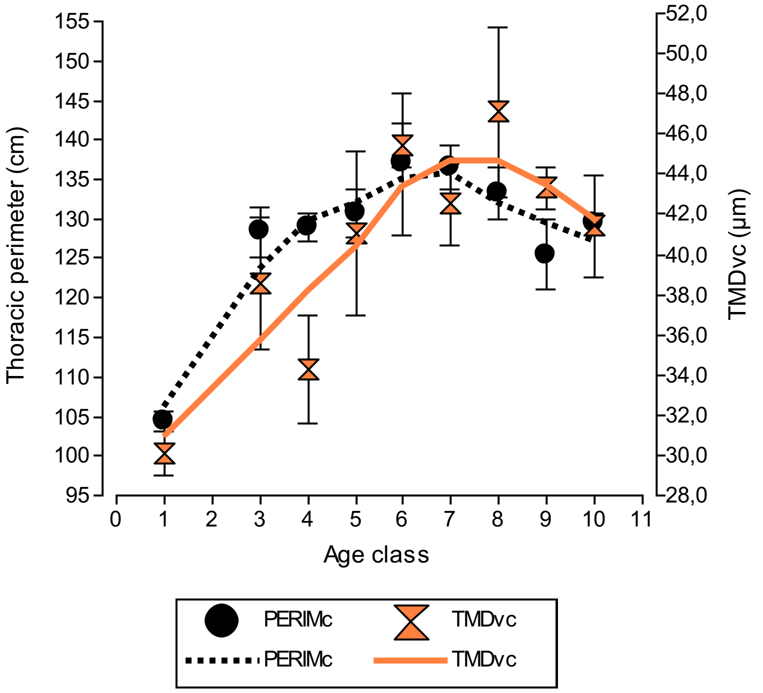


	1	2	3	4	5	6	7	8	9	10	11
TMDv:					D	D	D	D	D	D	D
				C	C	C	C	C	C		C
			B	B							
	A	A	A								
TMDp:						E	E	E	E	E	E
					D	D	D	D	D		D
				C	C	C		C			C
		B	B	B	B						B
	A	A	A								
TMDn:						E	E	E	E	E	E
					D	D	D	D	D		D
				C	C	C					C
		B	B	B	B						B
	A	A	A								
Age class:	1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

TMD: Total mean diameter.
TMDv: TMD measured for a sample, which was taken from a fleece, experimental data.
TMDw: TMD weighted by the weight of the 3 FGs.
TMDn: TMD weighted by the fibre frequency of the 3 FGs.

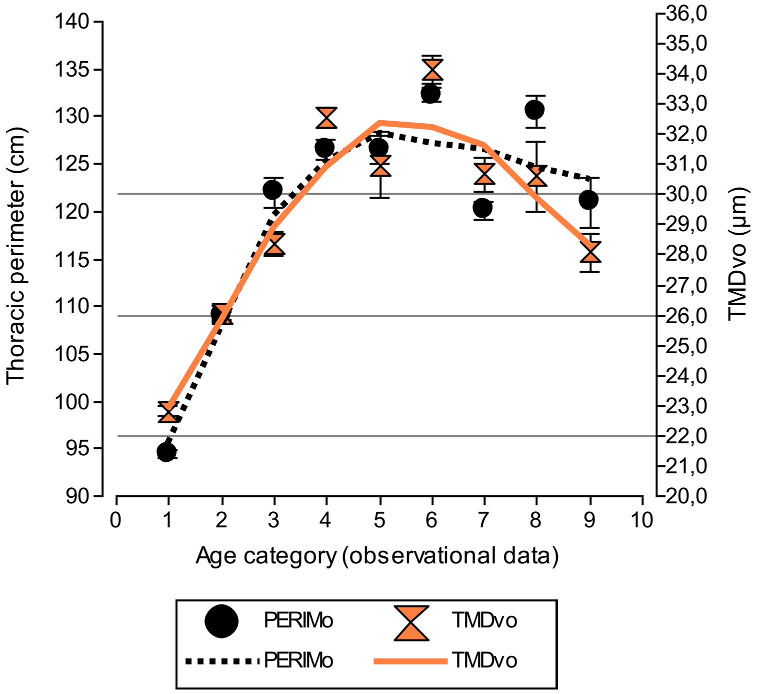
Figure 8: Modification of TMDv, TMDw and TMDn regarding age class. (Experimental animals)



PERIMc: Thoracic perimeter measured for the complete experimental flock.

TMDvc: Total MD measured for a sample, which was taken from a fleece, measured for the complete experimental flock.

Figure 9: Modification of thoracic perimeter (PERIMc) and total mean diameter (TMDvc) regarding age class. (Experimental Animals)

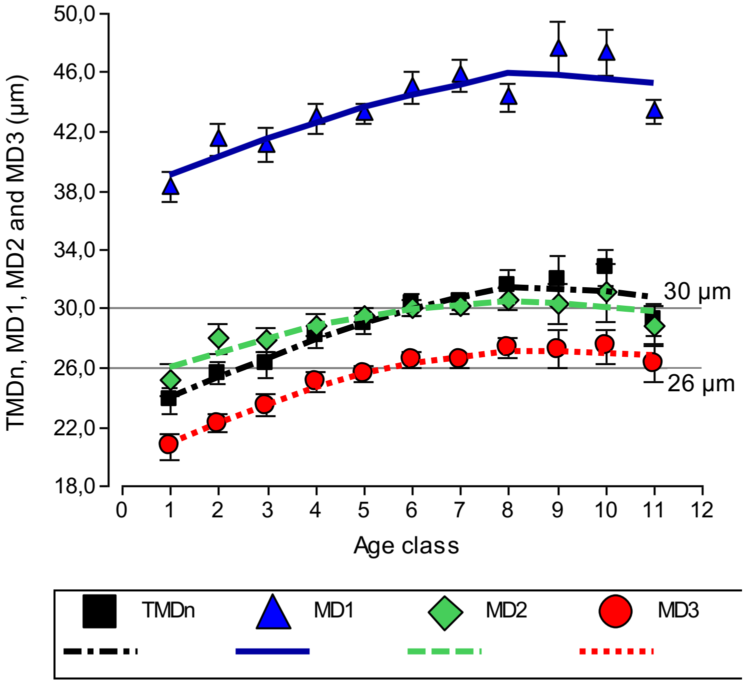


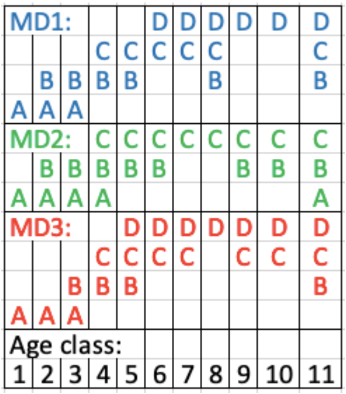
PERIMo: Thoracic perimeter, observational data.

TMDvo: Total MD measured for a sample which was taken from a fleece, observational data.

Figure 10: Modification of thoracic perimeter (PERIMo) and total mean diameter (TMDvo) regarding age category. (Observational animals)

The TMD chosen to be repeated in Figure 11 is the TMDn as it is a MD weighted by fibre frequency or number (Equation 3), just like the MDs of the three FGs (MD1, MD2 and MD3, Equation 4). MD1, MD2 and MD3 are implicitly included in TMDn (Equation 3) and Figure 11 shows how the TMDn can be broken down into these three MDs. The coarse fibres (MD1) are considerably coarser than the fine or intermediate fibres, but, as they have a lower frequency, they do not influence TMDn as much. Each FG separately shows the curvilinear path, starting with low values and tending to increase in value as the age increases until it stabilises, and, then, decreases. In the case of TMDvo, the MD starts decreasing in age classes 6-7 (Figure 26, observational data) and for the MDs of experimental data in older age classes, but with the same tendency to decrease as age increases. The MD2 and MD3 curves fitted to a second-degree polynomial (R^2=0.16 and 0.35) have their maximum at 8.1 and 8.7 years respectively, while the MD1 curve (R^2=0.22) has its maximum only at 10.0 years.





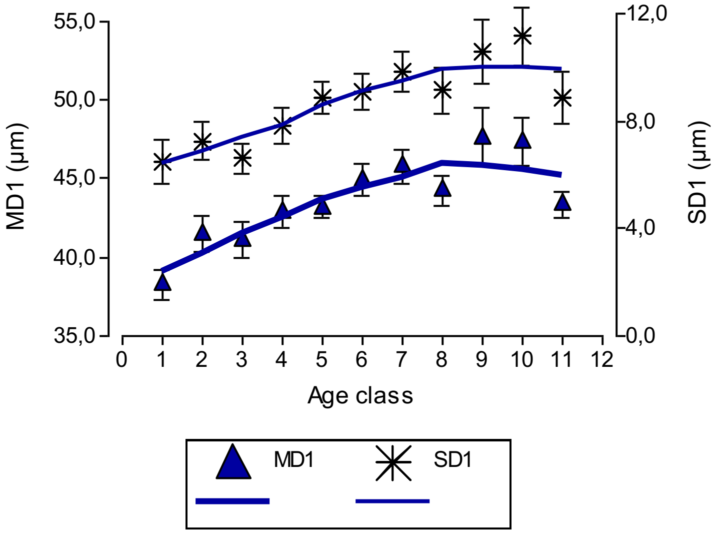
MD1:					D	D	D	D	D	D
			C	C	C	C	C			C
	B	B	B	B			B			B
A	A	A								
MD2:			C	C	C	C	C	C	C	C
	B	B	B	B	B			B	B	B
A	A	A	A							A
MD3:				D	D	D	D	D	D	D
			C	C	C	C		C	C	C
		B	B	B						B
A	A	A								
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05)

FG: Fibre group.
MD: Mean fibre diameter.
TMDn: Total MD weighted by the fibre frequency of the 3 FGs.
MD1: MD of FG1.
MD2: MD of FG2.
MD3: MD of FG3.

Figure 11: Modification of MD, according to FG, and TMDn regarding age class. (Experimental animals)

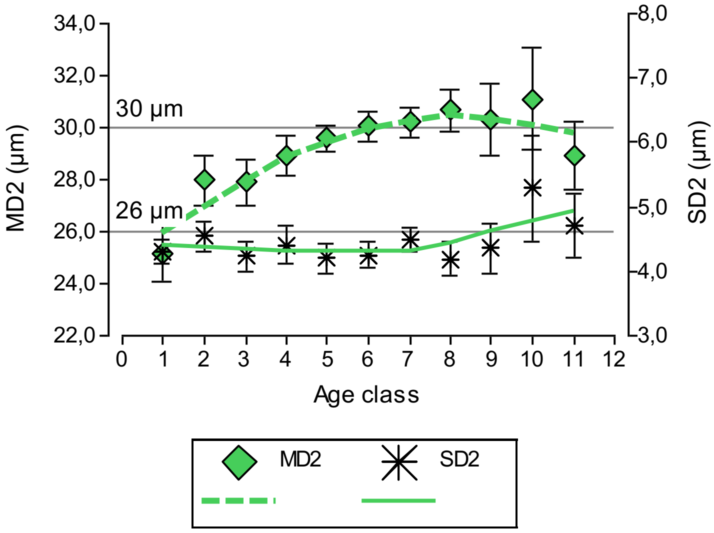
Each Figure from 12 to 14 repeats one of the three curves in Figure 11 and, with a Y-axis to the right, also plots the standard deviation of the diameter of each FG (SD1, SD2 and SD3). The MD and SD of the 3 FGs were plotted regarding the age to show that the SD increases as the MD increases, which is less noticeable for MD2.



Left Y-axis: MD1
Right Y-axis: SD1

MD: Mean fibre diameter.
SD: Standard deviation.
MD2: MD of FG2.
SD2: SD of MD of FG2.

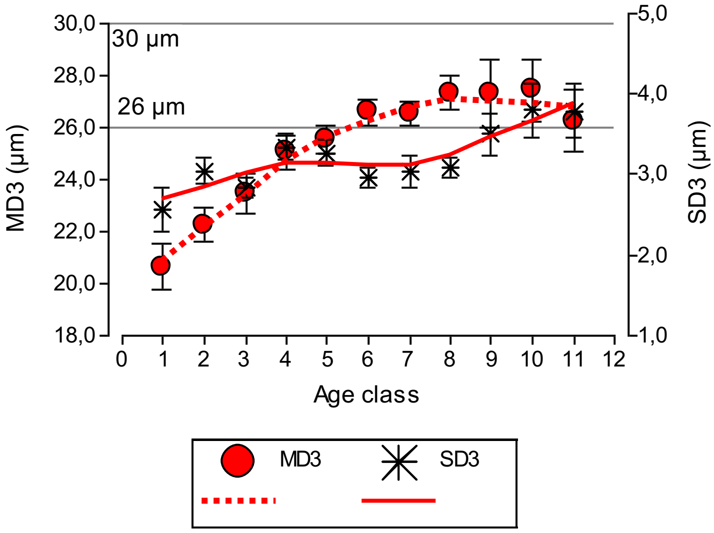
Figure 12: Modification of MD1 and SD1 regarding age class, for FG1. (Experimental animals)



Left Y-axis: MD2
Right Y-axis: SD2

MD: Mean fibre diameter.
SD: Standard deviation.
MD2: MD of FG2.
SD2: SD of MD of FG2.

Figure 13: Modification of MD2 and SD2 regarding age class, for FG2. (Experimental animals)

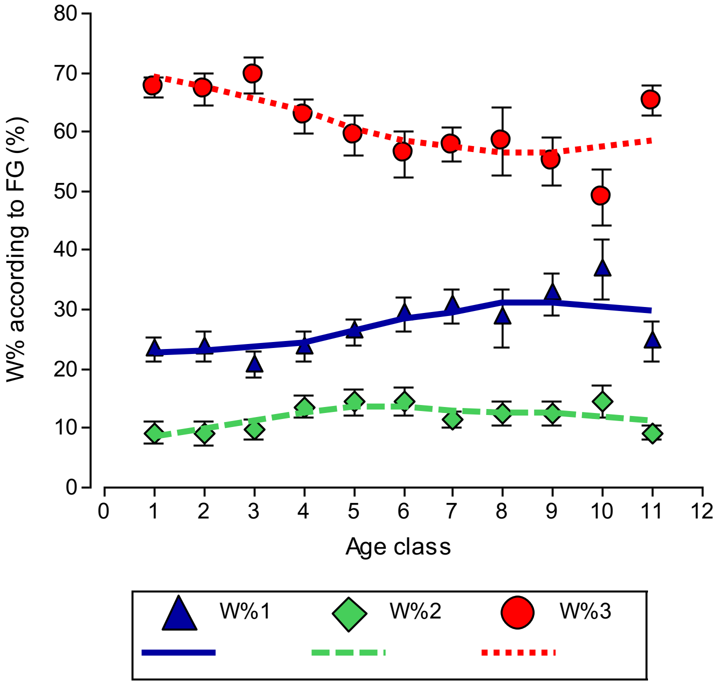


Left Y-axis: MD3
Right Y-axis: SD3

MD: Mean fibre diameter.
SD: Standard deviation.
MD3: MD of FG3.
SD3: SD of MD of FG3.

Figure 14: Modification of MD3 and SD3 regarding age class, for FG3. (Experimental animals)

It is important to highlight that MD1 is very high from age class 1 on (Figure 12) and that, at the same time, MD3 shows low values, that is to say, interesting values regarding its textile quality, especially during the first age classes (Figure 14).



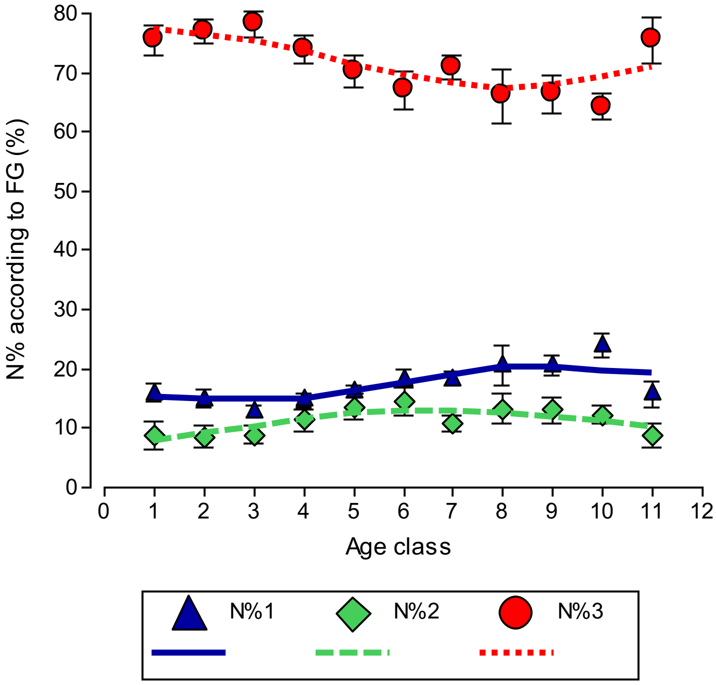
W%3:										
A	A	A	A	A			A			A
B			B	B	B	B	B			B
			C	C	C	C	C	C	C	C
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

Not significant for W%1 and W%2 (w>0.05).

FG: Fibre group.
W%1: Relative weight of FG1.
W%2: Relative weight of FG2.
W%3: Relative weight of FG3.

Figure 15: Modification of relative weight regarding age class, according to FG. (Experimental animals)



N%3:										
A	A	A	A							A
B	B		B	B		B				B
C			C	C	C	C	C	C		C
			D	D	D	D	D	D	D	D
N%1:										
D				D	D	D	D	D	D	D
C			C	C	C	C	C			C
B	B		B	B	B		B			B
A	A	A	A							A
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

Not significant for N%2 (w>0.05).

FG: Fibre group.
N%1: Relative fibre frequency of FG1.
N%2: Relative fibre frequency of FG2.
N%3: Relative fibre frequency of FG3.

Figure 16: Modification of relative fibre frequency regarding age class, according to FG. (Experimental animals)

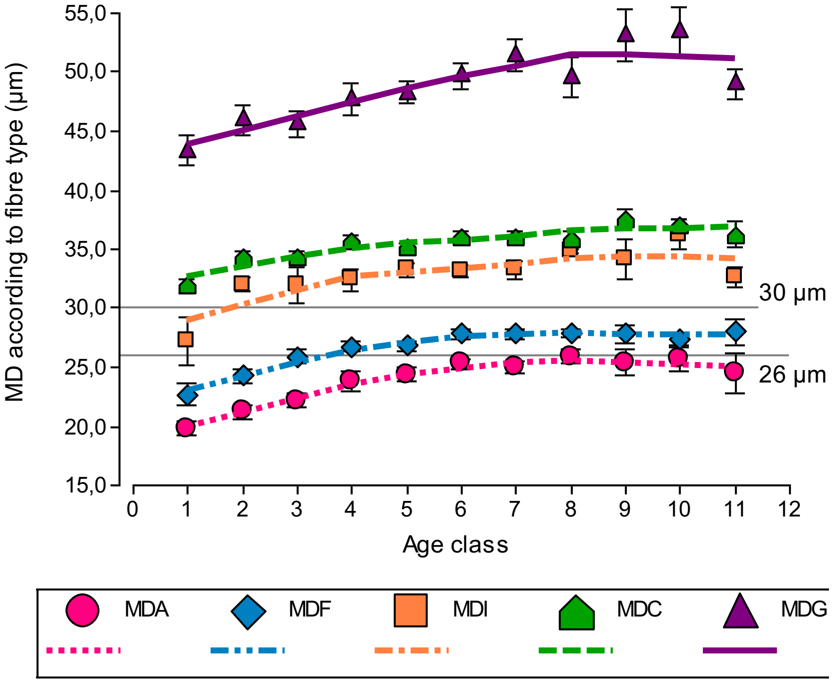
Figure 15 and Figure 16 plot the relative weight of each FG (W%1, W%2 and W%3), and the relative fibre frequency of each FG (N%1, N%2 and N%3). As well as the MD of each FG (MD1, MD2 and MD3), these variables are also used to calculate TMDw and TMDn (Equations 2 and 3). In order to understand the fleece structure, it is important to learn what the characteristics of the fibres forming a staple are like. For example, in Figure 15 case, the complete staple is represented by the set of 3 data of the same age class, that is to say, one datum from each of the 3 curves, as shown in Figure 19 (central part) regarding the example of age class 1. In this way, the fleece structure is shown by the prevalence of fibres according to the different FGs, that is to say, to different fineness.

According to the curves in Figures 15 and 16, within the llama fleece, there is a high prevalence of fine fibres (W%3 and N%3), which confirms a high yield potential at dehairing. These curves also show the age effect on the fleece structure and the trend that the percentage of fine fibres (W%3 and N%3) decreases with age while the coarse fibre percentage (W%1 and N%1) increases. But the comparison using the KW test is not significant for W%2 ($w>0.05$) and does not show a logical trend for W%1 nor for W%3. Furthermore, a low presence of intermediate fibres (W%2 and N%2) can be observed, which means that fine fibres (FG3) and coarse fibres (FG1) are the ones that actually define the fleece structure and are the most important fibre groups. This is reflected in the schematization of Figure 46, in which only the fine and coarse fibres are drawn.

1.2. Mean diameter according to fibre type

In Division 1.1, it was shown how the mean total diameter (TMD), in that case TMDn, can be broken down into the MDs (MD1, MD2 and MD3) of the 3 FGs resulting from the Three Group Dissection. Another way to break down the TMD is by means of the 5 groups that are based on the 5 fibre types defined through their respective medulla types (A, F, I, C and G) (Figure 17). This is another way of illustrating the llama fleece structure. The curves show a curvilinear behaviour, that is to say, the same trend with respect to the modification regarding the increasing age as the MD previously described. The MDA, MDF and MDI curves fitted to a second-degree polynomial ($R^2=0.33$, 0.38 and 0.25) have their maximum at 8.5, 7.6 and 8.8 years respectively, while the MDC and MDG curves ($R^2=0.25$ and 0.20) have their maximum just at 10.2 and 12.8 years.

By means of the analysis according to medulla type, the MD evaluation moves from the level of the three FGs, which are determined by macroscopic fibre characteristics, to a level defined by a microscopic characteristic such as the medulla type. The MD according to medulla type is measured for each FG separately (e.g., MDA1, MDA2 and MDA3 for non-medullated fibres) and the variable representing the whole staple is calculated by means of Equation 5 (Figure 5).

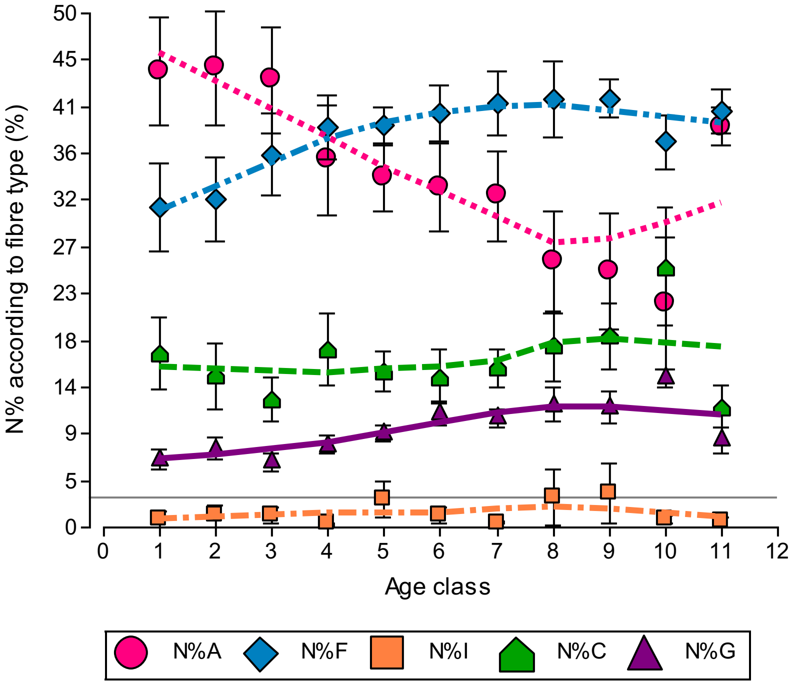


MDG:				C	C	C	C	C	C	C
	B	B	B	B	B		B			B
A	A	A								
MDC:			C		C	C	C	C	C	C
	B	B	B	B	B	B	B			B
A	A									
MDI:			C	C	C	C	C	C	C	C
	B	B	B	B	B	B		B		B
A	A	A	A							A
MDF:			C	C	C	C	C	C	C	C
		B	B	B	B	B		B	B	B
A	A									
MDA:				D	D	D	D	D	D	D
			C	C	C	C		C	C	C
		B	B	B						B
A	A	A								
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

MDA: MD of non-medullated fibres.
MDF: MD of fragmented medullated fibres.
MDI: MD of interrupted medullated fibres.
MDC: MD of continuous medullated fibres.
MDG: MD of large medullated fibres.

Figure 17: Modification of MD regarding age class, according to fibre type.
(Experimental animals)



N%A:										
A	A	A	A	A	A	A				A
B			B	B	B	B	B			B
			C	C	C	C	C	C	C	C
N%F:			Not significant							
N%C:			Not significant							
N%G:							E	E	E	
				D	D	D	D	D		D
			C	C	C	C	C			C
B	B		B	B						B
A	A	A	A							A
N%I:			Not significant							
Age class:										
1	2	3	4	5	6	7	8	9	10	11

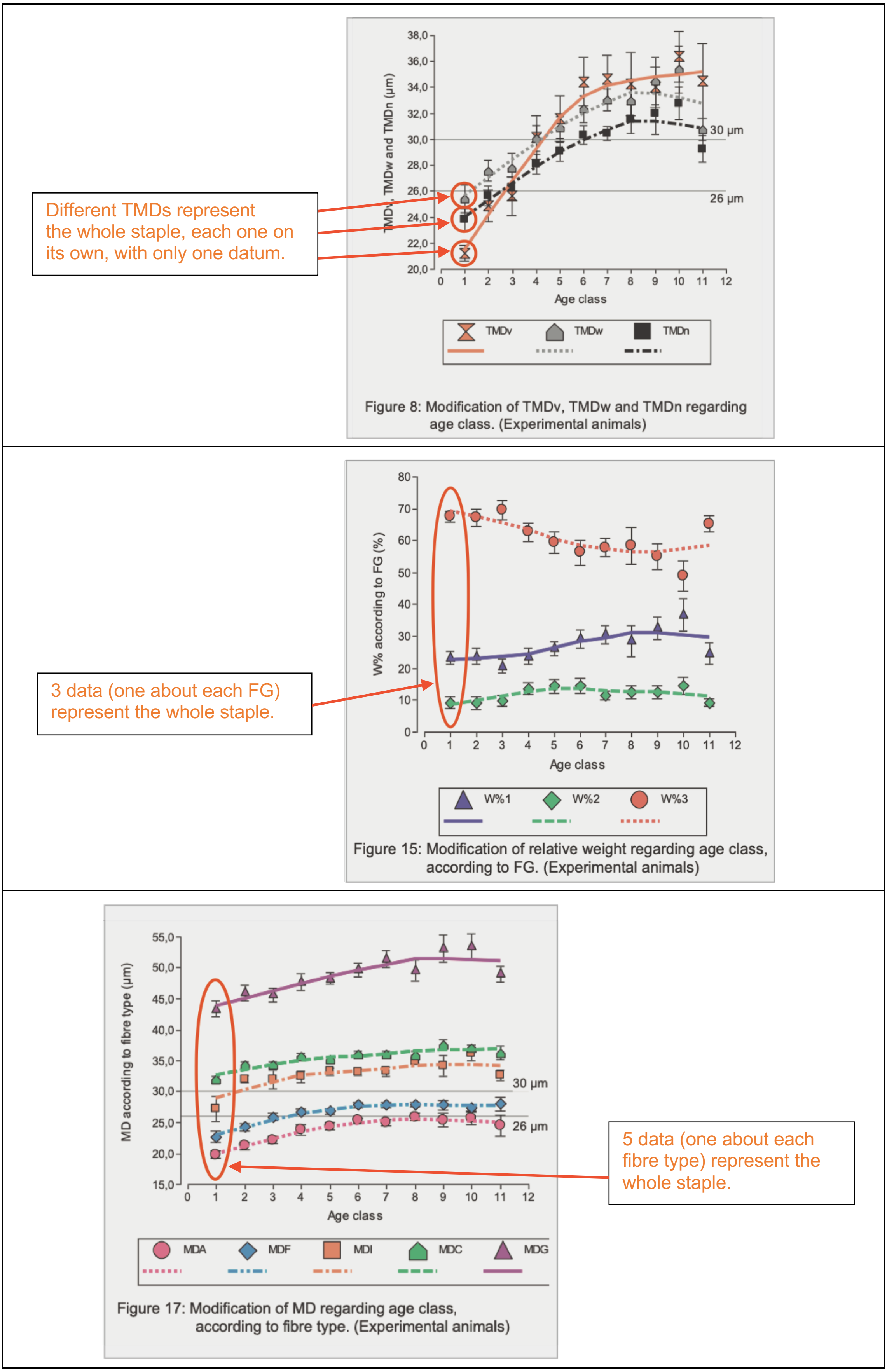
Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
N%A: N% of non-medullated fibres.
N%F: N% of fragmented medullated fibres.
N%I: N% of interrupted medullated fibres.
N%C: N% of continuous medullated fibres.
N%G: N% of large medullated fibres.

Figure 18: Modification of N% regarding age class, according to fibre type.
(Experimental animals)

Figures 17 and 18 show the whole staple in a single graph, that is to say, the set of 5 data from the same age class represents a whole staple, as shown in Figure 19 (see below). However, Figures 21 and 22 show the whole staple in a sequence of 3 graphs, that is to say that the set of all data about all 3 FGs of the same age class describes the whole staple, as explained in Figure 20. This means that information about each of the 3 FGs is revealed separately and this allows a graphical comparison between the FGs. The 5 medulla types represent 5 subgroups within each of the 3 FGs formed by means of the Three Group Dissection, that is to say, information about the age effect is detailed and completed in a differentiated way as per each FG.

Figures 21 and 22 are the ones that best show the llama fleece structure due the fact that they plot the 3 FGs (FG1, FG2 and FG3) separately and, at the same time, they reveal the particulars with respect to the 5 subgroups related to the fibre types (medulla). The variables included in both figures are those arising from the projection microscope method (those variables written in italics in Figure 5). There are 15 MD variables measured on the projection microscope which describe the 3 FGs (FG1, FG2 and FG3), on the one hand, and the 5 fibre types (A, F, I, C and G), on the other hand, that is to say, 5 variables by 3 times. At the same time, 15 N% variables arise, also 5 variables by 3 times, which also describe the 3 FGs (FG1, FG2 and FG3), on one hand, and the 5 fibre types (A, F, I, C and G), on the other hand. These MD variables are plotted in Figure 21 and Figure 22 respectively. They are the least ones to be plotted, but the first ones to be measured. Based on these variables, all other variables related to the MD in the experimental database are weighted, as shown in Figure 5. These variables are not found in the real context of fibre production, but arise exclusively due to the method (Three Group Dissection) that was implemented in this thesis. This method was fundamental to reveal the fleece structure. Also, this method was necessary to acquire a deeper understanding of the llama fleece.

What is most visually striking in Figure 21 is the presence of 2 curves at the top of the graph related to coarse fibres (Figure 21, top, FG1), which shows how this FG is defined by coarse fibres of continuous and large medulla. This is true from age class 1 on and remains true as the animal grows, the only modification being that the increased coarseness becomes even more significant with increasing age. Correspondingly, a gap can be seen at the bottom of this graph as FG1 does not contain any fine fibres. In the same way, it is striking to see the presence of 3 curves in the lower part of the graph related to fine fibres (Figure 21, lower part, FG3), that is to say that FG3 is well defined, mainly by non-medullated fibres and fibres of fragmented medulla, accompanied by a low percentage of continuous medulla fibres. This is also true for older animals. Furthermore, the great variability of the intermediate fibres is well illustrated (Figure 21 and Figure 22, central part, FG2) as well as the resulting lack of definition with respect to what this FG represents.



Different TMDs represent the whole staple, each one on its own, with only one datum.

Figure 8: Modification of TMDv, TMDw and TMDn regarding age class. (Experimental animals)

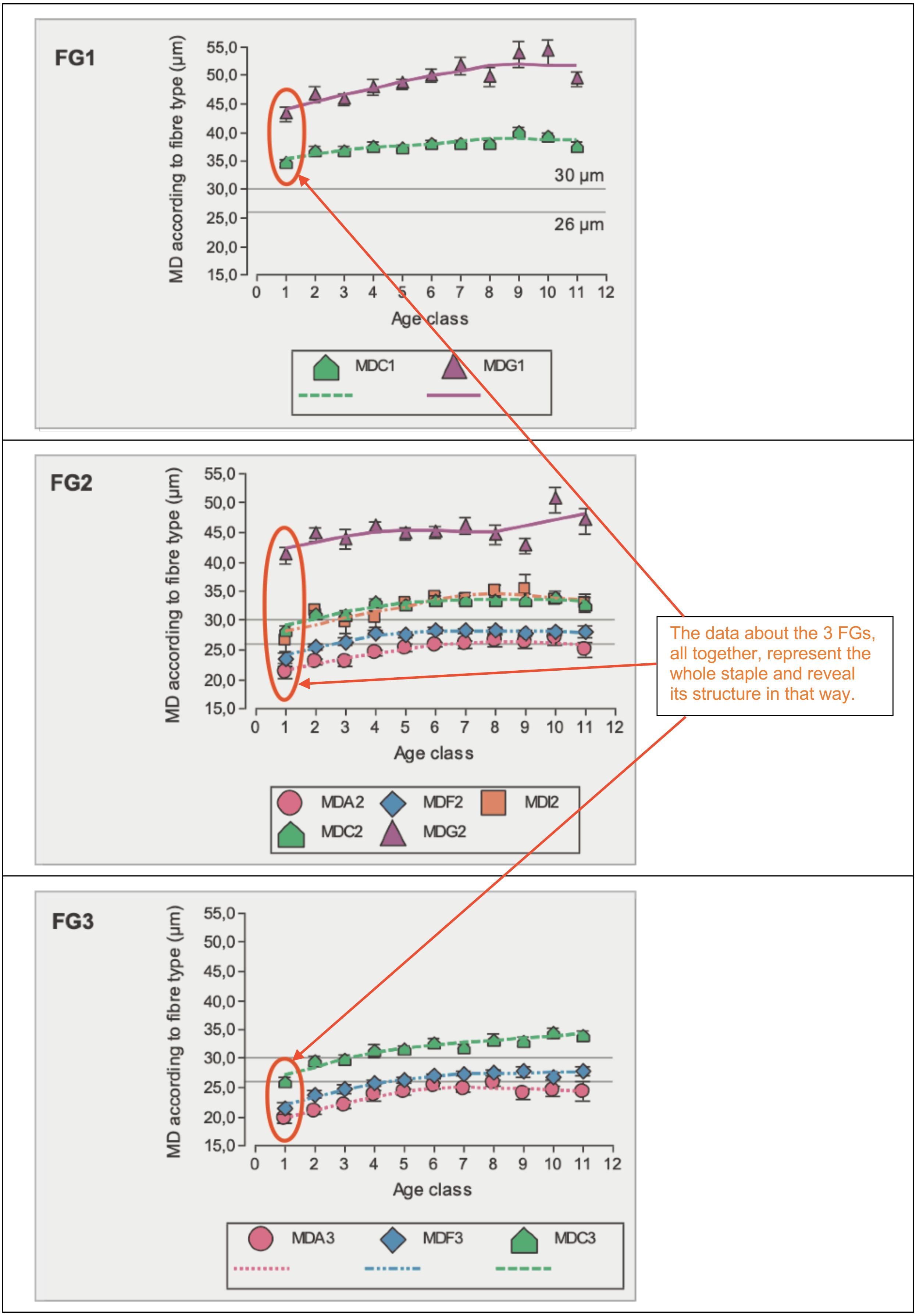
3 data (one about each FG) represent the whole staple.

Figure 15: Modification of relative weight regarding age class, according to FG. (Experimental animals)

Figure 17: Modification of MD regarding age class, according to fibre type. (Experimental animals)

5 data (one about each fibre type) represent the whole staple.

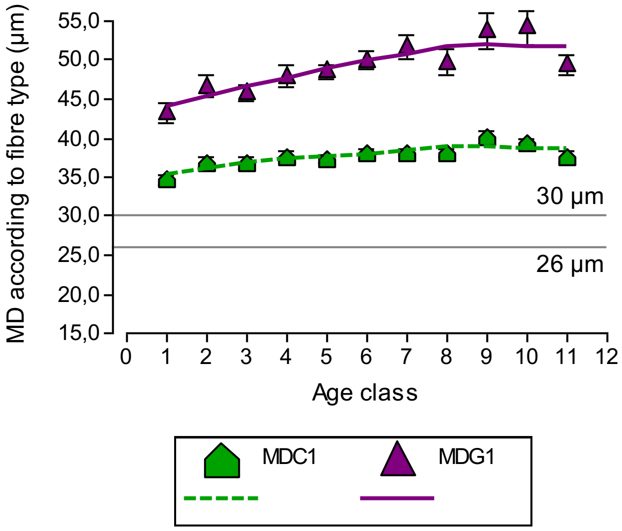
Figure 19: Examples of the amount of data describing a whole staple in different graphs for the case of age class 1.



The data about the 3 FGs, all together, represent the whole staple and reveal its structure in that way.

Figure 20: Example of the amount of data describing a whole staple for the case of age class 1.

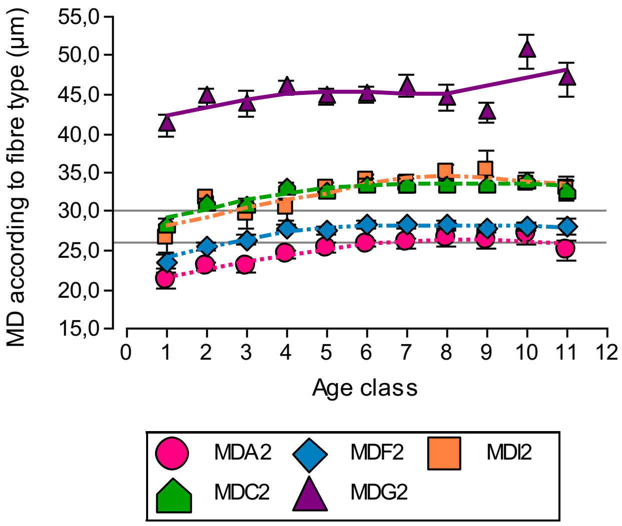
FG1*



MDG1:				D	D	D	D	D	D	D
	C		C	C	C		C			C
	B	B	B	B			B			B
A	A	A								
MDC1:			C		C	C	C	C	C	C
	B	B	B	B	B	B	B			B
A	A	A		A						A
MDI1:			Not significant							
MDF1:			Not significant							
MDA1:			Not significant							
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
* MDA1, MDF1 and MDI1 are not plotted because their frequency is very reduced, as it is shown in Figure 22.

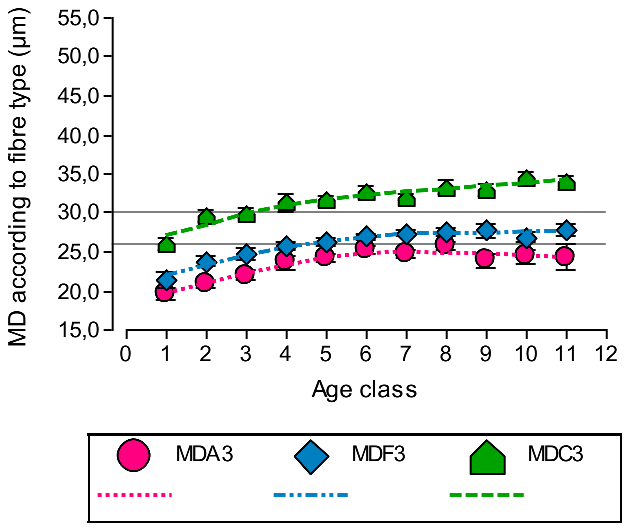
FG2



MDG2:			Not significant							
			C	C	C	C	C	C	C	C
	B	B		B						B
A	A	A								
MDI2:										
	D			D	D	D	D	D	D	D
	C		C	C		C		C	C	C
	B	B	B	B		B			B	B
A	A	A	A							
MDF2:			D	D	D	D	D	D	D	D
		C	C	C				C	C	C
	B	B	B	B						B
A	A	A								
MDA2:			B	B	B	B	B	B	B	B
A	A	A	A							A
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

FG3**



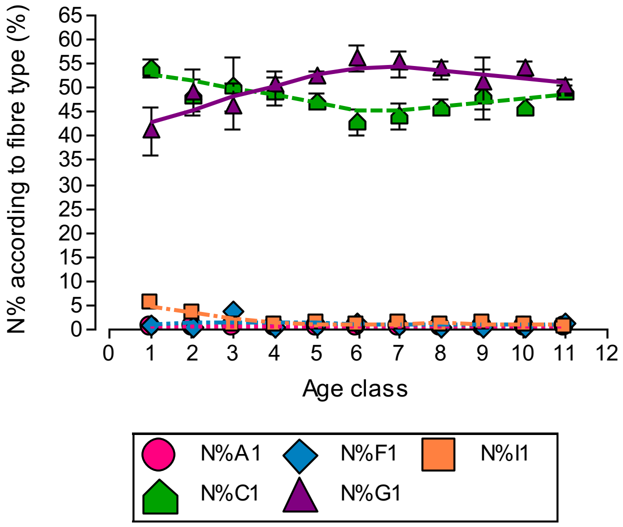
MDG3:			Not significant							
MDC3:					D		D	D	D	D
			C	C	C	C	C	C		C
	B	B	B	B		B				
A	A									
MDI3:			Not significant							
MDF3:			D	D	D	D	D	D	D	D
		C	C	C					C	
	B	B	B							
A	A									
MDA3:				D	D	D	D	D	D	D
			C	C		C		C	C	C
		B	B	B				B		B
A	A	A								
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
** MDI3 and MDG3 are not plotted because their frequency is very reduced, as it is shown in Figure 22.

Abbreviations: See next page.

Figure 21: Modification of MD regarding age class, according to fibre type - plotted for each FG separately. (Experimental animals)

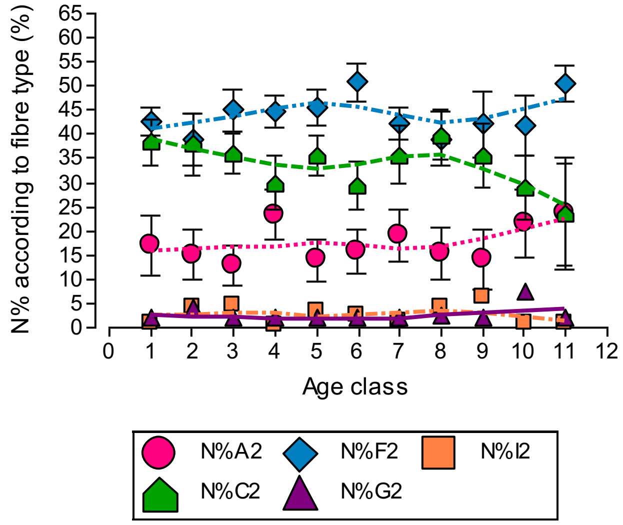
FG1



N%G1:										
	B	B	B	B	B	B	B	B	B	B
A	A	A								A
N%C1:										
A	A	A								A
	B	B	B	B		B	B		B	B
		C	C	C		C	C	C	C	C
			D	D	D	D	D	D	D	D
N%I1:	Not significant									
N%F1:										
B		B		B	B	B		B		B
A	A	A	A	A	A	A	A	A	A	
N%A1:	Not significant									
Age class:										
1	2	3	4	5	6	7	8	9	10	11

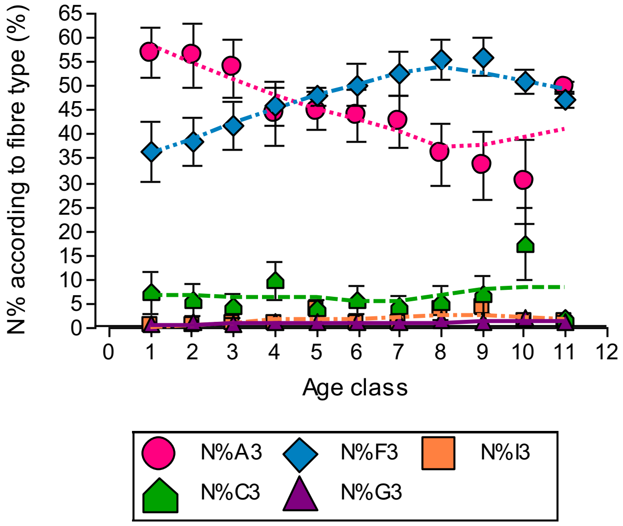
Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

FG2



Kruskal–Wallis test:
Not significant for N%A2, N%F2, N%I2, N%C2 and N%G2
(w>0.05).

FG3



N%G3:										
			B	B	B	B	B	B	B	B
A	A	A	A	A	A	A		A		A
N%C3:	Not significant									
N%I3:	Not significant									
N%F3:	Not significant									
N%A3:	Not significant									
Age class:										
1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05)

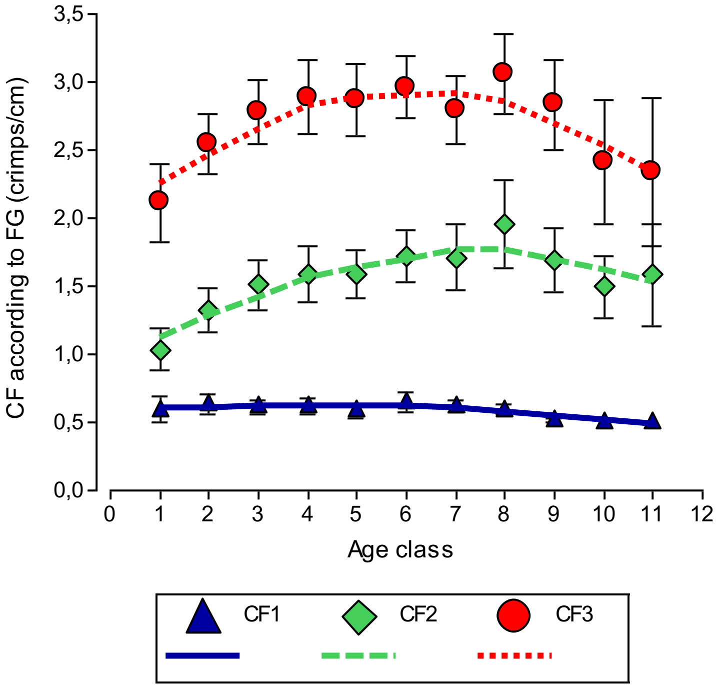
Abbreviations: See next page

Figure 22: Modification of N% regarding age class, according to fibre type - plotted for each FG separately. (Experimental animals)

Abbreviations in Figure 21:	Abbreviations in Figure 22:
MD: Mean fibre diameter	N%: Relative fibre frequency.
MDA1: Non-medullated fibres MD of FG1.	N%A1: Non-medullated fibres N% of FG1.
MDF1: Fragmented medullated fibres MD of FG1.	N%F1: Fragmented medullated fibres N% of FG1.
MDI1: Interrupted medullated fibres MD of FG1.	N%I1: Interrupted medullated fibres N% of FG1.
MDC1: Continuous medullated fibres MD of FG1.	N%C1: Continuous medullated fibres N% of FG1.
MDG1: Large medullated fibres MD of FG1.	N%G1: Large medullated fibres N% of FG1.
MDA2: Non-medullated fibres MD of FG2.	N%A2: Non-medullated fibres N% of FG2.
MDF2: Fragmented medullated fibres MD of FG2.	N%F2: Fragmented medullated fibres N% of FG2.
MDI2: Interrupted medullated fibres MD of FG2.	N%I2: Interrupted medullated fibres N% of FG2.
MDC2: Continuous medullated fibres MD of FG2.	N%C2: Continuous medullated fibres N% of FG2.
MDG2: Large medullated fibres MD of FG2.	N%G2: Large medullated fibres N% of FG2.
MDA3: Non-medullated fibres MD of FG3.	N%A3: Non-medullated fibres N% of FG3.
MDF3: Fragmented medullated fibres MD of FG3.	N%F3: Fragmented medullated fibres N% of FG3.
MDI3: Interrupted medullated fibres MD of FG3.	N%I3: Interrupted medullated fibres N% of FG3.
MDC3: Continuous medullated fibres MD of FG3.	N%C3: Continuous medullated fibres N% of FG3.
MDG3: Large medullated fibres MD of FG3.	N%G3: Large medullated fibres N% of FG3.

1.3. Crimp frequency

Figure 23 shows that the three FGs differ well in relation to their CF, FG1 having the straightest fibres, FG3 having the most crimped fibres and FG2 having intermediate values. The CF of FG1 shows practically no change regarding age, while FG3 shows the greatest change, with an increase in the CF during the first years and a subsequent reduction.



Kruskal–Wallis test:
Not significant
For CF1, CF2 and CF3
(w>0.05).

FG: Fibre group.
CF1: Crimp frequency
of FG1.
CF2: Crimp frequency
of FG2.
CF3: Crimp frequency
of FG3.

Figure 23: Modification of CF regarding age class, according to FG.
(Experimental animals)

1.4. Crimp groups

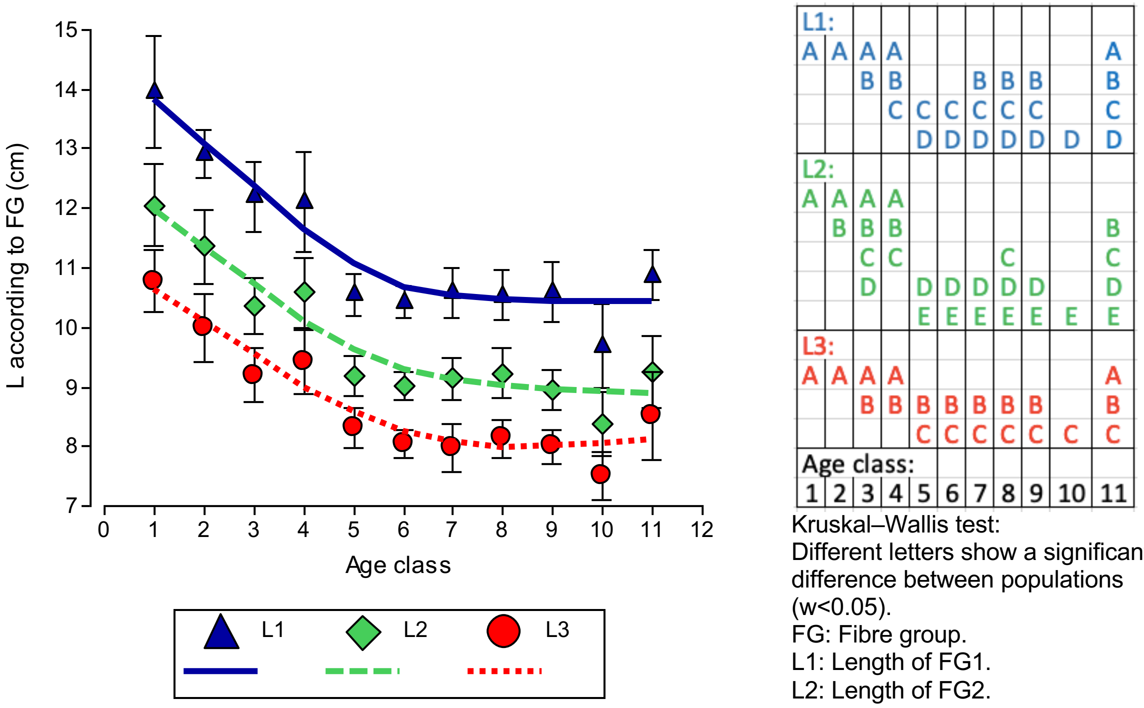
For 100% of the fibres analysed which belonged to the coarse fibre group (FG1), the crimp group (CG) is CG4. This is true for all FTs, as shown in the second column of Table 2. With respect to the age classes, in FG1, there were no modifications, which is in accordance with the CF of FG1. In general, FG2 and FG3 did not show any modifications according to age. The presence of CG3 fibres increased slightly only in the CG3 of the DC fleece and the presence of CG4 fibres increased slightly in the CG3 of the L fleece, that is to say that these modifications were very limited to a single FG as well as very small and did not change the fleece structure.

Table 2: CG according to FG for each FT (experimental animals).

	FG1	FG2	FG3
DC	only for CG4	CG3 and CG4 in equal parts	CG2 and CG3, slightly more FG3
IC	only for CG4	CG3 and CG4, more FG4	CG2 and CG3, more FG3
SC	only for CG4	CG3 and CG4, slightly more FG3	CG2 and CG3, slightly more FG2
HL	only for CG4	almost only CG4, a little FG3	CG3 and CG4, slightly more FG2
Lustre	only for CG4	almost only CG4, a little FG3	CG3 and CG4, slightly more FG2

1.5. Fibre length

Figure 24 shows that the longest length was measured for the young animals and the trend in length shows a reduction with increasing age until age class 5, where it stabilises.



L1:										
A	A	A	A							A
		B	B			B	B	B		B
			C	C	C	C	C	C		C
				D	D	D	D	D	D	D
L2:										
A	A	A	A							
	B	B	B							B
		C	C				C			C
		D		D	D	D	D	D		D
				E	E	E	E	E	E	E
L3:										
A	A	A	A							A
		B	B	B	B	B	B	B		B
				C	C	C	C	C	C	C
Age class:										
1	2	3	4	5	6	7	8	9	10	11

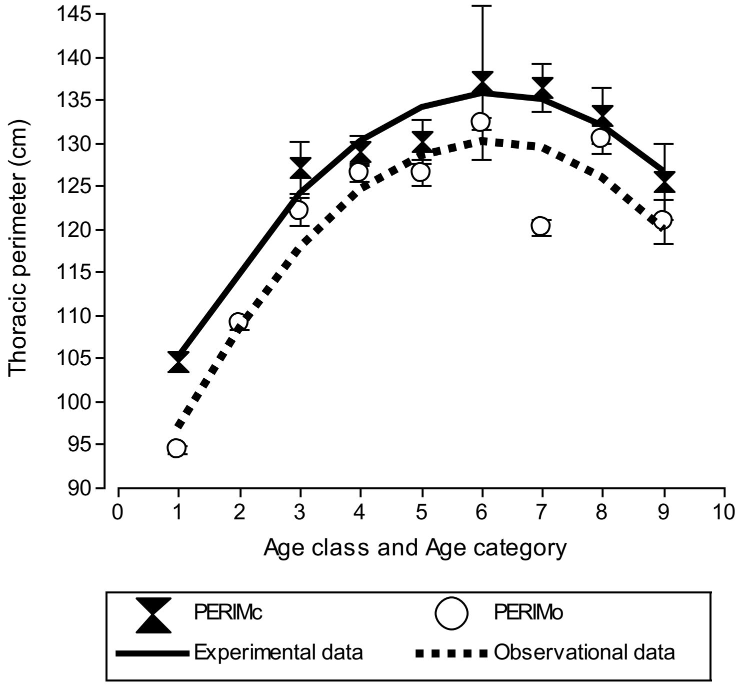
Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
FG: Fibre group.
L1: Length of FG1.
L2: Length of FG2.
L3: Length of FG3.

Figure 24: Modification of length regarding age class, according to FG.
(Experimental animals)

1.6. Consistency of experimental and observational databases

The 3 graphs in Division 1.6 include data from both databases, the experimental as well as the observational database, to provide information on how well both of them are consistent to each other. The variables used in this context are the thoracic perimeter (PERIM) in Figure 25, the total mean diameter (TMD) in Figure 26 and the MDs of each fibre type (according to medulla type: MDA, MDF, MDI, MDC and MDG) in Figure 27.

The age class indicates the age of the experimental animals and the age category indicates the age of the observational animals. Both variables can be taken as equivalent and can therefore be included in the same X-axis. The curves of PERIMc and PERIMo, which are variables of the experimental and observational animals respectively, show a very similar curve, both with a maximum at age class 6.

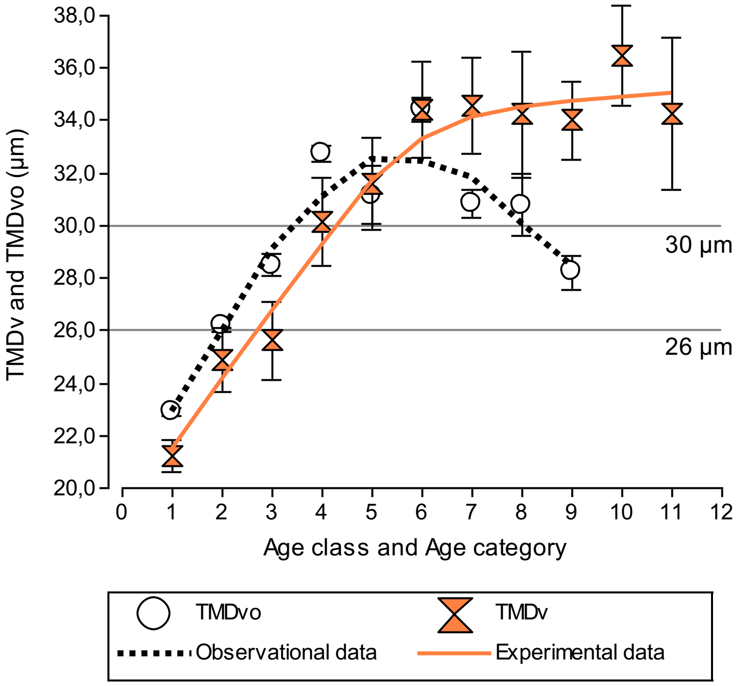


PERIMc: Thoracic perimeter measured for the complete experimental flock. (Experimental data, age class)

PERIMo: Thoracic perimeter. (Observational data, age category)

Figure 25: Modification of PERIMc and PERIMo regarding age class and age category. (Experimental and observational animals)

The TMDv curve shown in Figure 26 is the same as the one in Figure 8. Likewise, the curves of MDA, MDF, MDI, MDC and MDG shown in Figure 27 are identical to those ones in Figure 17.

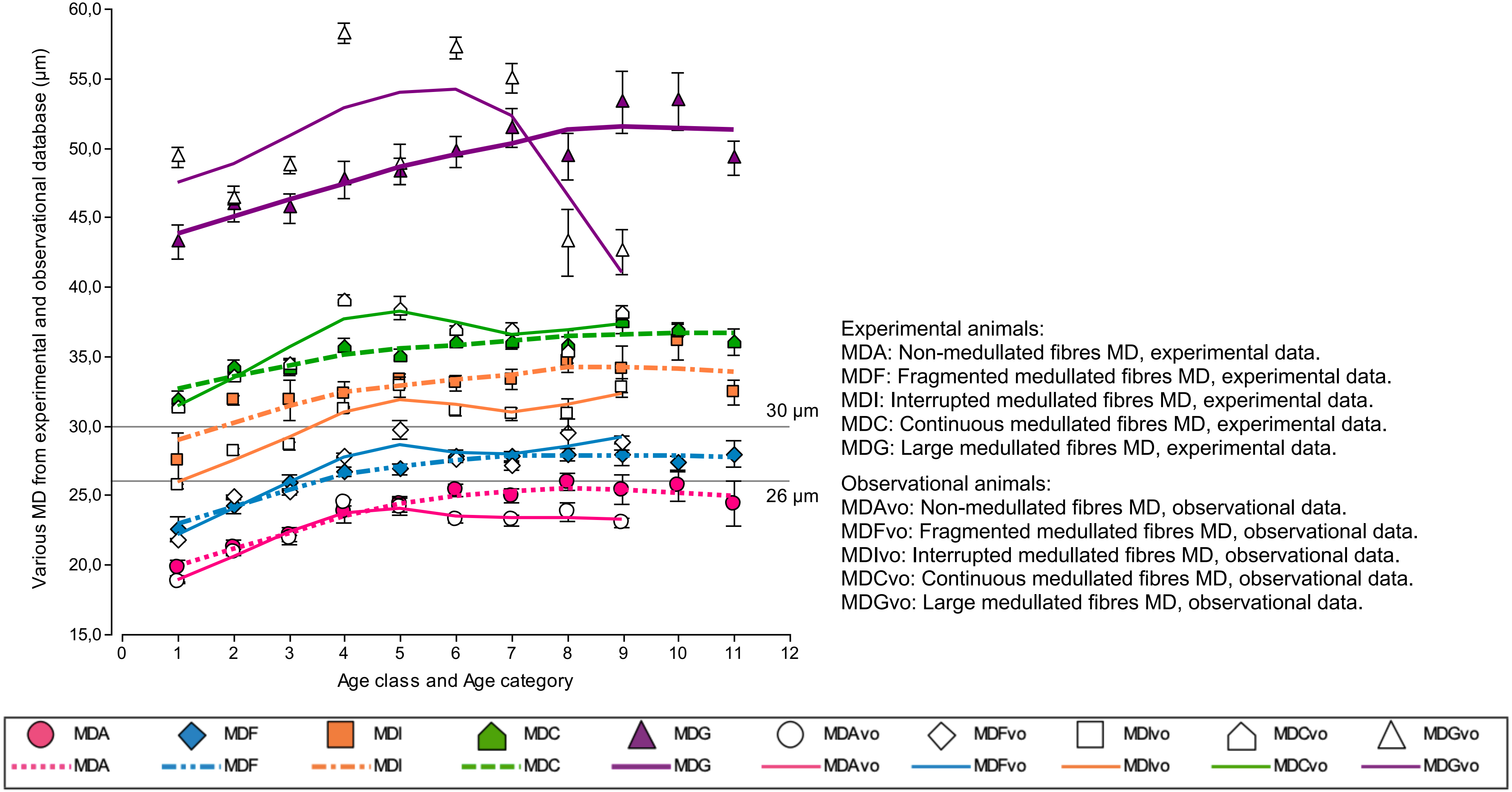


TMDv:					D	D	D	D	D	D	D
				C	C	C	C	C	C		C
			B	B							
	A	A	A								
TMDvo:											
				D	D	D	D	D			
			C		C		C	C	C		
		B	B						B		
	A										
Age class:	1	2	3	4	5	6	7	8	9	10	11

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

TMD: Total mean diameter.
TMDv: TMD measured for a sample, which was taken from a fleece, experimental animals.
TMDvo: TMD measured for a sample, which was taken from a fleece, observational animals.

Figure 26: Modification of TMDv and TMDvo regarding age class and age category. (Experimental and observational animals)



Experimental animals:
MDA: Non-medullated fibres MD, experimental data.
MDF: Fragmented medullated fibres MD, experimental data.
MDI: Interrupted medullated fibres MD, experimental data.
MDC: Continuous medullated fibres MD, experimental data.
MDG: Large medullated fibres MD, experimental data.

Observational animals:
MDAvo: Non-medullated fibres MD, observational data.
MDFvo: Fragmented medullated fibres MD, observational data.
MDIvo: Interrupted medullated fibres MD, observational data.
MDCvo: Continuous medullated fibres MD, observational data.
MDGvo: Large medullated fibres MD, observational data.

Figure 27: Modification of various MD regarding age class and age category, according to fibre type.
(Experimental and observational animals)

2. Dehairing effect on llama fibre structure

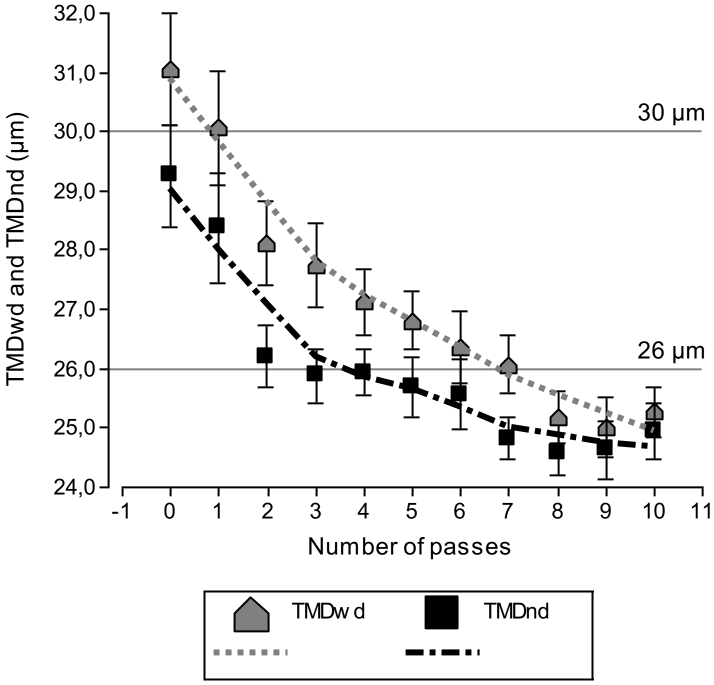
2.1. Total mean diameter and mean diameter according to fibre groups (FGs)

Figure 28 shows the dehairing effect that leads to the reduction of the total mean diameter (TMD) achieved through the dehairing process, represented by the weight-weighted TMD (TMDwd) and the fibre frequency-weighted TMD (TMDnd) of the dehairing product. Both trends are curvilinear, that is to say that they do not form a linear curve, but possibly a quadratic one. The curve drops more sharply at the beginning and, at a given point, becomes stable at a minimum.

The TMDnd curve is repeated in Figure 29 and, in this graph, it is accompanied by the subproduct TMD (TMDns). The product TMD curves (TMDnd and TMDwd) represent the actual dehairing process together with its successive passes, as the product of one pass through the dehairing machine (AM2) is the raw material for the next pass. In the Figure 7 flow chart, this is represented by the arrows showing the dehairing process. The process starts with the whole fleece, which passes through the AM2 forming Product 1, passes through the AM2 again, etc. and ends at Product 10. However, the subproduct corresponds strictly to each pass only, as it is not processed any further, and only the product is further processed in the successive passes.

All 16 fleeces as if having been processed as one fibre lot, have a TMDnd of 29.3 μm at the beginning and a TMDnd of 25.9 μm is achieved after the first 3 passes through the AM2, reaching the 26 μm threshold (Figure 29). With the successive passes, the TMDnd is further reduced, reaching 24.9 μm after the tenth pass. The TMD of the subproduct (TMDns) is significantly higher.

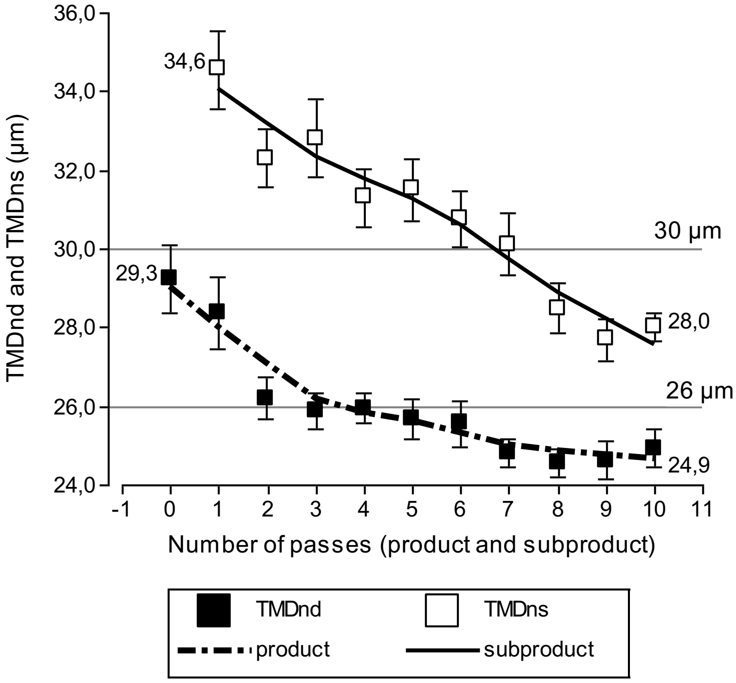
In Figure 30 the TMDnd curve is repeated and it shows how the TMDnd can be broken down into the MD curves for each of the 3 FGs of the product (MD1d, MD2d and MD3d). In Figure 31 MD1d, MD2d and MD3d are repeated and are accompanied by the MDs of the 3 FGs of the subproduct (MD1s, MD2s and MD3s). This graph shows how the dehairing effect is produced by separating the whole fleece into product and subproduct. For example, for the coarse fibre group (FG1), the MD of the whole fleece (MD1d: 46.7 μm) is separated into two MDs: on the one hand, the product MD is reduced (MD1d: 45.2 μm) and, on the other hand, the subproduct MD is increased (MD1s: 49.1 μm).



TMDwd:										
A	A	A								
	B	B	B							
		C	C	C	C	C				
			D	D	D	D	D			
						E	E	E	E	E
TMDnd:										
A	A									
	B	B			B					
		C	C	C	C	C	C			C
						D	D	D	D	D
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
TMD: Total mean diameter.
TMDwd: TMD weighted by the weight of the 3 FGs.
TMDnd: TMD weighted by the fibre frequency in the 3 FGs.

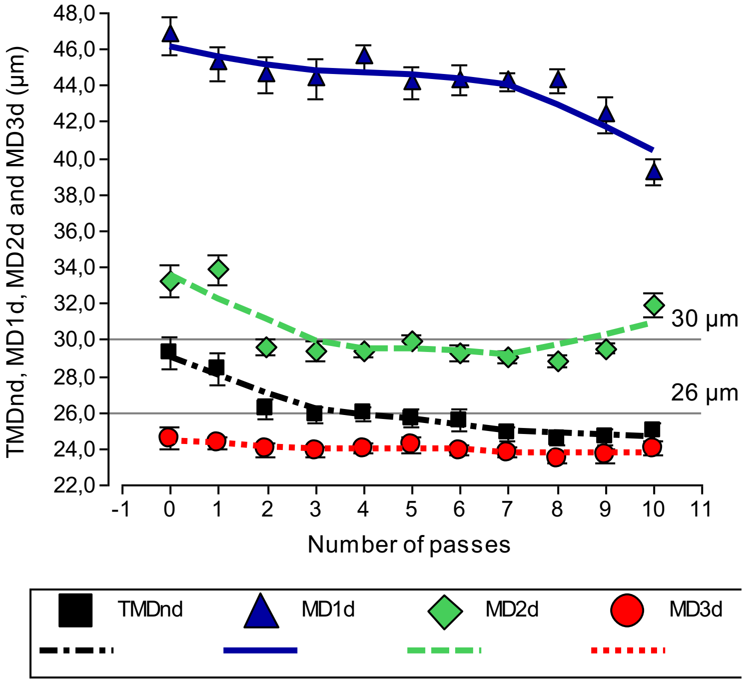
Figure 28: Modification of TMDwd and TMDnd regarding the successive passes – product. (Fibre during the dehairing process)

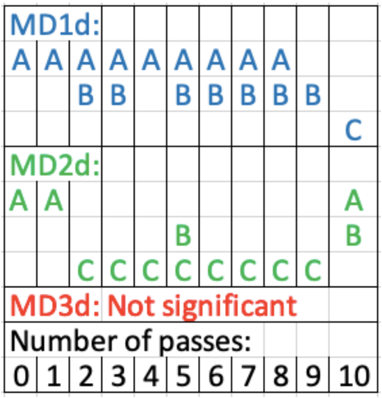


	TMDns:									
	A	A	A	A	A					
		B	B	B	B	B				
				C	C	C	C			
						D	D	D		
							E	E		E
								F	F	F
TMDnd:										
A	A									
	B	B			B					
		C	C	C	C	C	C			C
						D	D	D	D	D
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
TMD: Total mean diameter
Product:
TMDnd: Total MD weighted by the fibre frequency in the 3 FGs.
Subproduct:
TMDns: Total MD weighted by the fibre frequency in the 3 FGs.

Figure 29: Modification of TMDnd and TMDns regarding the successive passes – product and subproduct. (Fibre during the dehairing process)





MD1d:										
A	A	A	A	A	A	A	A	A		
		B	B		B	B	B	B	B	
										C
MD2d:										
A	A									A
					B					B
		C	C	C	C	C	C	C	C	
MD3d: Not significant										
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

MD: Mean fibre diameter.
TMDnd: Total MD weighted by the number of the 3 FGs.
MD1d: MD of FG1.
MD2d: MD of FG2.
MD3d: MD of FG3.

Figure 30: Modification of MD, according to FG, and TMDn regarding the successive passes – product. (Fibre during the dehairing process)

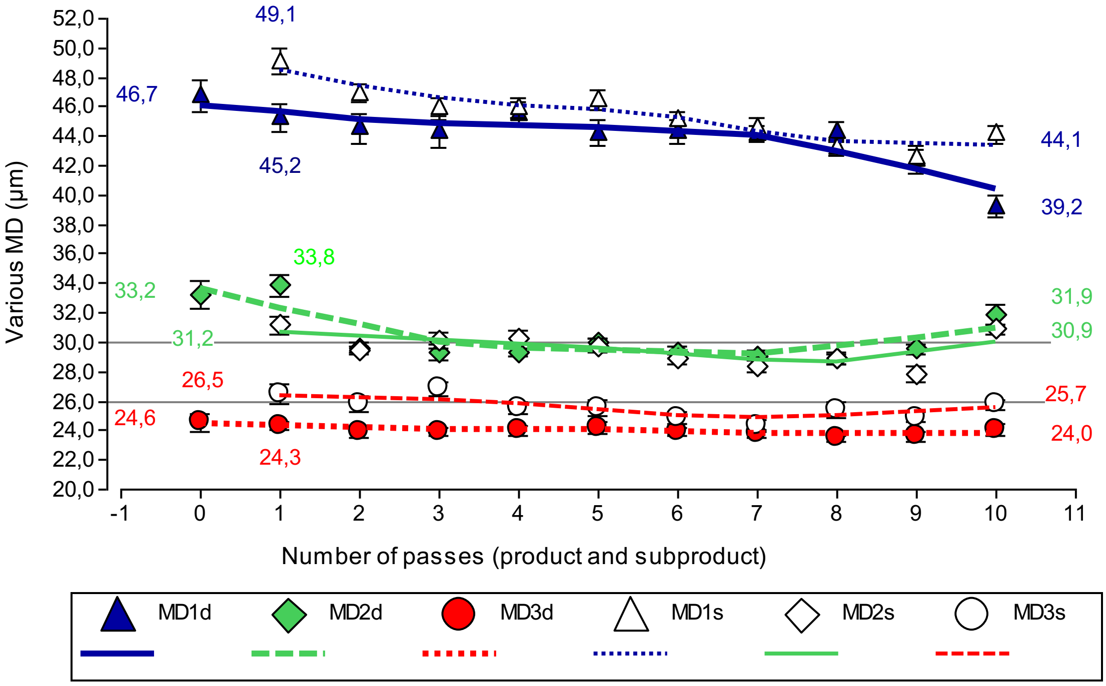
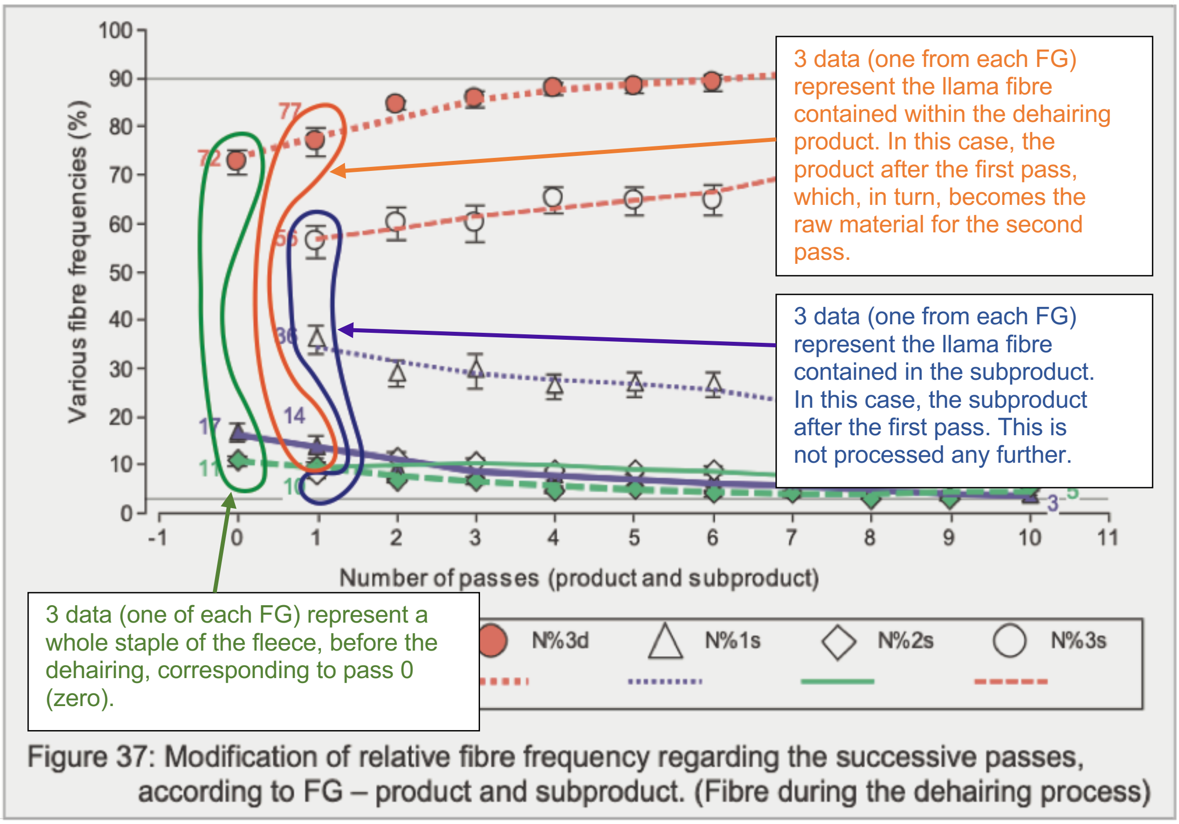


Figure 31: Modification of MD, according to FG, regarding the successive passes – product and subproduct. (Fibre during the dehairing process)

Product:	Subproduct:
MD1d: MD of FG1.	MD1s: MD of FG1.
MD2d: MD of FG2.	MD2s: MD of FG2.
MD3d: MD of FG3.	MD3s: MD of FG3.

This MD difference between the product and the subproduct is accompanied by a difference in the relative fibre frequency of the product and subproduct, which decreases from the whole fleece value (N%1d: 17%) to the product value (N%1d: 14%) and increases the subproduct value (N%1s: 36%), as seen in Figure 37. This achieves the TMDnd reduction as it is shown in Figure 29 and, in addition, the dehairing effect also occurs for intermediate (FG2) and fine (FG3) fibres. With each pass through the AM2, what was described for the first pass, is repeated leaving it open to evaluate how many passes are required to achieve the desired product. Figure 32 illustrates how to read the graphs which include the product and subproduct data at the same time, so that the composition of the product and the subproduct can be differentiated, and so their respective fibre structures.



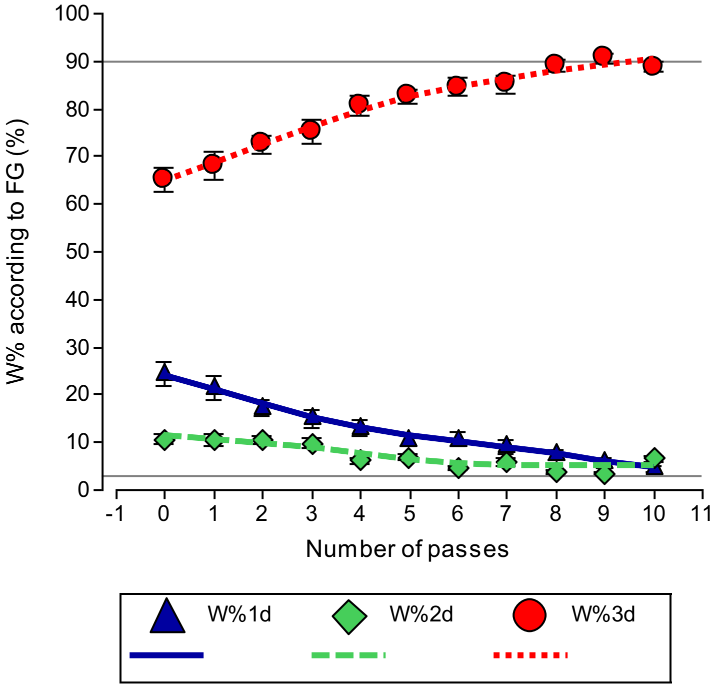
3 data (one from each FG) represent the llama fibre contained within the dehairing product. In this case, the product after the first pass, which, in turn, becomes the raw material for the second pass.

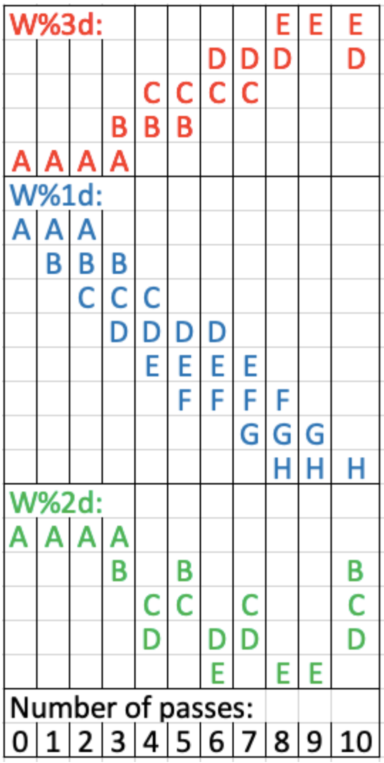
3 data (one from each FG) represent the llama fibre contained in the subproduct. In this case, the subproduct after the first pass. This is not processed any further.

3 data (one of each FG) represent a whole staple of the fleece, before the dehairing, corresponding to pass 0 (zero).

Figure 37: Modification of relative fibre frequency regarding the successive passes, according to FG – product and subproduct. (Fibre during the dehairing process)

Figure 32: Example of the amount of data describing the llama fibre for the case of the whole staple before dehairing (Pass 0) and after the first pass (Pass 1).





W%3d:										
								E	E	E
						D	D	D		D
				C	C	C	C			
			B	B	B					
A	A	A	A							
W%1d:										
A	A	A								
	B	B	B							
		C	C	C						
			D	D	D	D				
				E	E	E	E			
					F	F	F	F		
							G	G	G	
								H	H	H
W%2d:										
A	A	A	A							
			B		B					B
				C	C		C			C
				D		D	D			D
						E		E	E	
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

FG: Fibre group.
W%1d: Relative weight of FG1.
W%2d: Relative weight of FG2.
W%3d: Relative weight of FG3.

Figure 33: Modification of the relative weight regarding the successive passes, according to FG – product. (Fibre during the dehairing process)

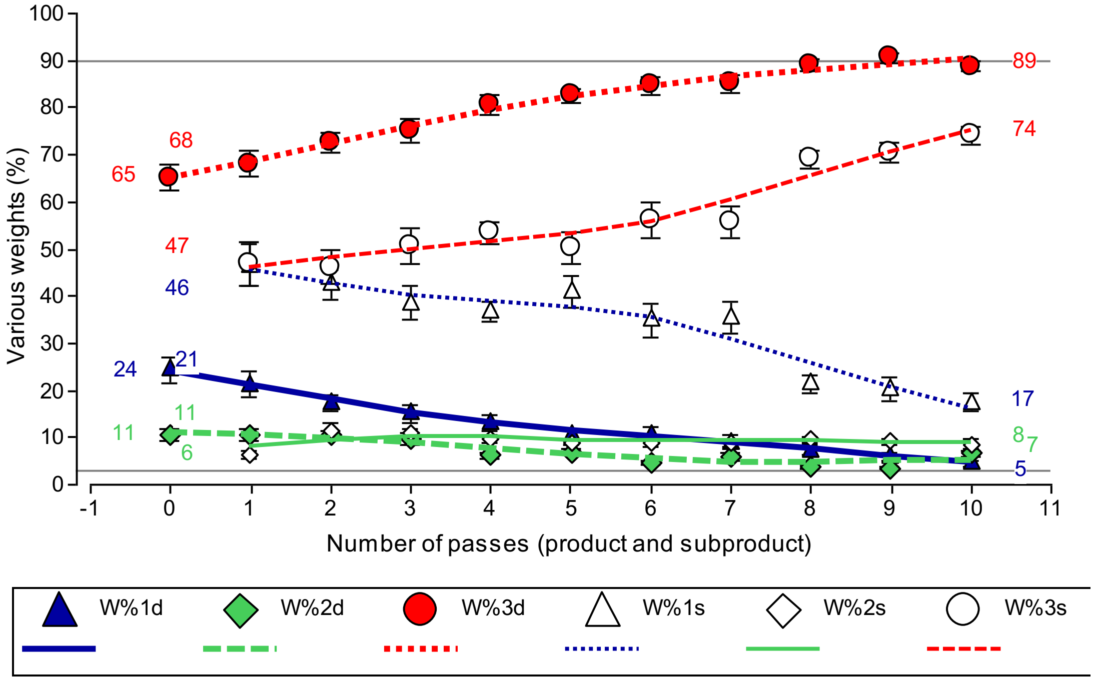


Figure 34: Modification of relative weight regarding the successive passes, according to FG – product and subproduct. (Fibre during the dehairing process)

Product:	Subproduct:
W%1d: Relative weight of FG1.	W%1s: Relative weight of FG1.
W%2d: Relative weight of FG2.	W%2s: Relative weight of FG2.
W%3d: Relative weight of FG3.	W%3s: Relative weight of FG3.

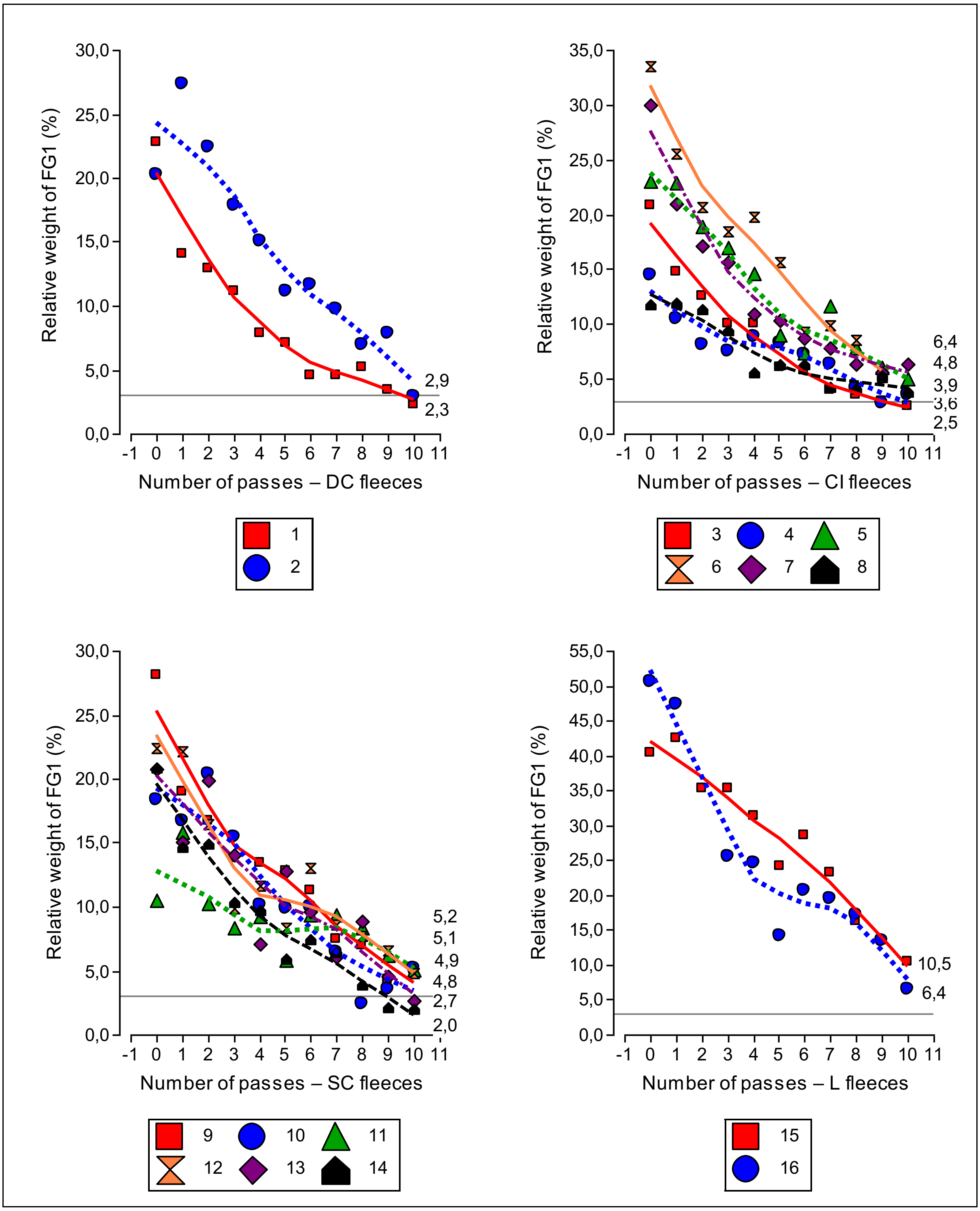
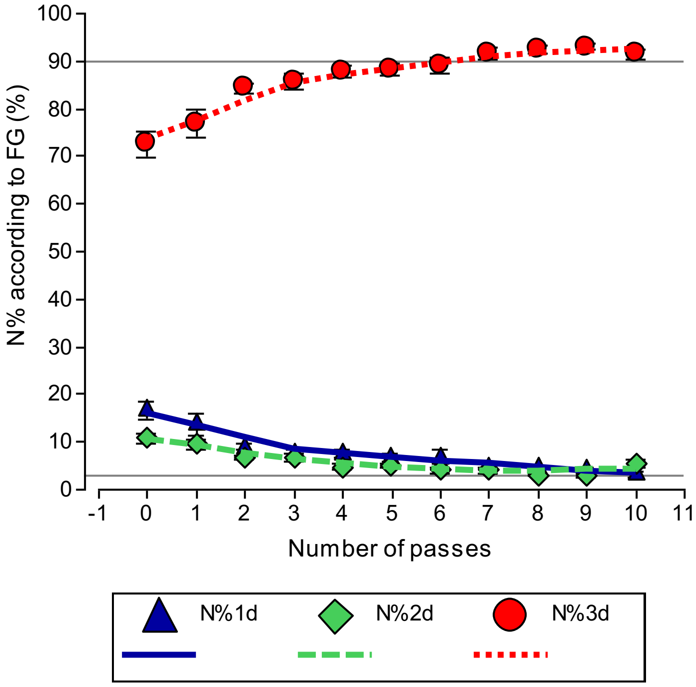


Figure 35: Modification of the relative weight of different fleeces of FG1 (W%1d) regarding the successive passes, plotted for each fleece type separately - product. (Fibre during the dehairing process)

In Figure 35, each curve represents a single fleece, that is to say that each of the 16 fleeces processed in the dehairing trial is plotted separately. Only the FG data belonging to the coarse or objectionable fibres (FG1) are shown and, regarding each of the four graphs, the fleece type is differentiated. The FG1 relative weight of the product (W%1d) shows a relatively similar behaviour for the DC, IC and SC fleeces, with a close approach up to the 3 % threshold, while the 2 lustre fleece types have a higher W%1d and until the tenth pass do not manage to approach the 3% threshold.



N%3d:						G	G	G	G	G
					F	F	F			F
				E	E	E				E
			D	D	D	D				
		C	C	C						
	B	B	B							
A	A	A								
N%1d:										
A	A	A								
		B	B	B	B					
			C	C	C	C				
					D	D	D	D		
						E	E	E	E	
							F	F	F	F
N%2d:										
A	A	A	A							
		B	B		B					B
			C	C	C					C
				D	D	D	D			D
				E		E	E	E		
						F	F	F	F	
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

FG: Fibre group.
N%1d: Relative fibre frequency of FG1 fibres.
N%2d: Relative fibre frequency of FG2 fibres.
N%3d: Relative fibre frequency of the FG3 fibres.

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

Figure 36: Modification of relative fibre frequency regarding the successive passes, according to FG – product. (Fibre during the dehairing process)

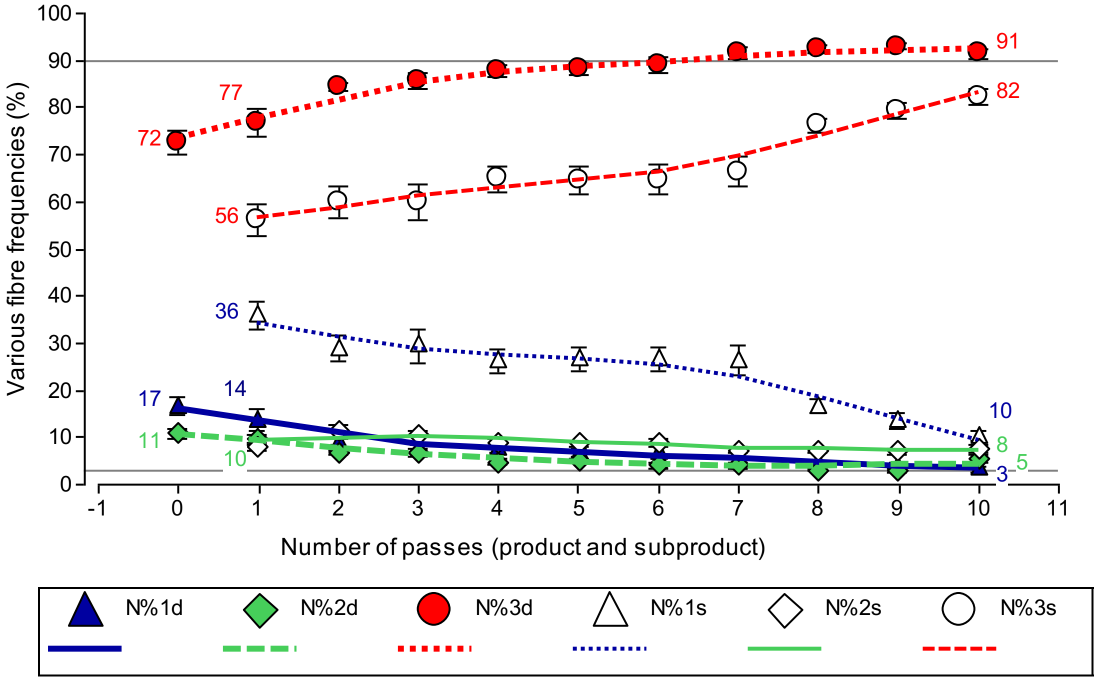


Figure 37: Modification of relative fibre frequency regarding the successive passes, according to FG – product and subproduct. (Fibre during the dehairing process)

Product:
N%1d: Relative fibre frequency of FG1.
N%2d: Relative fibre frequency of FG2.
N%3d: Relative fibre frequency of FG3.

Subproduct:
N%1s: Relative fibre frequency of FG1.
N%2s: Relative fibre frequency of FG2.
N%3s: Relative fibre frequency of FG3.

Figure 38 plots the relative frequency of the coarse fibres (FG1). Each curve represents a single fleece, as in Figure 35, and the same can be observed in relation to the differences according to fleece types: DC, IC and SC fleeces show similar behaviour, which is different for the Lustre fleece.

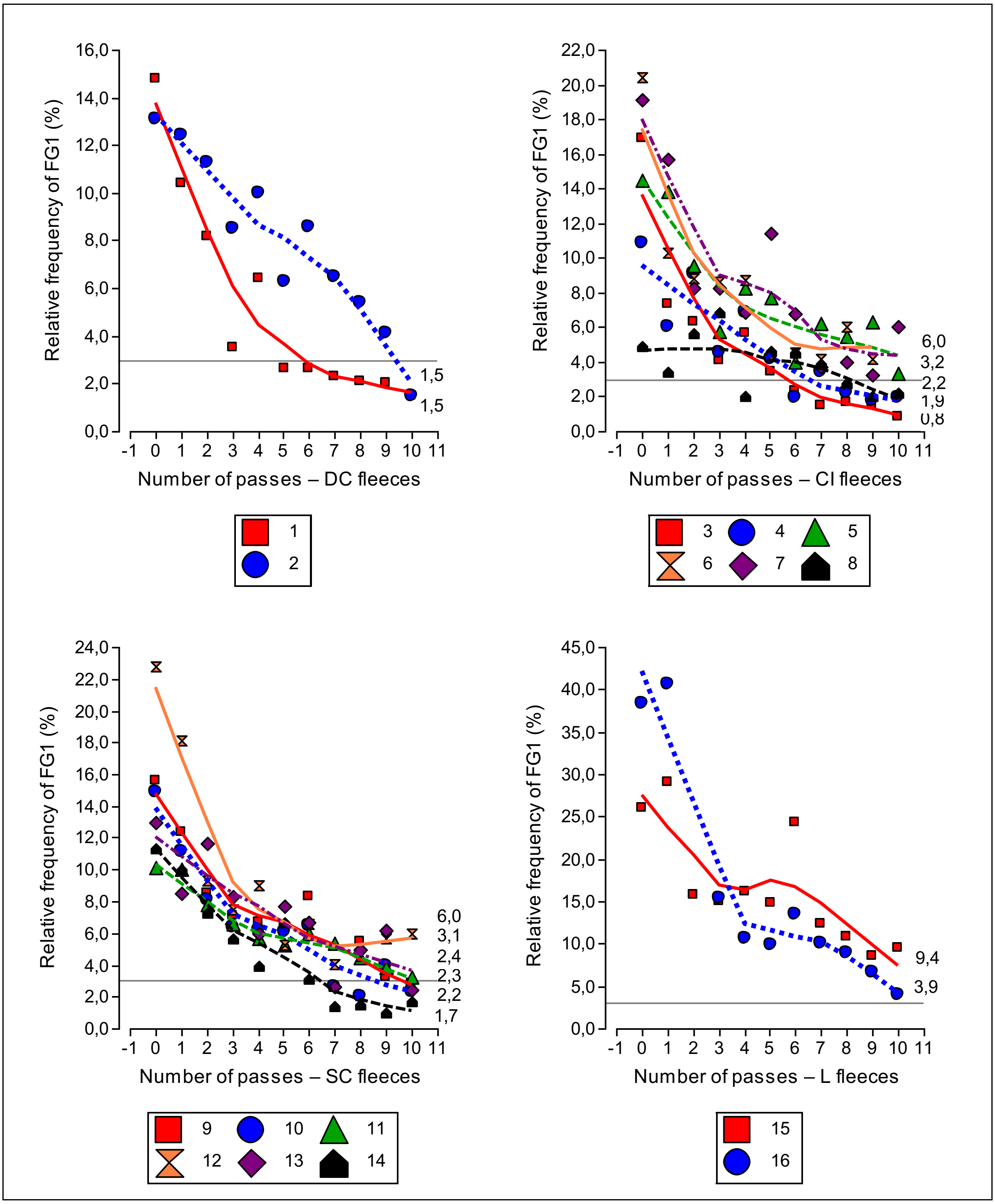


Figure 38: Modification of the relative fibre frequency of different fleeces of FG1 (N%1d) regarding the successive passes, plotted for each fleece type separately - product. (Fibre during the dehairing process)

Table 3 complements the information given in Figures 35 and 38, and it is also differentiated according to fleece type. The last column shows the minimum value (for FG1 and FG2) and the maximum value (for FG3) according to the first derivative of a polynomial equation. The penultimate column shows the quantity of dehairing passes in which this minimum or maximum value is reached for each FG, taking two variables representing the objectionable fibres: the relative weight and the relative fibre frequency.

In all cases the y-intercept (constant) is very significant or highly significant (w<0.01 or w<0.001), which is very important because the value of the y-intercept is the real value of the coarse fibre content of the original, not dehaired sample (X=0). In all cases, there is also the estimate standard error, which allows to establish the confidence interval (very important for point 3.10.) and the relative error that fluctuated between 10% (acceptable) and 20% (admissible) (Di Rienzo, 2015), with some cases below 10%.

The linear slope was significant for both variables for all fleece types and all FGs, with the exception of FG2, the W% for Lustre fleece type, where no difference of zero was verified. The relative error was also verified here and ranged from 5 to 21%, being higher in the non-significant constant (W% of the FG2s).

The constant corresponding to the curvilinear slope (quadratic) shows a variable behaviour as expected. It is not significant in W% for the 3 FGs of the DC fleece type, in N% for the FG2 of Lustre fleece type, as well as in W% for the 3 FGs of the same fleece type. The value of the concave slope is variable in magnitude, which would indicate that there is not always a change of concavity and that the relative standard error ranges between 12 to 25%.

The coefficient of determination (fitted to n) is from high to very high for all fleece types and FGs with the exception of FG2, which shows significant fluctuation. The value of W% is always higher than N% for all FG1s and FG2s, and lower for FG3s. This behaviour has been already verified in the previous analyses.

Table 3: Reduction or increase in relative weight or relative fibre frequency by dehairing, according to FG, for each FT. (Fibre during the dehairing process - Product)

FT	FG	Variable	Constant	b	b^2	R^2	Pass	Min/Max value
DC	FG1	W%1d	22.02***	-3.25***	0.14^{ns}	0.75	12	3.18%
	FG1	N%1d	13.05***	-2.08**	0.10*	0.77	10	2.25%
	FG2	W%2d	14.05***	-1.82*	0.08^{ns}	0.43	11	3.71%
	FG2	N%2d	13.00**	-2.65**	0.17**	0.64	8	2.68%
	FG3	W%3d	66.91***	5.06***	-0.20^{ns}	0.70	10	97.51%
	FG3	N%3d	77.84***	4.83***	-0.27***	0.76	9	99.44%
IC	FG1	W%1d	20.71***	-3.33***	0.16**	0.67	10	3.41%
	FG1	N%1d	12.57***	-2.32***	0.14***	0.58	8	2.97%
	FG2	W%2d	9.20***	-1.25***	0.07*	0.37	9	3.62%
	FG2	N%2d	8.78***	-1.74***	0.12***	0.40	7	2.48%
	FG3	W%3d	73.15***	4.69***	-0.23**	0.71	10	97.05%
	FG3	N%3d	82.74***	4.25***	-0.27***	0.57	8	99.46%
SC	FG1	W%1d	19.52***	-2.73***	0.12**	0.75	11	4.01%
	FG1	N%1d	13.53***	-2.42***	0.14***	0.74	9	3.09%
	FG2	W%2d	12.36***	-1.78***	0.1**	0.42	9	4.44%
	FG2	N%2d	9.93***	-1.77***	0.11***	0.61	8	2.81%
	FG3	W%3d	71.02***	4.65***	-0.21***	0.79	11	96.76%
	FG3	N%3d	80.23***	4.43***	-0.27***	0.82	8	98.39%
L	FG1	W%1d	44.70***	-5.36***	0.18^{ns}	0.69	15	4.82%
	FG1	N%1d	31.67***	-5.24***	0.28*	0.62	9	7.19%
	FG2	W%2d	11.48***	-0.66^{ns}	0.02^{ns}	0.12	17	6.04%
	FG2	N%2d	14.62***	-2.00***	0.12^{ns}	0.54	8	6.30%
	FG3	W%3d	44.04***	6.12***	-0.19^{ns}	0.88	16	93.32%
	FG3	N%3d	54.71***	7.73***	-0.43***	0.69	9	89.45%

Pass: result of the first derivative of the polynomial equation that indicates the pass with the minimum/maximum achievable value.

Min/max value: value of the slope corresponding to that minimum/maximum.

ns: Not significant (w>0.05); *Significant (w<0.05); **Significant (w<0.01); ***Significant (w<0.001)

FT: Fleece type.
DC: Double coated.
IC: Intermediate coated.
SC: Simple coated.
HL: Hemi lustre.
L: Lustre.

FG: Fibre group.
FG1: Coarse fibres.
FG2: Intermediate fibres.
FG3: Fine fibres.

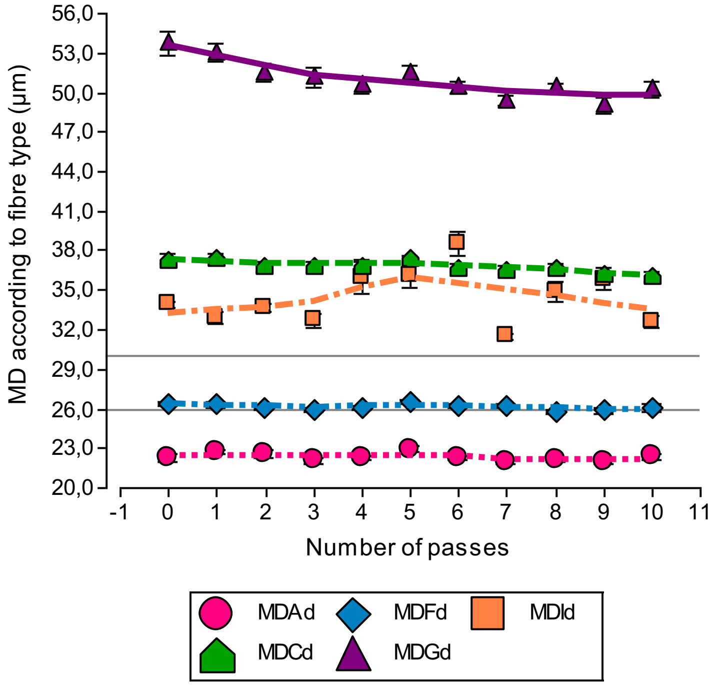
W%1d: Relative weight of FG1.
W%2d: Relative weight of FG2.
W%3d: Relative weight of FG3.
N%1d: Relative fibre frequency of FG1.
N%2d: Relative fibre frequency of FG2.
N%3d: Relative fibre frequency of FG3.

2.2. Mean diameter according to fibre type

Figures 39 and 40 show the MD and the N% according to fibre type, thus revealing the dehairing effect explained according to these 5 fibre groups that make up the whole staple. It is clear that the dehairing effect consists mainly in separating the fibre types from each other, that is to say, in reducing the coarse fibres percentage in the product (N%Cd and N%Gd), rather than in reducing the MD of each of these fibre types. The KW is not significant for the different fibre types MDs, with the exception of the interrupted medulla fibres (MDId). However, the result for this fibre type is not included in Figure 39 because it does not show a coherent logic and the "ups and downs" of the curve should be more related to a problem of identifying that type of fibre when performing the method of projection microscope. Moreover, its frequency (N%Id) is very low as it ranges between 1.1 and 0.0%, so it is not included in the discussion because it does not have the possibility to influence the fibre structure.

The only fibre type showing a MD reduction is the large medulla fibre (MDGd). This confirms that the coarsest fibres separated at the beginning of dehairing are the coarsest fibres of all the ones contained within the fibre and, over the successive passes, the separated coarsest fibres are slightly less coarse. Anyways, the few fibres that remain in the product are clearly objectionable as they have a coarseness of around 50 μm. This means that it is fundamental to verify how many of these fibres remain in the product (N%Gd in Figure 40). N%Gd is clearly reduced below the threshold value of 3%. It approaches this threshold at the end of the second pass (3.8%) and exceeds it at the end of the fifth pass (2.6%). It keeps falling further down, reaching 0.9% after the 10th pass. The continuous medulla fibres also reduce their percentage significantly, but they show a less satisfactory behaviour, as their percentage becomes stable at a value above the 3% threshold, with a minimum value of 5.4% at the end of the 7th pass.

Figure 39 and Figure 40 represent the data of the dehairing product as a whole, while the data in Figure 41 and Figure 42 plot the three FGs contained in the product separately. This is important to highlight because it means that Figure 39 and Figure 40 represent the characteristics of a set of fibres that exists in the real textile processing, precisely because they represent the product that is generated by implementing the dehairing process, and unlike this, what is plotted in Figures 41 and 42 shows the information of the three FGs (FG1, FG2 and FG3) broken down, which only exists by dissecting the product and forming these three FGs. This is useful to better understand the fibre structure of the product and people involved in fibre processing can implement dissection to obtain this type of information.

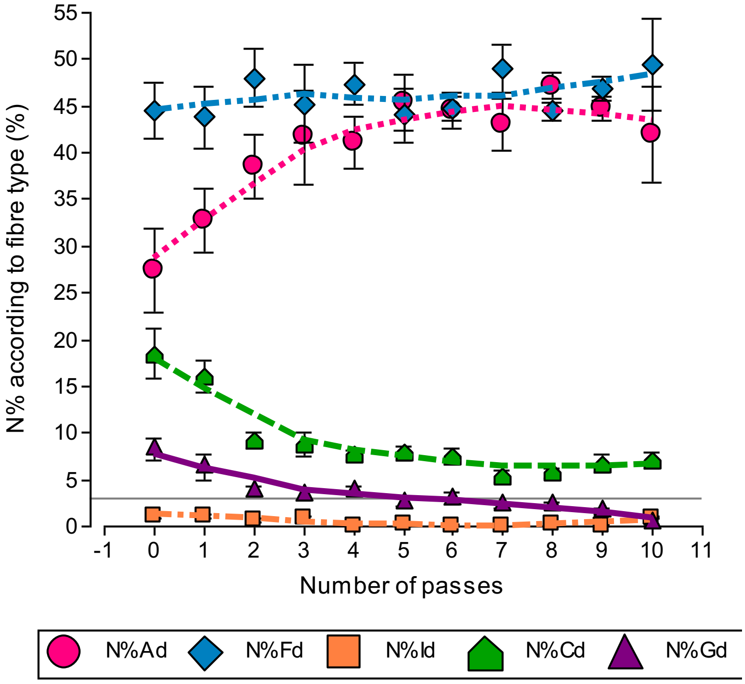


Kruskal–Wallis test:
Not significant for MDAd, MDFd, MDCd and MDGd
(w>0.05).

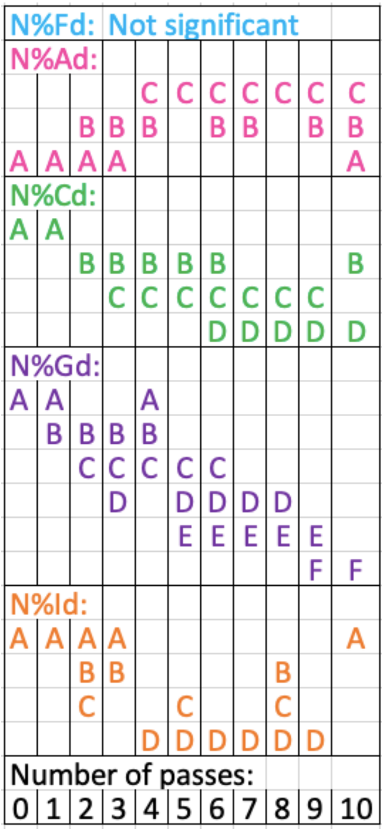
(Kruskal–Wallis test significant for MDId. The results are not included due to very reduced N%Id, between 1.1 and 0.0%).

MD: Mean fibre diameter.
MDAd: MD of non-medullated fibres.
MDFd: MD of fragmented medullated fibres.
MDId: MD of interrupted medullated fibres.
MDCd: MD of continuous medullated fibres.
MDGd: MD of large medullated fibres.

Figure 39: Modification of MD regarding the successive passes, according to fibre type – product. (Fibre during the dehairing process)



N%: Relative fibre frequency.
N%Ad: N% of non-medullated fibres.
N%Fd: N% of fragmented medullated fibres.
N%Id: N% of interrupted medullated fibres.
N%Cd: N% of continuous medullated fibres.
N%Gd: N% of large medullated fibres.



N%Fd:			Not significant							
N%Ad:										
				C	C	C	C	C	C	C
		B	B	B		B	B		B	B
A	A	A	A							A
N%Cd:										
A	A									
		B	B	B	B	B				B
			C	C	C	C	C	C	C	
						D	D	D	D	D
N%Gd:										
A	A			A						
	B	B	B	B						
		C	C	C	C	C				
			D		D	D	D	D		
					E	E	E	E	E	
									F	F
N%Id:										
A	A	A	A							A
		B	B					B		
		C			C			C		
				D	D	D	D	D	D	
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

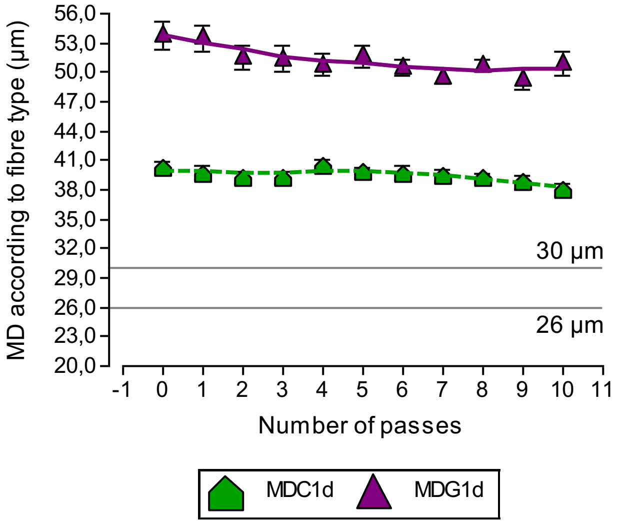
Kruskal–Wallis test:
Different letters show a significant difference between populations
(w<0.05)

Figure 40: Modification of the N% regarding the successive passes, according to fibre type – product. (Fibre during the dehairing process)

Furthermore, this explanation aims to point out that in Sub-chapters 1 and 3, FG3 is referred to as the product of a potential dehairing, which is correct, because in that context everything starts with the whole fleece that can be dehaired. However, this logic changes in Sub-chapter 2 because the plotted information represents the product (or the subproduct) by itself, generated by the dehairing process. Thus, in the context of this sub-chapter, FG3 does not represent the dehairing product, but one of the three parts of the product, simply one of the 3 FGs formed by implementing the Three Group Dissection for a fibre sample of the product (or the subproduct) helping to clarify the structure of a fibre lot found within the dehairing textile process.

To describe the structure of a fibre lot, the characteristics of the different FGs that make up that lot are described, that is to say, the characteristics of the fibres contained in each of the three FGs. What is explained in Figures 19 and 20 in relation to the data set describing a fibre staple of a fleece also applies to a llama fibre sample, which represents the fibre found in the textile process of dehairing. In addition to that, Figure 32 shows how the fleece data, prior to dehairing, becomes the product and subproduct data.

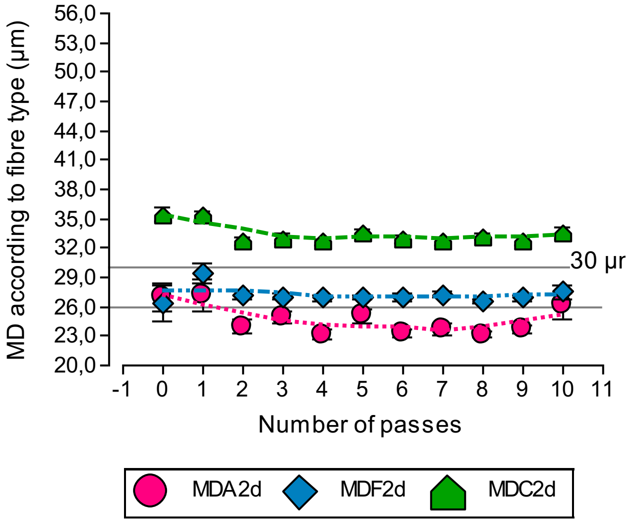
FG1*



Kruskal–Wallis test:
Not significant for MDA1d, MDF1d, MDC1d and MDG1d (w>0.05).

* MDA1d, MDF1d and MDI1d are not plotted because their frequency is very reduced, as it is shown in Figure 42.

FG2**

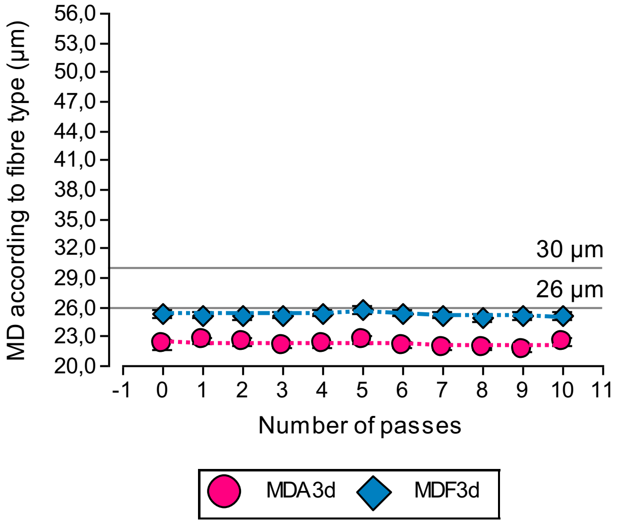


Number of passes:	0	1	2	3	4	5	6	7	8	9	10
MDG2d:	Significant, but almost no fibres										
MDC2d:	A	A	B	B	B	B	B	B	B	B	B
MDI2d:	Not significant										
DMF2d:	Not significant										
MDA2d:	A	A B	A B C D	A B C	D	A B C	C D	B C D	D	C D	A B C D

Kruskal–Wallis test: Different letters show a significant difference between populations (w<0.05)

** MDI2d and MDG2d are not plotted because their frequency is very reduced, as it is shown in Figure 42.

FG3***



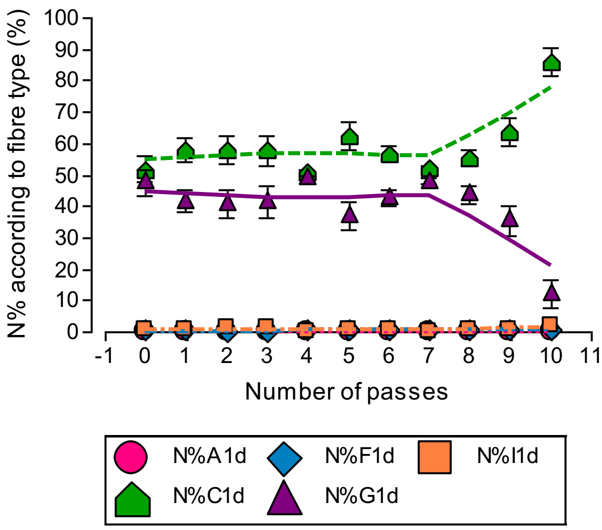
Kruskal–Wallis test:
Not significant for MDA3d, MDF3d, MDI3d, MDC3d and MDG3d (w>0.05).

*** MDI3d, MDC3d and MDG3d are not plotted because their frequency is very reduced, as it is shown in Figure 42.

Abbreviations: See next page

Figure 41: Modification of MD regarding the successive passes, according to fibre type, plotted for each FG separately – product. (Fibre during the dehairing process)

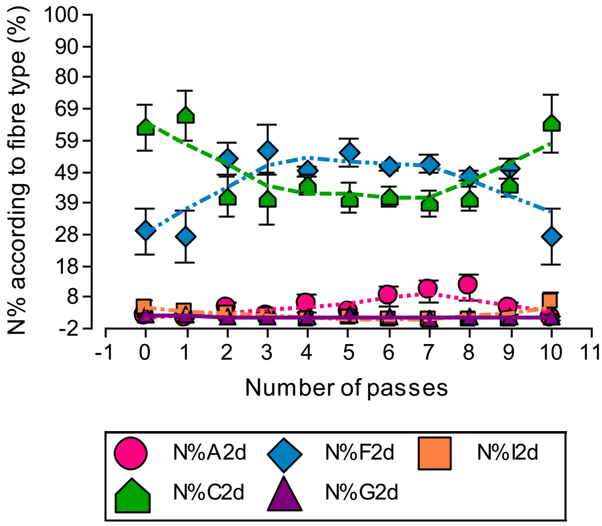
FG1



N%C1d:										D
	C	C	C		C	C		C	C	
B	B	B	B			B	B	B		
A	A			A			A	A		
N%G1d:										
A	A			A			A	A		
B	B	B				B	B	B		
C	C	C	C		C	C		C	C	
										D
N%I1d:				Significant,						
		but almost no fibres								
N%F1d:				Not significant						
N%A1d:				Not significant						
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

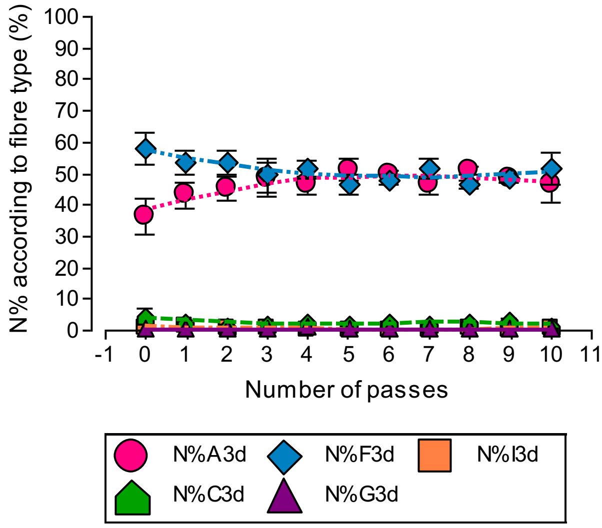
FG2



N%C2d:										
A	A								A	A
				B					B	B
		C	C	C	C	C	C	C	C	
N%F2d:										
		B	B	B	B	B	B	B	B	
A	A							A	A	A
N%A2d:										
				C	C	C	C	C	C	
		B	B	B	B				B	
A	A	A	A							A
N%I2d:				Significant,						
		but almost no fibres								
N%G2d:				Significant,						
		but almost no fibres								
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

FG3



N%F3d:				Not significant						
N%A3d:				Not significant						
N%C3d:										
A		A	A		A		A			A
B	B		B	B	B		B	B	B	
C	C			C	C	C	C	C	C	
N%I3d:				Significant,						
		but almost no fibres								
N%G3d:				Not significant						
Number of passes:										
0	1	2	3	4	5	6	7	8	9	10

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).

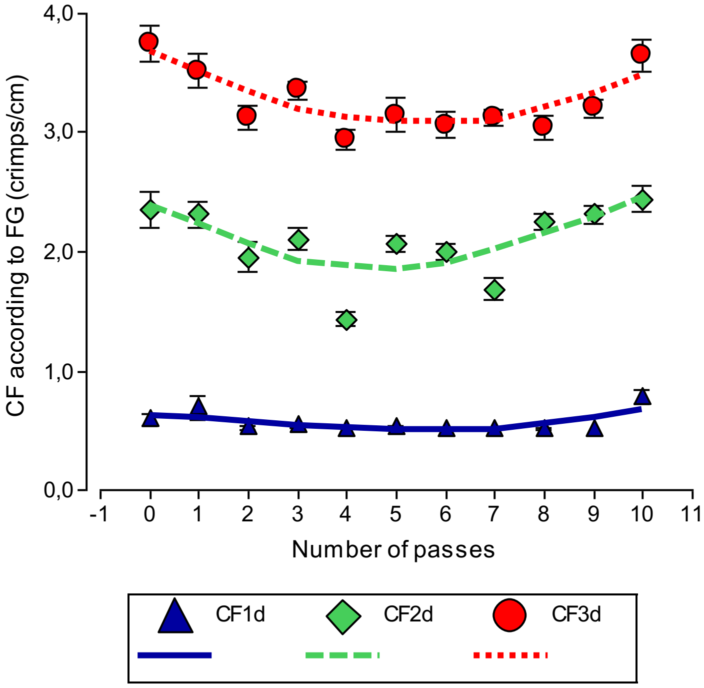
Abbreviations: See next page

Figure 42: Modification of N% regarding the successive passes, according to fibre type, plotted for each FG separately – product. (Fibre during the dehairing process)

Abbreviations in Figure 41:	Abbreviations in Figure 42:
MD: Mean fibre diameter.	N%: Relative fibre frequency.
MDA1d: Non-medullated fibres MD of FG1.	N%A1d: Non-medullated fibres N% of FG1.
MDF1d: Fragmented medullated fibres MD of FG1.	N%F1d: Fragmented medullated fibres N% of FG1.
MDI1d: Interrupted medullated fibres MD of FG1.	N%I1d: Interrupted medullated fibres N% of FG1.
MDC1d: Continuous medullated fibres MD of FG1.	N%C1d: Continuous medullated fibres N% of FG1.
MDG1d: Large medullated fibres MD of FG1.	N%G1d: Large medullated fibres N% of FG1.
MDA2d: Non-medullated fibres MD of FG2.	N%A2d: Non-medullated fibres N% of FG2.
MDF2d: Fragmented medullated fibres MD of FG2.	N%F2d: Fragmented medullated fibres N% of FG2.
MDI2d: Interrupted medullated fibres MD of FG2.	N%I2d: Interrupted medullated fibres N% of FG2.
MDC2d: Continuous medullated fibres MD of FG2.	N%C2d: Continuous medullated fibres N% of FG2.
MDG2d: Large medullated fibres MD of FG2.	N%G2d: Large medullated fibres N% of FG2.
MDA3d: Non-medullated fibres MD of FG3.	N%A3d: Non-medullated fibres N% of FG3.
MDF3d: Fragmented medullated fibres MD of FG3.	N%F3d: Fragmented medullated fibres N% of FG3.
MDI3d: Interrupted medullated fibres MD of FG3.	N%I3d: Interrupted medullated fibres N% of FG3.
MDC3d: Continuous medullated fibres MD of FG3.	N%C3d: Continuous medullated fibres N% of FG3.
MDG3d: Large medullated fibres MD of FG3.	N%G3d: Large medullated fibres N% of FG3.

2.3. Crimp frequency

Figure 43 shows a good differentiation of the 3 FGs according to CF. For FG1 there is no dehairing effect on the crimp frequency (CF1d) and the KW is not significant. The curves for FG2 and FG3 show a slight dehairing effect on the CF (CF2d and CF3d), but the KW result does not indicate a clear trend.



Number of passes:	0	1	2	3	4	5	6	7	8	9	10
CF3d:											
	A	A		A							A
		B		B						B	
			C	C		C	C	C		C	
			D		D	D	D	D	D	D	
CF2d:											
	A	A		A					A	A	A
	B	B		B		B			B	B	
	C	C		C		C	C		C		
			D	D		D	D				
			E				E	E			
					F			F			
CF1d:											
	A	A	A	A	A	A	A	A	A	A	
		B									B

Kruskal–Wallis test:
Different letters show a significant difference between populations (w<0.05).
CF1d: Crimp frequency of FG1.
CF2d: Crimp frequency of FG2.
CF3d: Crimp frequency of FG3.

Figure 43: Modification of the CF regarding the successive passes, according to FG – product. (Fibre during the dehairing process)

2.4. Crimp groups

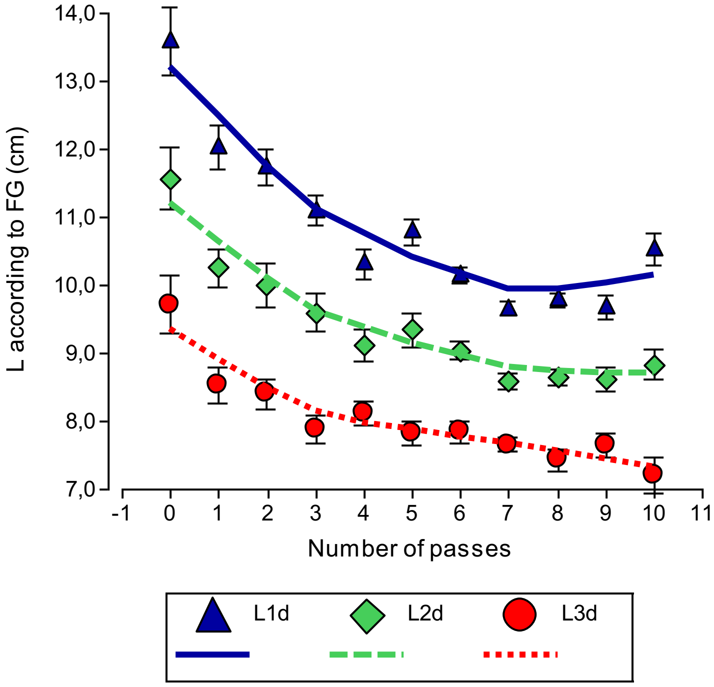
For 100% of the fibres analysed which belonged to the coarse fibre group (FG1), the crimp group (CG) belongs to the CG4. Table 4 shows that this is true for all fleece types and does not change with the successive passes. With respect to CG2 and CG3, the CG of the different fleece types are similar, except for a trend towards a CG with lower CF for the Lustre fleece type. Due to the fact that in this sub-chapter the Lustre fleece type is represented only by one actual Lustre fleece, which is joint by a HL fleece, the difference in relation to the CG in respect to DC, IC and SC fleeces is not so noticeable. Within the Result chapter, in Sub-chapter 1, Division 1.4, and in Sub-chapter 3, Division 3.4, it is shown that Lustre fleeces typically contain more CG4 fibres in FG2 and even in FG3 fibres of CG4 are present.

Table 4: CG according to FG for each FT. (Fibre during the dehairing process)

	1	2	3	4	5	6
	Product: Modification of the presence of a certain CG implementing dehairing.					
	FG1		**FG2**		**FG3**	
	CG	Modification	CG	Modification	CG	Modification
DC	Only CG4	No modification	A lot of CG3, some of CG4.	CG3 increases	CG2 and CG3, more of CG2.	No modification
IC	Only CG4	No modification	A lot of CG3, some of CG4.	CG3 increases	CG2 and CG3, more of CG2.	CG2 increases
SC	Only CG4	No modification	A lot of CG3, some of CG4.	CG3 increases	A lot of CG2, some of CG3.	CG2 increases
Lustre	Only CG4	No modification	CG3 and CG4, more of CG3.	No modification	CG2 and CG3, more of CG3.	No modification
	Subproduct: Modification of the presence of a certain CG implementing dehairing.					
	FG1		**FG2**		**FG3**	
	CG	Modification	CG	Modification	CG	Modification
DC	Only CG4	No modification	A lot of CG4, some of CG3.	Only CG4	A lot of CG3, some of CG2.	Only CG3
IC	Only CG4	No modification	Almost only CG4, a few of CG3.	No modification	Almost only CG3, a few of CG2 and CG3.	No modification
SC	Only CG4	No modification	Almost only CG4, a few of CG3.	No modification	Almost only CG3, a few of CG4.	No modification
Lustre	Only CG4	No modification	Almost only CG4, a few of CG3.	Only CG4	Almost only CG3, a few of CG2 and CG3.	Only CG3

2.5. Fibre length

Figures 44 and 45 show the fibre length during successive passes in the product and the subproduct, and plot the differences between the 3 FGs.

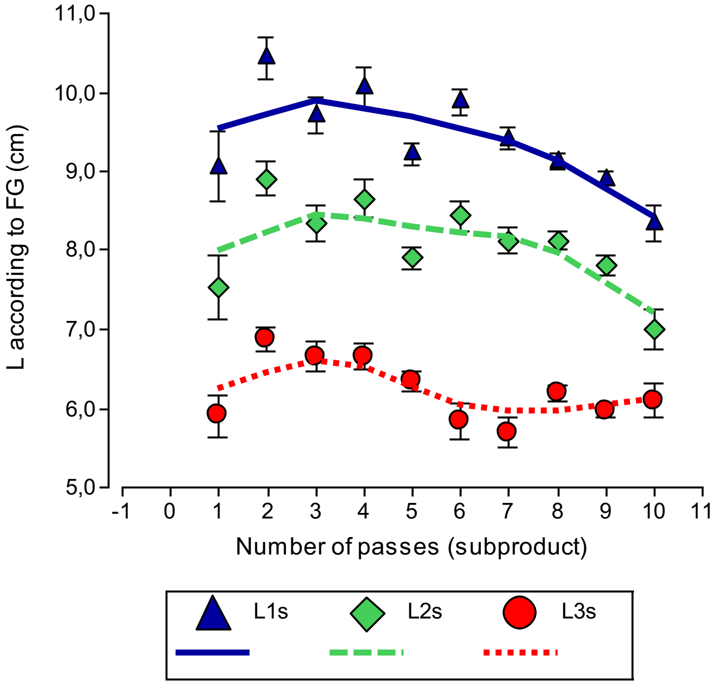


Number of passes:	0	1	2	3	4	5	6	7	8	9	10
L1d:	A	A B	A B	B C	D E	B C D	D E F	F	E F	E F	C D
L2d:	A	A B	A B C	B C	C D E	C D	C D E	E	D E	D E	D E
L3d:	A	A B	A B	B C D	B C	B C D E	B C D E	C D E	D E	C D E	E

Kruskal–Wallis test: Different letters show a significant difference between populations (w<0.05).

L1d: Length of FG1 - L2d: Length of FG2 - L3d: Length of FG3

Figure 44: Modification of length regarding the successive passes, according to FG – product. (Fibre during the dehairing process)



Number of passes:	1	2	3	4	5	6	7	8	9	10
L1s:	C B A	F	F E D	F E	D C B	F E	E D C	D C B A	B A	A
L2s:	B A	F	F E D	F E	D C B A	F E	E D C	E D C B	C B A	A
L3s:	B A	D	D C	D	D C B	B A	A	C B A	B A	B A

Kruskal–Wallis test: Different letters show a significant difference between populations (w<0.05).

L1s: Length of FG1 - L2s: Length of FG2 - L3s: Length of FG3

Figure 45: Modification of length regarding the successive passes, according to FG – subproduct. (Fibre during the dehairing process)

3. Effect of classing and of dehairing on fibre textile quality

3.1. Schematic and conceptual description of the fleece types

In Figure 46, the staple shapes are schematically illustrated according to fleece type.

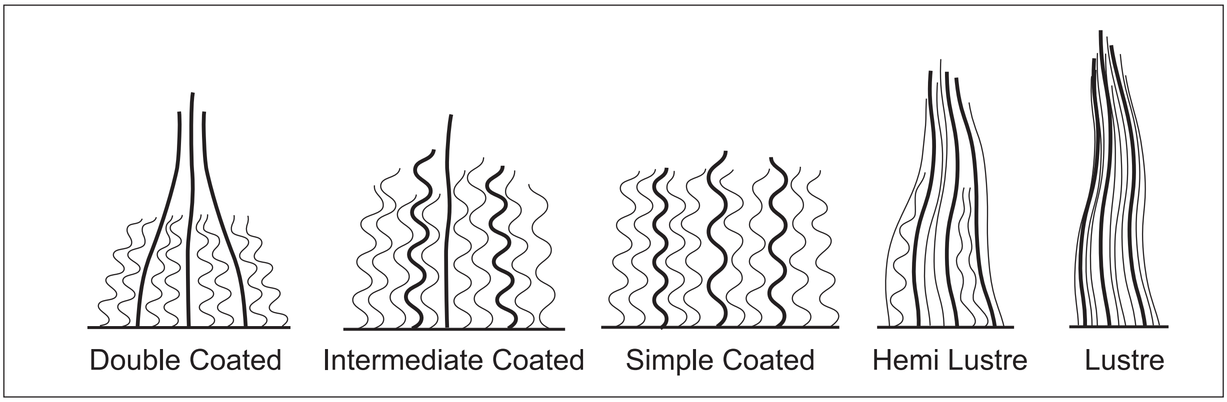


Figure 46: Schematic illustration of the staples of each fleece type
(modified from Frank et al. (2007a); Brodtmann et al., 2018).

The schematic illustration in Figure 46 is complemented by the description of the differences of the staple shapes (Table 5).

Table 5: Schematic description of the staple according to fleece type (FT).

DC	In the DC fleece, the primary and secondary fibres are the most heterogeneous ones. The staple has a lot of bulk, which is formed only by the crimped fibres of the down. These are intermingled with the coarse fibres, the cover fibres, which are almost straight. The staple forms a triangular shape with a wide base and a tip out of which the long cover fibres emerge.
IC	The IC fleece staple is formed as an intermediate between that of the DC and SC fleece staple.
SC	The SC fleece staple is homogeneous in appearance and shows a lot of bulk, which is produced by the primary and secondary fibres that are both crimped. The staple does not form a triangular shape, but shows many small tips.
HL	In relation to its shape, the HL fleece staple is very similar to that of the Lustre fleece, but the staple shows a little bit of bulk which is due to the fact that it contains some fibres of a slightly higher crimp frequency.
L	The L fleece staple is homogeneous in appearance, shows a glassy lustre and no bulk. The fibres form a helicoidal staple with a long undulation. The staple has a long, pronounced tip.

DC: Double coated, IC: Intermediate coated, SC: Simple coated, HL, Hemi lustre, L: Lustre.

To this schematic description a conceptual description of the fleece structure can be added, which results from the particularity of each fleece type (Table 6). According to this logic, each FT can be described through a specific concept according to which its structure is constituted.

Table 6: Conceptual description of the fleece structure according to fleece type (FT).

DC	The DC fleece is formed through the concept of combining long, coarse fibres that are almost straight with short, crimped, fine fibres, which all show an opaque lustre type.
IC	The IC fleece structure is formed as an intermediate between that of the DC and SC fleece structure.
SC	The SC fleece shows the concept of combining fibres that all have a high crimp frequency, an opaque lustre type and fibres of intermediate length. The fibres differ from each other mainly by their diameter.
HL	The HL fleece structure is formed as an intermediate between SC and Lustre.
L	The L fleece follows the concept of combining fibres that all have a long, regular undulation, high lustre and are relatively long. The fibres differ from each other mainly by their diameter.

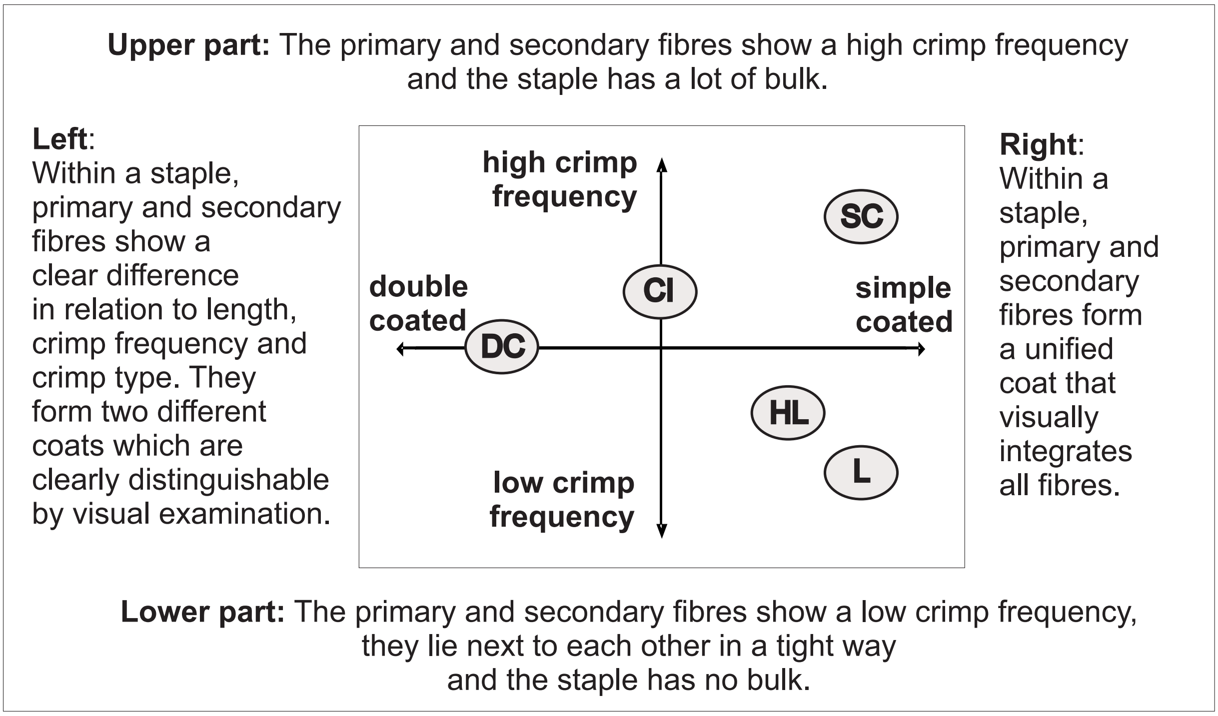
DC: Double Coated, IC: Intermediate Coated, SC: Simple Coated, HL, Hemi Lustre, L: Lustre.

3.2. Fleece Type differentiation according to opposite characteristics

This leads to the graph in Figure 47: on the left, there is a fleece type in which the two coats, corresponding to primary and secondary fibres, are clearly distinguishable in the appearance of a fibre staple. That is to say that it is a fleece in which the visual appearance makes it possible to distinguish the two coats. On the right-hand side of the graph, there are those fleece types in which, when looking at the whole staple, only one coat is visible, in other words, a simple coat. This is the case in these particular fleece types although in all fleece types primary and secondary fibres exist and therefore the two coats.

According to the specific concepts for each fleece type, the most heterogeneous type is the DC type. The SC and L types are more homogeneous and therefore the L type is also a simple coated fleece, that is to say that it visibly has only one coat, just like the so-called SC fleece type. At the same time, however, these two fleeces clearly differentiate from each other because each of them is composed of fibres of different crimp frequency, crimp type and lustre type. Figure 47 derives from this logic, showing how each fleece type is described by means of opposites in relation to certain fleece characteristics. These opposites are, on the horizontal axis, the fleece visual appearance as having a single coat (simple coated) versus two coats (double coated) and, on the vertical axis, high versus low crimp frequency. Here it is important to emphasise that, regardless of whether a fleece is double or single coated, all types of llama fleece are formed by a heterogeneous composition of different fibre types, each fibre type with its specific variations and each fleece type with its specific structure that makes it unique.

High versus low crimp frequency is equivalent to high versus low bulk, more precisely versus no bulk. This happens because the crimp type of the L fleece shows a very regular undulation and most of the fibres show the same crimp pattern, which allows all fibres to lie next to each other in a tight way. In contrast to that, the fibres of an SC fleece not only have a high CF, but also show different CF from each other as well as an irregular crimp type, which results in a very voluminous and "airy" staple structure in which the individual fibres are held relatively loosely among each other. This is in accordance with the results found in Frank et al. (2011a) who confirm that the bulk of the Lustre and Hemi Lustre fleece types is more reduced than the Double Coated, Intermediate Coated and Simple Coated fleece types.



Upper part: The primary and secondary fibres show a high crimp frequency and the staple has a lot of bulk.

Left: Within a staple, primary and secondary fibres show a clear difference in relation to length, crimp frequency and crimp type. They form two different coats which are clearly distinguishable by visual examination.

Right: Within a staple, primary and secondary fibres form a unified coat that visually integrates all fibres.

Lower part: The primary and secondary fibres show a low crimp frequency, they lie next to each other in a tight way and the staple has no bulk.

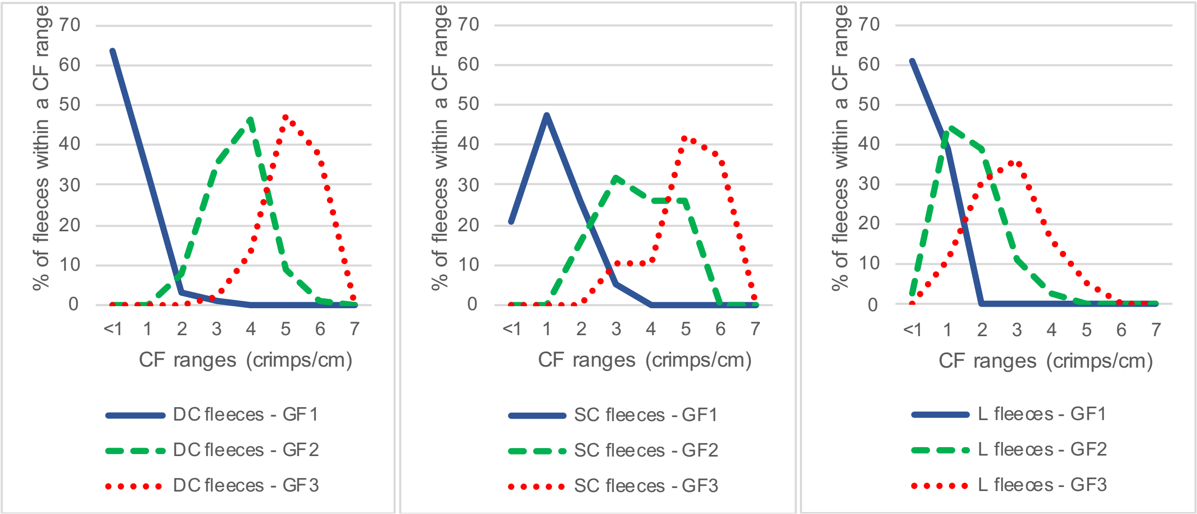
Reference: DC: Double Coated, IC: Intermediate Coated, SC: Simple Coated, HL, Hemi Lustre, L: Lustre.

Figure 47: Evaluation according to opposites in relation to the visual appearance of the fleece coats and the crimp frequency.

3.3. Crimp frequency according to fleece type

The average crimp frequency (CF) found was 2.8 crimps/cm and the range of measured CF included values from 0.5 to 6.7 crimps/cm, being the highest value of an IC fleece. The highest CF measured for a single fibre separately was 7.0 crimps/cm and corresponds to CG1. This value was recorded for fibres from DC, IC and SC fleeces. These are separate fibres and are not reflected in the frequency because this graph is plotted from the average value of three fibres, whose highest value is 6.33 crimps/cm and is included in the range of 6 crimps/cm.

Figure 48 shows the CF distributions of the fleece types DC, SC and Lustre. It was found that the IC fleeces behave in much the same way as the DC fleeces and that the HL fleeces are identical to the Lustre fleeces with respect to the CF of FG1 and show about 1 crimp/cm more in FG2 and FG3.



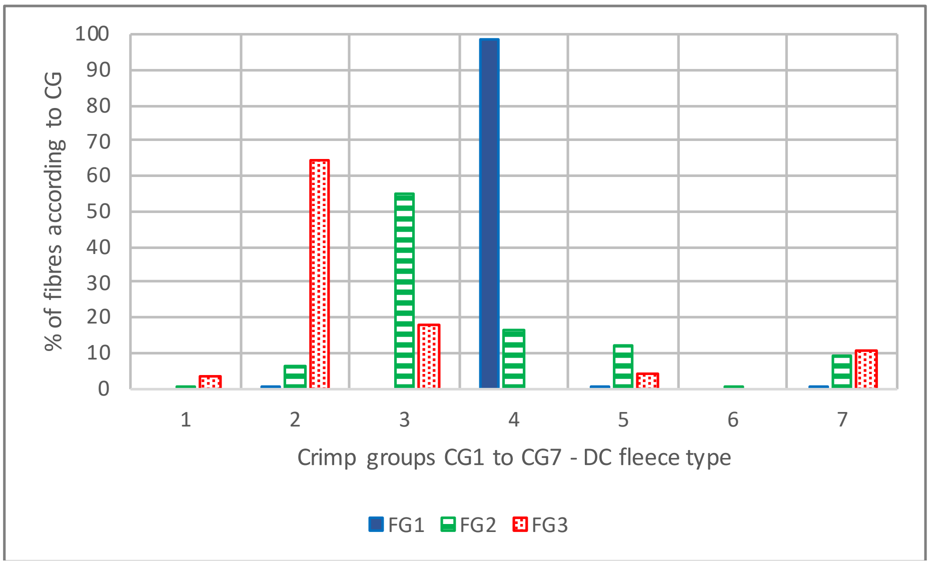
Reference: CF: Crimp frequency, DC: Double coated, SC: Simple coated, L: Lustre.

Figure 48: Distribution of crimp frequency (in crimps/cm) according to FG.

3.4. Crimp groups according to fleece type

Figures from 49 to 51 show the CGs that were found with respect to the fleece types DC, SC and Lustre. Only a few fibres were found in CG5, CG6 and CG7, therefore, they are not included in the discussion. Furthermore, apart from their three-dimensional shape, the fibres of these CGs are similar to those of CG1, CG2, CG3 and CG4. Few fibres were also found in CG1, most of which were from SC fleeces (7%).

With respect to the fine fibres, Figures from 49 to 51 show large differences among the fleece types: the DC and SC fleece types show similarity to each other and differentiate from the Lustre fleece type. Data referring to IC and HL fleeces were not included in the graphs, but the results show that IC fleece behaves similarly to DC and SC, and HL fleece behaves similarly to Lustre fleece. For DC and SC fleeces, CG2 covers a high percentage of the FG3 (64% and 56% respectively). CG2 and CG3 together even cover the vast majority of FG3 (82% for both fleece types). Furthermore, no CG4 fibres were found within this FG. The FG3 fibres of IC fleeces turned out to be of similar CG as the DC and SC fleeces (CG2 and CG3 together cover 85% and no CG4 fibres were found).

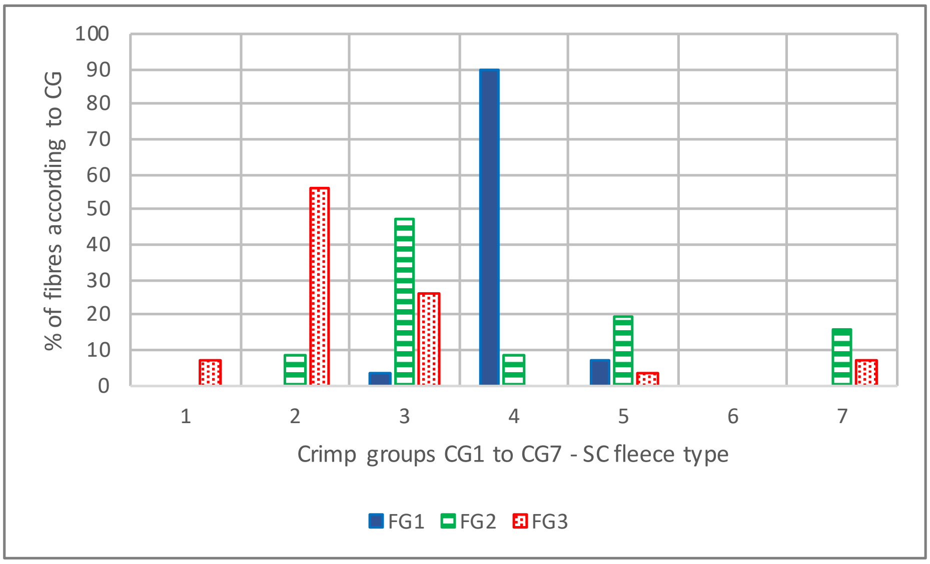


CG:
Crimp group.

FG:
Fibre group.

DC: Double
Coated fleece
type.

Figure 49: Distribution of fibres according to CG differing per FG - for the DC fleece type.

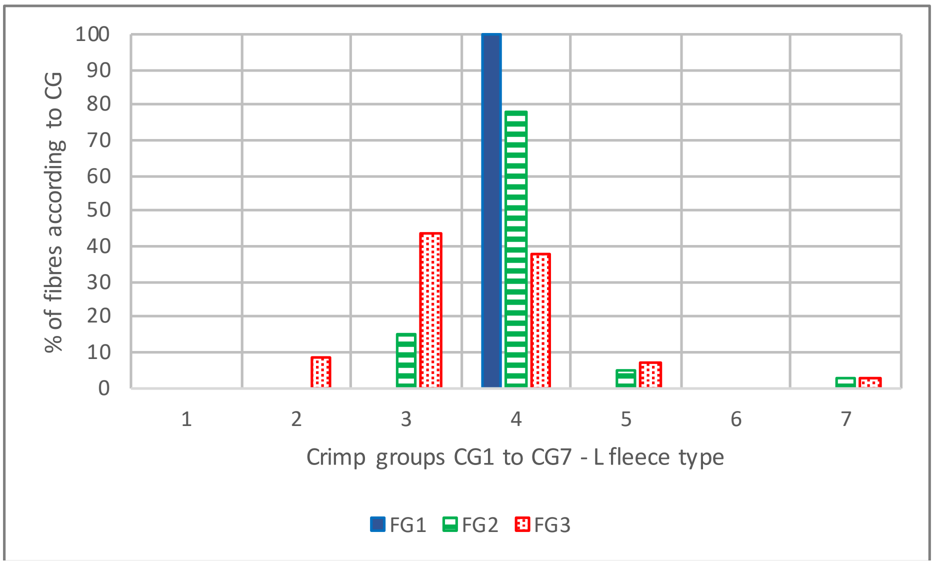


CG:
Crimp group.

FG:
Fibre group.

SC: Simple
Coated fleece
type.

Figure 50: Distribution of fibres according to CG differing per FG - for the SC fleece type.



CG:
Crimp group.

FG:
Fibre group.

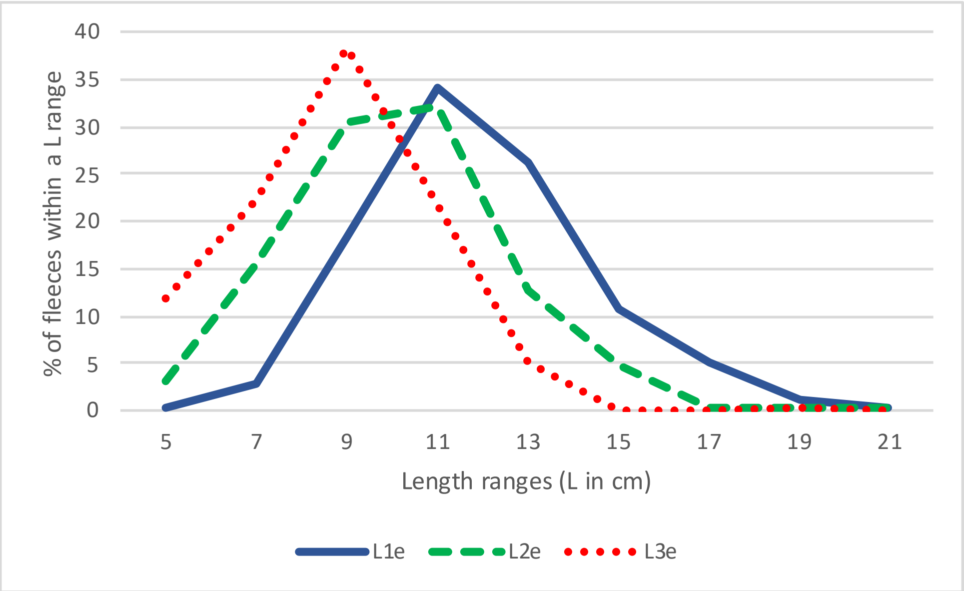
L: Lustre fleece
type.

Figure 51: Distribution of fibres according to CG differing per FG - for the Lustre fleece type.

In contrast to this, the FG3 fibres of the Lustre fleeces include only very few CG2 fibres (8%), but a high percentage of CG4 fibres (38%). The HL fleece behaves more similarly to the Lustre fleece than other fleece types as it shows the presence of CG4 fibres (12%). In addition, CG2 and CG3 fibres (20% and 55% respectively) show the extended and regular undulation pattern that is typical for Lustre fleece fibres and is contrary to the irregular undulation observed in DC, IC and SC fleeces.

3.5. Fibre length according to fleece type

As shown in Figure 52, the range of fibre lengths includes values from 4.0 to 26.0 cm with a mean at 9.9 cm. It was observed a general trend of longer FG1 fibres and shorter FG3 ones, but the specific difference between FGs depends on the individual fleece. The difference between the FGs with respect to fibre length is higher for DC fleeces and lower for SC fleeces.



L1e: Length of FG1 fibres.
L2e: Length of FG2 fibres.
L3e: Length of FG3 fibres.

Figure 52: Distribution of fibre length (L in cm) according to FG.

3.6. Mean diameter according to fleece type

Group of coarse fibres (FG1):

Table 7: Differences in mean MD1e according to FT, without classing (Kruskal–Wallis test).

FT	**N**	**Mean of MD1e µm**	**SD1e**	**K-W Ranks**	**Sig. (w<0.05)**		
L	36	40.25	3.90	67.90	A		
SC	19	40.68	5.65	77.13	A		
HL	46	41.68	5.39	88.83	A		
IC	50	46.18	5.31	140.80		B	
DC	101	49.65	8.37	166.75			C

(Different letters show a significant difference between populations (w<0.05))
(FT: fleece type, MD1e: Mean diameter of fibre group 1)

Tables 7 and 8 show the results of the analysis of a Kruskal Wallis test. In this division, coarse (FG1) and fine (FG3) fibres are analysed according to FT and without implementing a classing of the fleeces regarding fineness.

Group of fine fibres (FG3):

Table 8: Differences in mean MD3e according to FT, without classing (Kruskal–Wallis test).

FT	**N**	**Mean of MD3e µm**	**SD3e**	**K-W Ranks**	**Sig. (w<0.05)**		
SC	19	22.79	4.03	92.32	A		
L	36	22.88	2.86	96.79	A		
HL	46	23.86	4.64	114.33	A	B	
DC	101	25.03	3.84	138.33		B	C
IC	50	25.47	3.56	148.19			C

(Different letters show a significant difference between populations (w<0.05))
(FT: fleece type, MD3e: Mean diameter of fibre group 3)

3.7. Mean diameter according to fleece type with and without classing and/or dehairing

Group of fine fibres (FG3):

Table 9: Differences in mean MD3e according to FT, including TMDne<31µm fleeces (Kruskal–Wallis test).

FT	**N**	**Mean of MD3e µm**	**SD3e**	**Sig. (w<0.05)**
SC	17	21.72	2.59	A
L	34	22.49	2.40	A
HL	39	22.59	3.43	A
DC	65	22.94	2.34	A
IC	32	23.41	2.07	A

(Different letters show a significant difference between populations (w<0.05))
(FT: fleece type, MD3e: Mean diameter of fibre group 3)
(TMDne<31µm: Total mean diameter weighed by fibre frequency of TMD lower than 31 µm)

In order to elaborate Tables 9 and 10, a classing was simulated by excluding the data of some fleeces from the analysis, that is to say, that data of fleeces from a certain TMDne onwards were excluded. With respect to the effect of a classing regarding FT, only FG3 was analysed as it is the fibre group that represents the product that would result from a dehairing and it is the group of greatest textile interest.

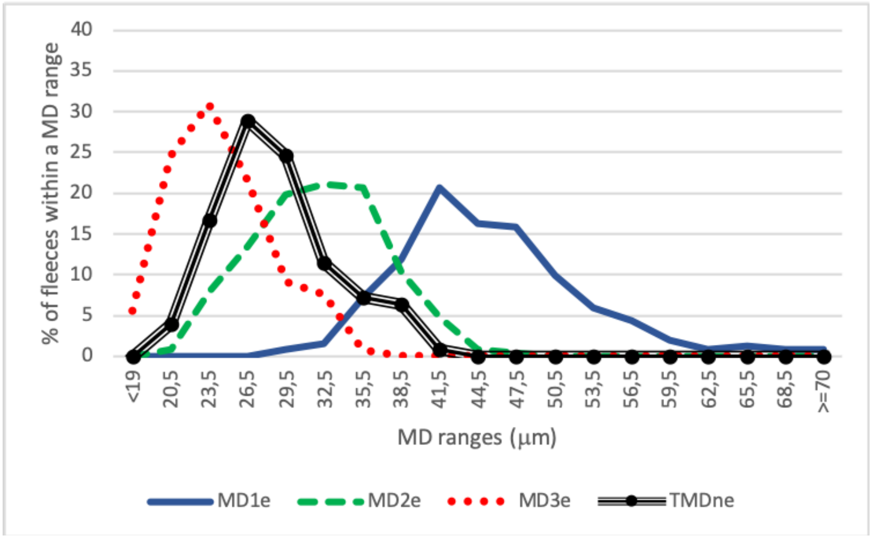
Table 10: Differences in mean MD3e according to FT, including TMDne<28µm fleeces (Kruskal–Wallis test).

FT	**N**	**Mean of MD3e µm**	**SD3e**	**Sig. (w<0.05)**
HL	26	20.72	2.47	A
SC	14	21.24	2.38	A
DC	37	21.66	1.79	A
L	30	22.01	2.00	A
IC	18	22.08	1.61	A

(Different letters show a significant difference between populations (w<0.05))
(FT: fleece type, MD3e: Mean diameter of fibre group 3)
(TMDne<28µm: Total mean diameter weighed by fibre frequency of TMD lower than 28 µm)

3.8. Mean diameter with/without classing and/or dehairing

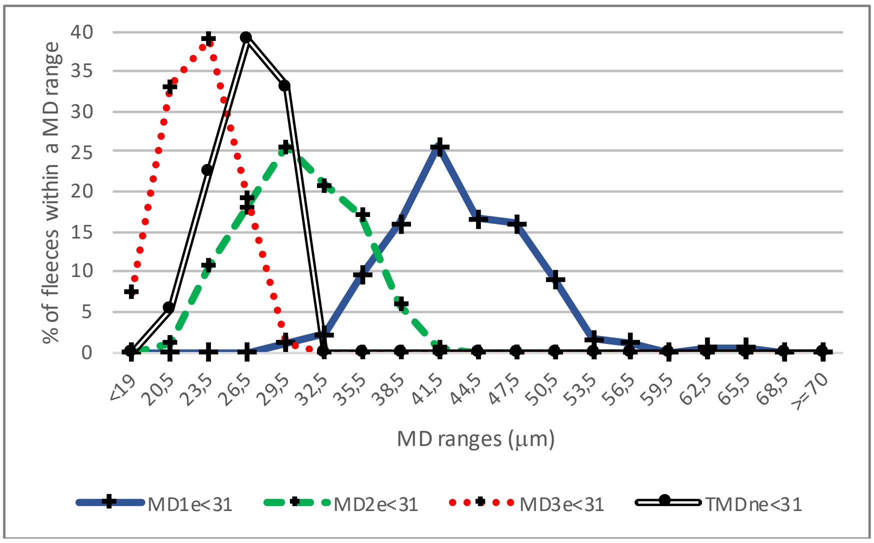
As mentioned above, with respect to the analyses described in Sub-chapter 3, no distinction according to FT was applied, but all fleeces were analysed as a whole. Figure 53 plots the distribution of different mean diameters without classing. On the one hand, it shows the distribution of the total mean diameter weighted according to fibre frequency (TMDne) and, in addition, it plots how the TMDne is broken down into the three distributions, one for each of the mean diameters according to FGs (MD1e, MD2e and MD3e). It shows that 29% of the 252 fleeces analysed had a TMDne within the range of 26.5 µm. The TMDne range resulted in values between 19.2 and 41.1 µm. The average TMDne of all fleeces as a whole was 28.7 µm, as shown in column 1 of Table 14. For FG3, the lowest MD3e measured were 16.3 and 17.4 µm, which were included in the range of <19 µm. For FG1, the coarsest MD1e measured were 75.3 and 86.5 µm, which were included in the range of ≥ 70.00 µm.



TMDne: Total MD weighted by the fibre frequency of each FG.

MD1e: MD of FG1.
MD2e: MD of FG2.
MD3e: MD of FG3.

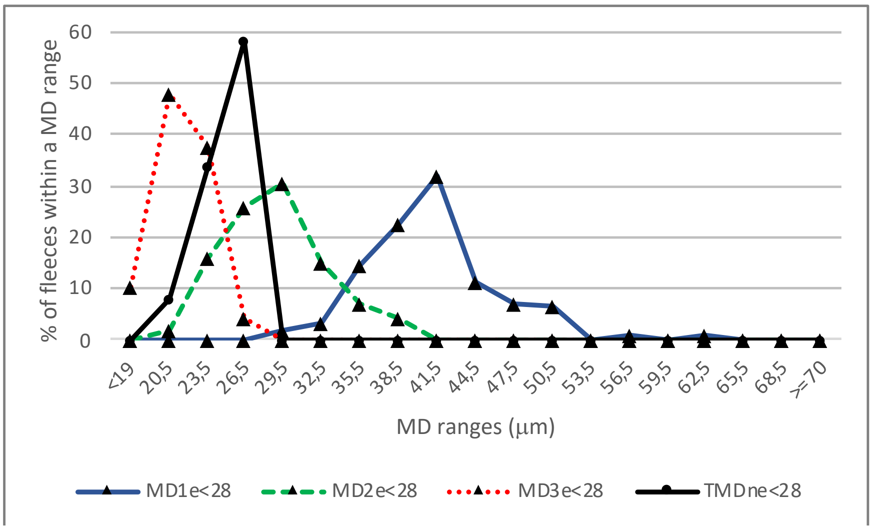
Figure 53: Distribution of different MDs (µm) (without classing, that is to say, including fleeces of all the TMDne).



TMDne<31: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<31µm.

MD1e<31: MD of FG1, only fleeces of TMDne<31µm.
MD2e<31: MD of FG2, only fleeces of TMDne<31µm.
MD3e<31: MD of FG3, only fleeces of TMDne<31µm.

Figure 54: Distribution of different MDs (µm) with initial classing (including fleeces of TMDne<31µm).



TMDne<28: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<28µm.

MD1e<28: MD of FG1, only fleeces of TMDne<28µm.
MD2e<28: MD of FG2, only fleeces of TMDne<28µm.
MD3e<28: MD of FG3, only fleeces of TMDne<28µm.

Figure 55: Distribution of different MDs (µm) with a more rigorous classing. (including fleeces of TMDne<28µm).

Group of coarse fibres (FG1):

Figure 56 repeats parts of the graphs in Figures from 53 to 55: the TMD of each of those figures (TMDne, TMDne<31 and TMDne<28) and the MDs of the coarse fibres (MD1e, MD1e<31 and MD1e<28) are repeated. The right part of Figure 56 that is related to the coarse fibres is equivalent to columns 2 and 3 of Table 14.

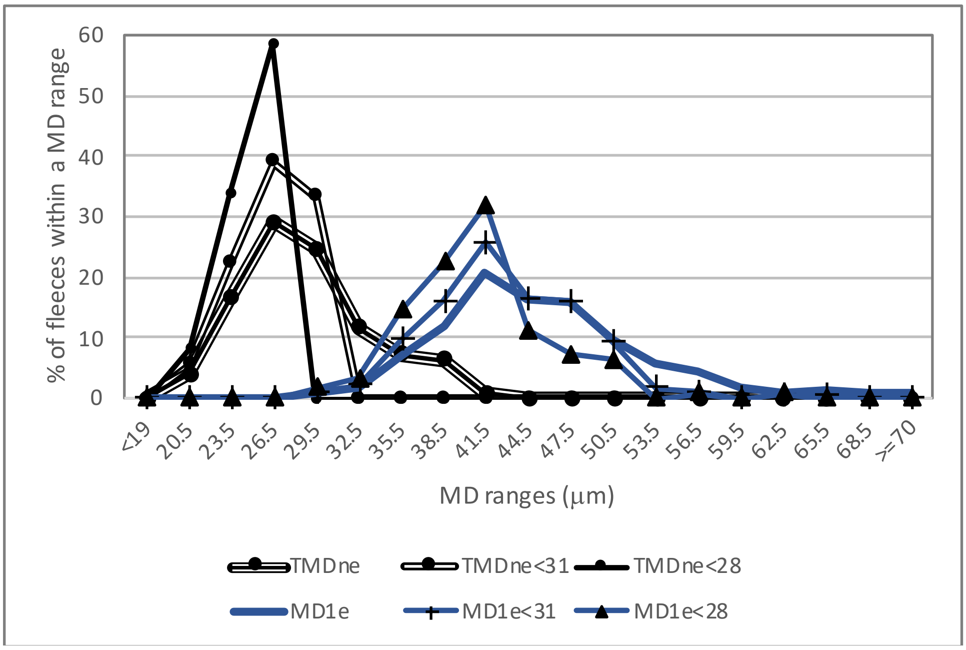


Figure 56: Distribution of different MDs (µm) with and without classing regarding fineness.
TMDne: Total MD weighted by the fibre frequency of each FG.
MD1e: MD of FG1.
TMDne<31: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<31µm.
MD1e<31: MD of FG1, only fleeces of TMDne<31µm.
TMDne<28: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<28µm.
MD1e<28: MD of FG1, only fleeces of TMDne<28µm.

3.9. Classing and dehairing potential

The results of four possible sequences that could be used in practice in order to obtain raw material suitable for the production of fine textiles are shown below:

- Table 11: Classing alone.
- Table 12: Dehairing alone.
- Table 13:
  - An initial classing, including TMDne fleeces<31µm, followed by dehairing.
  - A more rigorous classing, including TMDne fleeces<28µm, followed by dehairing.

MD reduction through classing, without dehairing:

Table 11 shows the results of a Kruskal Wallis test simulating the implementation of classing, without performing a subsequent dehairing. The second column shows the number of fleeces (N), which decreases downwards as a certain number of fleeces are excluded from the analysis by simulating the classing. The results show a reduction of the initial mean from 28.7

µm to 26.5 µm when including fleeces of a TMDne<31µm and to 25.0 µm when including even fewer fleeces of only TMDne<28 µm. As seen in Column 1 of Table 14, the reduction is 2.2 and 3.7 µm respectively.

Table 11: Differences in the TMDne mean due to classing (Kruskal–Wallis test).

Fleeces	**N**	Mean of **TMDne µm**	**Sig. (w<0.05)**
All fleeces	252	28.7	A
TMDne<31µm fleeces include	187	26.5	B
TMDne<28µm fleeces include	125	25.0	C

(Different letters show a significant difference between populations (w<0.05))
(TMDne: distribution of total mean diameter weighted according to fibre frequency)
(TMDne<31µm: Total mean diameter weighed by fibre frequency of TMD lower than 31 µm)
(TMDne<28µm: Total mean diameter weighed by fibre frequency of TMD lower than 28 µm)

MD reduction through dehairing, without prior fleeces classing:

Table 12 shows the results of a Kruskal Wallis test simulating the implementation of a dehairing by comparing the MD of the whole fleece (TMDne) with the MD of the fine fibre group (FG3). In this analysis no classing was simulated, as seen in the second column containing the N, since in both rows the whole N of 252 fleeces is verified. The initial mean of 28.7 µm is reduced to 24.4 µm, as seen in row 1 of Table 14: Reduction 4.3 µm.

Table 12: Difference between the TMDne mean and the Md3e mean, corresponding to a dehairing (without classing) (Kruskal–Wallis test).

Fleeces (Variable)	**N**	**Mean of TMDne or MD3e µm**	**Sig. (w<0.05)**
All fleeces (TMDne mean)	252	28.7	A
All fleeces (Md3e mean)	252	24.4	B

(Different letters show a significant difference between populations (w<0.05))
(TMDne: distribution of total mean diameter weighted according to fibre frequency)
(MD3e: distribution of each mean diameter of fibre group 3)

MD reduction through a combination of classing and dehairing:

Table 13 shows the results of a combination of the two evaluated measures that have potential to reduce the MD, classing with dehairing. The only exception is the highest row, where no fleeces were excluded by classing and only a dehairing is applied, achieving a MD3e of 24.4 µm. This row is equivalent to what is summarised in Table 12. The next row shows the result of an initial classing, including TMDne<31µm fleeces, followed by a dehairing, thus achieving a MD3e of 22.8 µm. The bottom row shows the results of a more rigorous classing, including only TMDne<28µm fleeces, also followed by a dehairing. This way, a MD3e of 21.6 µm is achieved. Table 13 is equivalent to columns 6 and 7 of Table 14 and the corresponding reduction is seen in column 9 of Table 14.

Table 13: Differences in the MD3e mean due to classing and dehairing (Kruskal–Wallis test).

MD3e	**N**	**Mean of MD3e µm**	**SD3e**	**K-W Ranks**	**Sig. (w<0.05)**
All fleeces	252	24.4	4.1		A
TMDne<31µm flee included	187	22.8	3.8		B
TMDne<28µm flee included	125	21.6	3.7		C

(Different letters show a significant difference between populations (w<0.05))
(TMDne<31µm: Total mean diameter weighed by fibre frequency of TMD lower than 31 µm)
(TMDne<28µm: Total mean diameter weighed by fibre frequency of TMD lower than 28 µm)
(MD3e: distribution of each mean diameter of fibre group 3)

The following table summarises information from all graphs and tables in Division 3.8 and 3.9.

Table 14: Differences between means of different types of mean diameter (MD) and its Standard Deviation (SD).

	Column	1	2	3	4	5	6	7	8	9
Row		Mean of TMDne µm **Reduction** µm	Mean of MD1e µm	SD1e µm	Mean of MD2e µm	SD2e µm	Mean of MD3e µm	SD3e µm	**Reduction by dehairing** µm	**Reduction by classing and dehairing** µm
1	Without classing regarding fineness	28.7	45.5	8.9	32.1	6.5	24.4	4.1	**4.3**	**---**
2	Includes fleeces TMDne<31µm **Reduction by classing** µm	26.5 **2.2**	43.0	8.2	30.5	6.1	22.8	3.8	**3.7**	**5.9**
3	Includes fleeces TMDne<28µm **Reduction by classing** µm	25.0 **3.7**	41.1	7.7	28.8	5.7	21.6	3.7	**3.4**	**7.1**

(TMDne: distribution of total mean diameter weighted according to fibre frequency)
(MD1e, MD2e and MD3e: mean diameter of fibre groups 1, 2 3)
(Dd1e, SD2e and SD3e: MD1e, MD2e and MD3e Standard Deviation)
(TMDne<31µm and TMDne<28µm: Total mean diameter weighed by fibre frequency of TMD lower than 31 µm and 28 µm)

Group of fine fibres (FG3):

Figure 57 repeats parts of the graphs in Figures from 53 to 55: the TMD of each of these figures (TMDne, TMDne<31 and TMDne<28) and the MDs of the fine fibres (MD3e, MD3e<31 and MD3e<28) are repeated. It only shows the ranges from "<19" to "41.5". The left part of Figure 57 (red curves) that is related to the fine fibres is equivalent to columns 6 and 7 of Table 14.

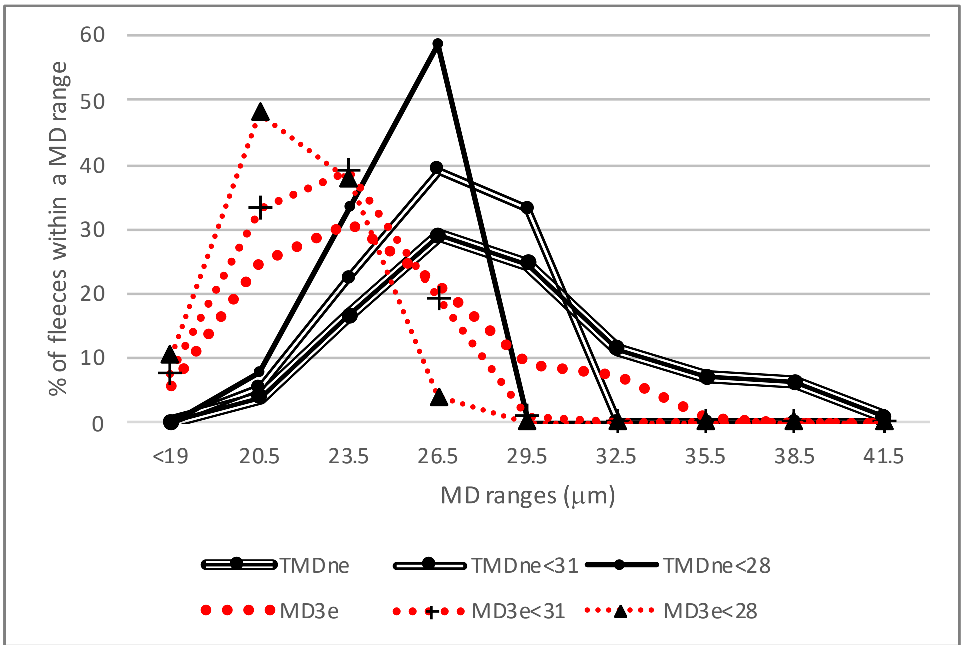


Figure 57: Distribution of different MDs (µm) with and without classing regarding fineness.
TMDne: Total MD weighted by the fibre frequency of each FG.
MD3e: MD of FG3.
TMDne<31: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<31µm.
MD3e<31: MD of FG3, only fleeces of TMDne<31µm.
TMDne<28: Total MD weighted by the fibre frequency of each FG, only fleeces of TMDne<28µm.
MD3e<28: MD of FG3, only fleeces of TMDne<28µm.

3.10. Simulation of a classing regarding fineness and a dehairing

Based on the parameters defined in Table 3, taking only the SC fleece type, and after classing the analysed llama fibre lot regarding fineness, the dehairing effect was simulated to bring the FG1 frequency to 3.09%, which is shown in Table 15. Each fibre sample was taken as corresponding to one fleece within a fibre lot.

The fibre samples from the database used in the age effect study in Sub-chapter 1 were chosen based on their fleece type or staple (only SC) and on their initial percentage of coarse fibres (N%1d) using as reference the confidence interval of the y-intercept (constant in Table 3), assuming that this ordinate is real because it represents the value of the coarse fibre frequency of the original unprocessed sample, which is supported by the theory of regression analysis (Di Rienzo, 2015). Through this, samples with a total mean diameter higher than 32 µm were taken out of the simulation, which in almost all cases corresponded to samples of an age class older than 9 years at the time of sampling.

Table 15: Fleece frequencies according to fineness, mean diameter and yield, before and after dehairing a llama fibre lot.

Fineness	Frequencies (%)	MD initial (µm)	Dehairing frequencies (%)	MD dehairing (µm)	Dehairing yield (%)	Difference in frequencies (%)	Difference in MD (µm)
SF	9.57	19.46	13.68	18.43	76.50	4.11	1.03
F	42.55	23.96	83.57	23.85	76.22	41.02	0.11
M	30.85	27.14	2.74	26.80	53.25	-28.11	0.34
G	17.02	34.13	0.00	-	4.78	-17.02	-
	Addition:	Average:	Addition:	Average:	Average:		
	100	**26.24**	100	**23.15**	57.00	0.00	

The change of frequencies for the different fineness is remarkable: in superfine (SF) it increased by 4.11%, in fine (F) it increased dramatically by 41.02%, while in medium (M) it decreased by 28.11% and in coarse (G) it decreased by 17.0%, taking it to 0%. The mean diameter weighted according to frequency of the MD fleece lot of 26.24 µm decreased to a MD of 23.15 µm, that is to say that it decreased by 3.09 µm. The yield is very varied in the different fineness, high in SF and F, medium in M and low in G. What was taken into account for the yield is only what corresponds to the fibre, eliminating the percentage that normally corresponds to soil content, cellular desquamation and vegetable matter, regarding the industry's opinion in this respect (Seghetti Frondizi, D.G., personal communication).

CHAPTER V. DISCUSSION

1. Age effect on llama fleece structure

1.1. Total mean diameter and mean diameter according to fibre groups (FGs)

The increase in the total mean diameter (TMD) with increasing age was confirmed for the different measured variants (TMDv, TMDw and TMDn). The difference between the different TMD values is from 2.2 to 4.3 µm in age classes from 1 to 10, and it rises to 5.2 µm in the age class of 11 years old. But, beyond these differences, all curves show the same biological effect, which involves a low initial MD that increases until it stabilises at a certain age and, then, it starts to decrease. This happens for the TMDv at age class 5 and for TMDw and TMDn at age class 6.

The MD coarsening regarding the age of the animal is a fact known from the available literature and can be confirmed in studies on this subject carried out for Australian alpacas (McGregor & Butler, 2002; Idem, 2004), New Zealand alpacas (Aylan-Parker & McGregor, 2002; Wuliji et al., 2000), Argentine guanacos (Bacchi et al., 2010), Bolivian llamas (Iñiguez et al., 1998; Martínez et al., 1997), Argentine llamas (Frank et al., 2006a), Chilean alpacas (Crossley et al., 2014), in Merino wool (Atkins, 1996), in mohair (Van Der Westhuysen et al., 1985; Martin et al., 1998) and in cashmere (McGregor & Butler, 2008a) as all these studies confirm a fibre coarsening regarding age. In Australian alpacas the increase in diameter is from 22 to 40 µm and is accompanied by an increase in body weight (McGregor, 2006). When exploring the optimal age to sample for diameter selection in Australian alpacas, it was determined that it should be above 2 years old (low repeatability) and that the increase occurs up to 7.5 years old (McGregor & Butler, 2004). In this case, a linear relationship between body weight gain and diameter was obtained, with an increase in diameter of 0.64 µm for Huacayas and 0.36 µm for Suris for every 10 kg of weight gain. In llamas from the Argentine altiplano a TMD increase is verified up to the age of 6 years old, with a flattening after this age and having no significant decrease (Frank et al., 2006a). In this work, it is clearly shown that shearing frequency does not affect TMD and the interaction between shearing frequency and age is not significant. In many observations of alpacas from Puno region, a similar quadratic linear trend is obtained, but it is stabilised at around 5 years old (Cucho, 2018). The equivalence of the curve of diameter increase and body size increase is also established in other species: in crossbred sheep a growth plateau is verified at 3 years old and coincides with the maximum increase in diameter (Sumner & Upsdell, 2001). Diameter in Merino sheep of different lines increases up to 5 years old, together with other quality characteristics (Mullaney et al., 1969; Hatcher et al., 2005). In Angora goats, the relationship fits a cubic model, reaching the largest diameter between 3.5 and 4 years old, coinciding with the highest fleece weight, but it is negatively related to weaning weight in some of these goats, indicating some relationship with the proper development of the follicle (McGregor et al., 2012). Indeed, in Argentine llamas, an increase in diameter up to 4 years old was verified in relation to the reduction in follicular density and the increase in body size (Frank et al., 2006a), which would explain the increase in fibre diameter.

The innovative aspect of this analysis is to reveal where the TMD increase originates, that is to say which FGs or fibre types contribute the most to this increase. The different MD variables plotted in Figures from 11 to 14 as well as in Figures 17 and 21 provide information in this respect, which is also discussed in the following paragraphs. Furthermore, the TMD increase is explained in terms of the weight and frequency of certain fibre types (Figures 15, 16, 18 and 22). Describing fibre coarsening through the TMD means staying on a general level, while analysing the different fibre groups (FG1, FG2 and FG3) or fibre types (A, F, I, C and G) and their respective frequencies leads the analysis to a more specific level that allows us to investigate the origin of the coarsening or micron blowout, taking into account that the dehairing removes certain fibre types that can influence the mean diameter (Singh, 2003). In order to provide definitions of the age effect with respect to the textile quality, it is fundamental to analyse two aspects: on the one hand, how much the fine fibres (MD3), which are the desired fibres for the production of fine clothing, increase in coarseness, and, on the other hand, how much the presence of objectionable fibres increases, being these fibres the responsible ones for the prickle effect on the skin and should be removed by dehairing.

The TMDv was measured on the original fibre sample: whole staples as extracted from the fleece, while the TMDw and TMDn were measured after the implementation of the Three Group Dissection, that is to say, after the weighting by fibre samples of each of the three formed FGs (Figure 5). Figure 8 shows the relationship among these three TMD variables. Each of the three curves is complemented with the information which results from a Kruskal Wallis (KW) test. The results are very similar, only differing by one year with respect to the age at which TMD stabilises, which is age class 5 for TMDv and 6 for TMDw and TMDn. The discussion about the age at which the peak of the curve is determined is accomplished in division 1.6, as it is of importance for the concordance of both databases.

Figure 2 provides a visual impression about the coarsening by showing staples of a SC fleece extracted from the annually collected fibre samples, placed on a velvet cloth. The staple on the left is of age class 1 and looks softer and less compact, while the appearance of the staple on the right which is of age class 5 is coarser and more compact.

With respect to the TMD, it was found that the specific hypothesis of Sub-chapter 1 is validated since an increase in the mean fibre diameter is unfavourable from the point of view of the textile quality. Also, it is equivalent to a loss for the producer since a fundamental price-determining characteristic is the mean diameter (Vinella, 1994).

The three MD curves of the different FGs (MD1, MD2 and MD3) show evidence of accompanying the TMDn biological effect, that is to say, they show that both fine and coarse fibres contribute to the TMDn coarsening. The difference between the lowest and highest MD is approximately 9.3, 9.0 and 6.8 µm for fibre groups FG1, FG2 and FG3 respectively, that is to say that a greater coarsening can be confirmed with respect to the coarse fibres (FG1 and FG2). Furthermore, the SD of the mean diameter of the three FGs (SD1, SD2 and SD3) also accompanies this biological effect as it has a trend to increase together with increasing age (Figures from 12 to 14). This is also verified in sheep, but is not as noticeable as the diameter change and it is smaller in magnitude in some Merino lines (Sumner & Upsdell, 2001). However, the diameter variation expressed as standard deviation is always correlated with the average, which confirms its bias with respect to the normal diameter distribution (Naylor, 1992a).

The percentage of fibres larger than 30 µm was found to be a good predictor of the prickle sensation produced by the fabric on the skin (Naylor, 1992b). However, there are several factors that can change this threshold value and it could be stated that it fluctuates between 26 and 35 µm, and further experimental evidence is required (Frank et al., 2015). In any case, taking these values as a reference, it is confirmed that the FG1 fibres are clearly objectionable fibres in terms of coarseness, while, during the first 5 age classes, the mean diameter of the FG of the fine fibres (MD3) remains below the 26 µm threshold, which separates the higher value fineness from the rest (McGregor, 2006). This is a fundamental aspect when determining the potential textile value of a llama fleece since, if these fibres can be separated from the group of coarse fibres, they can be used for the production of higher value fine textiles, independently of the elimination of the prickle factor (no literature references have been found on this assertion).

Group of coarse fibres (FG1):

In relation to the coarse fibre group in Figure 12, it should be noted that the finest fibres within that FG, even in the first age class, have a high MD1 (38.3 µm), that is to say that they are clearly above 35 µm. This confirms that even for the first shearing of animals being only one year old it is necessary to implement a dehairing if the aim is to provide raw material for the production of fine textiles, if the frequency of the fine fibres (yield) justifies it (Frank et al., 2014).

The results with respect to the MD of the intermediate fibres FG (MD2) plotted in Figure 13 confirm that, in general, it would not be desirable for this FG to form part of the dehairing product, given the value of its MD, at least this is asserted in the case of cashmere dehairing (Smith, 1988). The only exception would be the finest part of the fleeces of the first age class. Therefore, it is confirmed that it is appropriate to consider that only FG3 represents the product of a potential dehairing (Brodtmann et al., 2018).

Group of fine fibres (FG3):

The FG of the fine fibres (FG3) is the one that shows the potential textile quality of the llama fibre, as it is the one that represents the dehairing process product. For the first three age classes, the fineness of MD3 is 20.6 to 23.5 µm (superfine and fine according to Table 1), that is to say that these are fleeces that provide raw material with a high potential for dehairing and confirm the high textile potential provided by llama fibre. Even for age classes 4 and 5, the MD3 is below the threshold of 26 µm (McGregor, 2006), thus confirming that these age classes also provide fleeces which can be considered for dehairing, depending on how high the requirements of the final product are.

At older ages the purpose of dehairing would be questionable because, although the finer fibres have a fineness that could justify the investment of dehairing within the textile chain, the low yield that would be obtained restrains this process (Seghetti Frondizi, 2014). It can be considered that from age class 6 onwards, textile quality clearly loses value. The MD3 maximum value was found to be at age class 10 with 27.4 µm. With regard to the fleece structure, it is confirmed that the age effect occurs for all 3 fibre groups, that is to say also for the fine fibre group and the modification results in a decrease of the textile quality. Therefore, the first specific hypothesis is confirmed, also with respect of this aspect of textile quality.

Figure 15 provides a reference for yield at dehairing as the variable used to define the yield is the weight of the FG3 in relation to the weight of the whole dissected staple (Frank et al., 2009). Figure 15 shows how yield is modified regarding the age. During the first three age classes, the yield average is 68%. For the age classes 4 and 5, it is around 61%, and then drops to approximately 50%. This raises the question up to which age of the animal a dehairing is justified. In any case, it must be considered that the yield depends not only on the diameter and frequency of the fibres present in the staple, but also on other factors such as the content of impurities (mainly soil) and the fleece condition when sheared (felting) (McGregor & Butler, 2008b; Seghetti Frondizi, 2014).

The relative weight (W%) curves in Figure 15 show a very similar trend towards the relative fibre frequency (N%) curves in Figure 16. However, an important difference between both graphs is that the relative weight of the FG of coarse fibres (W%1) and the relative fibre frequency of the FG of coarse fibres (N%1) differ from each other, with W%1 always being around almost 10% above N%1. That is to say that FG1 has a higher incidence in relation to the weight of its fibres than in relation to the quantity of those fibres or, in other words, the coarse fibres reach a higher weight even though there are relatively few of them. The same is true for the fine fibres (FG3) in the other sense, as they reach a lower weight even though their quantity is greater. The relatively higher W%1 possibly explains why the TMDw curve turns out to be slightly above the TMDn curve because the averages are weighted by the frequencies (Equations 2 and 3, Figure 8).

With regard to which fibres contribute most to the coarsening of TMDw and TMDn, it can be confirmed that those are the coarse fibres (FG1) since this is the curve that increases in relation to its relative weight and relative fibre frequency (W%1 and N%1), while the presence of fine fibres (FG3), which decreases significantly according to the KW comparison, nevertheless contributes to the change. However, the intermediate fibres remain more or less stable and do not show a significant change in W%2 nor N%2, and therefore do not contribute significantly to the change in TMD. Visually, the fibres that have the greatest impact on the TMD coarsening are those of FG1, which is indicated from the shape of the W%1 and N%1 curves, which increases with age, and because N%1 shows significant differences in the KW results. This finding based on the Three Group Dissection could not be contrasted with other published data. However, it is verified in the yarn made out of the dehaired and not dehaired llama fibre (Frank et al., 2012b). Division 1.2 discusses which fibre types make up FG1 and are therefore the ones leading to the TMD fibre coarsening, from a more biological point of view.

1.2. Mean diameter according to fibre type

Division 1.1 confirmed that the biological effect of coarsening exists, but beyond that, it remains an open question whether some of the fibre types are more responsive to this effect than others. Figure 17 plots the MD of each of the five fibre types, identified by their medulla (MDA, MDF, MDI, MDC and MDG), and its modification regarding age, that is to say that it exposes the phenomenon of micron blowout according to fibre type. Due to the shapes of the curves, it can be seen that the coarsening biological effect clearly exists for all fibre types. The KW results are significant for all 5 variables and the coarsening effect stabilises in age class 4 or 5 for all fibre types in the KW comparison. The difference between the lowest and highest MD is 6.1; 5.3; 9.0; 5.7 and 10.2 μm for non-medullated fibres and F, I, C and G medullated fibres respectively. It can be concluded that the TMD coarsening is better explained by the coarsening of the large medullated fibres, for which the MD rises 10 µm, than by the other fibre types. The MD of the interrupted medullated fibres is almost as high as 9 µm, but, being a fibre type with such a low fibre frequency (N%I in Figure 18), it has almost no influence on the TMD. The effect of the diameter of each fibre type identified by its medulla type and the total mean diameter is in agreement by what was already established in Frank (2001), more recently revised and put into perspective (Frank et al., 2019b; Idem, 2019c). However, the phenomenon was unpublished until this work in relation to age.

An indirect reference to the fibre types present in alpaca fleece was published by McGregor (2012). In Australian Huacaya and Suri alpacas, the presence of medullated fibre increased linearly from 10 to 60% weight/weight as TMD measured on the animal's flank increased from 22 to 40 µm (McGregor, 2006). For Huacaya and Suri alpacas the incidence of measured fibre increased 3.1 and 2.5% respectively for every 10 kg gain in live weight. The average incidence of medullated fibre in animals aged 5 to 8 years old was approximately twice as high as in animals aged 1 to 4 years old. The medullated fibre is more noticeable in fine alpaca fibre, as for fine fleeces the MD of the medullated fibre is up to 40% higher than the fleece TMD, while the difference among fibre types drops to about 10% in coarser fleeces (McGregor, 2006). The coefficients of the corresponding regressions indicate that the alpaca fibre measured for the animal's flank would have no medullation if the TMD was 18 µm in Huacaya and 20 µm in Suri alpacas. Another publication showed that, on average, the alpaca "belly and legs" have 11% more medullated fibres than the fibre from the “back site" fibre (Aylan-Parker & McGregor, 2002). On the other hand, the level of medullation of Australian alpacas is apparently lower (McGregor, 2006) than the typical values of 65 to 80% found for South American camelids (Calle, 1984).

Figure 18 shows that the fleece structure is mainly composed of 4 fibre types (A, F, C and G) in all age classes, while interrupted medullated fibres (I) keep a very low frequency at all times. In addition, Figure 18 shows the trend towards a reduction in the amount of non-medullated fibres (N%A) regarding the increasing age although the KW result is poorly defined. There is a trend to increase regarding the frequency of the other fibre types (N%F, N%C and N%G) although the KW does not show a significant modification for N%F and N%C. The increase in the relative frequency of large medullated fibres (N%G) stabilises only at age class 8 (KW of N%G). This indicates that, for this fibre type, its frequency (N%G) keeps increasing until further in age than its mean diameter (MDG, Figure 17), which stabilises at age 5 (KW of MDG).

The KW result is very significant with respect to the comparison of large medullated fibres (N%G) regarding the increasing age. At the same time, it is interesting to see that, with respect to age class 1, it does not show a significant change until age class 4 or 5, so it can be considered that the loss of textile quality becomes more noticeable from age class 5 or 6 onwards. The trend of the continuous medullated fibres is not well defined through the curve in Figure 18 and it is interesting to observe that in Figure 22, in the upper part describing the coarse fibre group (FG1), it behaves inversely to the coarse fibres. This detail had already been observed in previous works (Frank et al., 2006a; Idem, 2007).

In Bolivian llamas, the percentage of medullated fibre was determined to be 43.1% and an increase in medullation regarding the increasing age was found (Martínez et al., 1997). In Argentine llamas from the province of Jujuy, the total percentage of the medullated fibre was established in 28.3% and also showed an increase regarding the increasing age. The samples analysed came from all five fleece types and the degree of medullation of continuous medullated fibres increases up to age 5 and the one in fibres without continuous medulla increases up to age 6 (Frank et al., 2006a). Figure 18 also plots all fleece types all together and the percentage of medullated fibre is 56% on average for the first three age classes and it increases regarding increasing age to a maximum of 78% at age class 10.

Group of fine fibres (FG3):

Figure 22 (lower part) shows the N% of each fibre type (A, F, I, C and G) for the fine fibre group (FG3). It is clear that FG3 is mainly composed of non-medullated fibres (A) and fragmented medullated fibres (F). This is still evident even as the animal continues to grow. Up to age class 8 the N% of the fragmented medullated fibres (N%F3) rises, while the N% of the non-medullated fibres (N%A3) decreases, that is to say that both curves behave inversely. The type A and F fibres are accompanied by a lower percentage of continuous medullated fibres (C), with N%C3 being between 3 and 10% approximately. These fibres have a MD (MDC3, Figure 21, lower part) between 26 and 30 µm up to age class 3 and then rises up to 33.9 µm. This is broadly consistent with altiplano Jujuy llamas despite the environmental difference, although the frequencies of A and F fibres were not significant regarding increasing age (Frank et al., 2006b).

In FG3, large medullated fibres range in percentage from 0% in the first two age classes to 0.8% in the three highest age classes. This means that they are almost not present, in fact, their presence can also be interpreted as a classing error, because they are high diameter fibres and when implementing the Three Group Dissection, they should not have been included in the FG3.

According to the ranges in Table 1, FG3 includes superfine (19 - 21.9 µm) and fine (22 - 24.9 µm) fibres in the first age class. Continuous medullated fibres are added to this, and with a MD of 26.0 µm, they are above the 26 µm threshold (MDA3 and MDF3 in Figure 21, lower part), but, as seen in Figure 22 (lower part), the vast majority of fibres (93%) are superfine and fine, non-medullated or fragmented medullated fibres. In age classes 2 and 3, the fibres are mostly fine (MDA3 and MDF3 in Figure 21, lower part) and the N% of these fibres together account for 93% and 94% respectively (N%A3 and N%F3 in Figure 22, lower part). The remaining fibres are of continuous medulla and of medium coarseness (25 - 29.9 µm). This was previously verified (Frank et al., 2006a; Idem, 2014).

The MD curve of the FG3 non-medullated fibres (MDA3) plotted in Figure 21 (lower part) is almost identical to the MD curve of the whole staple non-medullated fibres (MDA) in Figure 17, that is to say that the FG3 non-medullated fibres make up almost the total non-medullated fibres contained in a staple. This is also shown by the fact that the FG1 contains no non-medullated fibres (Figure 22, upper part) and, furthermore, the amount of non-medullated fibres is low in FG2 (Figure 22, central part), in addition to which the fibre frequency of FG2 (N%2) is low in itself (Figure 16). A similar situation is observed with fragmented medullated fibres, but it is not so noticeable. This was previously verified for fibres of llamas from Jujuy Altiplano (Frank et al., 2006a).

Group of coarse fibres (FG1):

Analogously to this, it can be said that the MD curve of the FG1 large medullated fibres (MDG1) shown in Figure 21 (lower part) overlaps with the MD curve of the large medullated fibres of the whole staple (MDG) in Figure 17, that is to say that FG1 explains the MD of the large medullated fibres of the whole staple. The age effect on the relative frequency of coarse and continuous medullated fibres within FG1 shows an inverse behaviour, because N%G1 rises while N%C1 decreases, and vice versa (Figure 22). The upper part of Figures 21 and 22, which is related to FG1, explains the large gap between the MD1 and MD2 curves seen in Figure 11, as FG1 contains only coarse and continuous medullated fibres (Figure 22) and these fibres are of increased coarseness (Figure 21).

Continuous medullated fibres are present in all three FGs, although the MD clearly changes from lower to higher MD between FG3 and FG1, being between 26.0 µm and 33.9 µm for FG3 (Figure 21, lower part), having higher values for FG2 (Figure 21, central part) and between 34.7 µm and 40.1 µm for FG1 (Figure 21, upper part).

Groups of fine and coarse fibres (FG1 and FG3), classing and dehairing:

The whole FG1 is made up of objectionable fibres as all of them are coarse or very coarse fibres (Figure 22, upper part). Thus, the same information can be extracted from this graph as from Figures 11 and 12 mentioned in the previous division. It is important to point out that this is true from age class 1 on, that is to say that also in the case of a first shearing carried out in age class 1, the need to implement dehairing for these fleeces should be analysed (Seghetti Frondizi, 2014).

In relation to FG2 (graphs in Figures 21 and 22, central part), the great variability of the fibre types and their respective MDs stands out: unlike FG1 and FG3, it is composed of all fibre types and these are of varied diameter. During the dehairing process and the successive passes through the dehairing machine, it will be necessary to see how they behave and whether they are included in the product or in the subproduct (Singh, 2003).

With respect to the FG3, the lower parts of Figures 21 and 22 show the same information as FG3 curves in Figures 11 and 14, but additionally they show which fibre types this FG is composed of. In the case of the fleeces of the experimental animals, the FG3 contains a small percentage of continuous medullated fibres. The question is whether these fibres, which are only 6.4 to 10.0 µm thicker than the non-medullated fibres and 4.6 to 7.6 µm thicker than the fragmented medullated fibres (Figure 21, lower part), can be separated during the dehairing process. Thus, in this context, the need to classify fleeces regarding fineness is very strongly confirmed since, from age class 4 onwards, fragmented medullated fibres have a MD similar to that of continuous medullated fibres of age class 1 and, in age classes from 6 to 8, the non-medullated fibres are also very close to this MD, complicating even further the separation of continuous medullated fibres through dehairing if fleeces of different fineness were mixed in the same fibre lot before the dehairing.

Three Group Dissection:

The discussion about the different FGs and their characteristics in the implementation of the Three Group Dissection, and the resulting formation of the three FGs, makes practical sense since it reveals fundamental information with respect to the textile quality of a fibre sample (Brodtmann et al., 2018). Furthermore, the Three Group Dissection stands out as a method that, due to its simple implementation, can be used in a rudimentary context location. A rough assessment of the MDs of each FG could also be made manually through tactile examination and through visual examination. Another possibility is by using a collection of fibre staple samples of different diameter and/or of separated fibres since the human eye is able to distinguish differences in fineness of a separated fibre of 2.5 micrometres or more (Lang, 1947).

An important thing to highlight is an oversight that could occur during the implementation of the Three Group Dissection: not really separating all the coarse fibres from the group of fine fibres could be a problem. There is no danger that fibres from FG1 will remain in FG3 because they are too different, but it could happen that fibres from FG2 are overlooked and they could remain in FG3.

1.3. Crimp frequency

Beyond the hypothesis of this sub-chapter, which is related to the MD and N%, it remains to develop the specific aim of studying the fleece structure according to fibre groups and the modification produced by the increasing age. For this purpose, as well as the MD and the N%, other fibre characteristics were evaluated, which are the crimp frequency (CF), the crimp group (CG) and, briefly, the fibre length (L). CF and CG are fundamental characteristics of the fibre when implementing the Three Group Dissection and assigning each fibre to an FG as they show the type of crimp. As this characteristic is the most striking during the visual examination of the different fibres, it is even more important than the fibre fineness or fibre length. Figure 23 shows a good differentiation of the 3 FGs according to the CF, which confirms the correctness of having thought of a dissection that breaks down the staple into 3 FGs. A curvilinear behaviour is seen in FG3, there is a smaller change in FG2 and no change in FG1. There are no bibliographic references available with respect to the crimp change depending on fibre groups.

1.4. Crimp groups

The crimp group (CG) is an essential factor in defining the homogeneity of the llama fibre as a raw material and, thus, its quality as a textile fibre since the crimp types shown by llama fibres are very different and are partly related to the fineness of the fibres. For example, CG1 and CG2 fibres are always superfine or fine, CG3 fibres increase somewhat their coarseness and CG4 fibres are always coarse, with the exception of fibres from fleece types HL and Lustre. Therefore, CG4 has a strong relationship with the objectionable fibre determination. This is important to be considered when dehairing because the effect on dehairing efficiency due to the crimp frequency of fine fibres has been demonstrated (McGregor & Butler, 2008b).

Differences according to FT are observed with respect to FG2 and FG3, which are detailed in the third and fourth column of Table 2. To summarise, it can be said that the fleece types DC and IC are very similar with respect to the CG. Even the SC fleece behaves similarly, it just shows a tendency towards a CG with a little more crimp. On the other hand, HL and Lustre fleeces differ from non-lustre FTs. For the Lustre fleece, the FG2 is defined almost solely by CG4, and the FG3 is composed of CG3 and CG4 fibres in almost equal parts. The HL fleece behaves almost the same as the Lustre fleece, having only a slight variation of the percentages of each CG for FG3, showing slightly more CG3 than CG4 (Frank, 2001; Frank et al., 2007; Idem, 2019a). This confirms that, in order to obtain more homogeneous raw material, it is convenient to implement FT classing regarding fleece type and to join together DC, IC and SC fleeces on the one hand and HL and Lustre fleeces on the other hand. The age effect is not well perceptible on the crimp types and their frequencies, however, in Merino sheep there is a decrease of crimps towards age 3 in a curvilinear form, but in relation to the curvature (degrees/mm), a linear decrease is established until age 5 (Sumner & Upsdell, 2001). This could be reflected visually as the staples corresponding to older animals seem more compact.

1.5. Fibre length

The fibre length of FG1 (L1) decreases significantly as the age increases. The same is true for FG2 and FG3 (L2 and L3), dropping, however, to an average length of 8 cm, which is still enough to be used for textile process. The fibre length of the first age class is the highest. This can be explained by the fast growth of the fibre itself, in addition to the fact that some of the fleeces may not have been sheared for the first time when the animal was one year old, but later.

The reduction in fibre length regarding the increasing age of the animal stabilises in age class 5. This effect is observed equally for the fibres of all 3 FGs. The coarse fibres (FG1) of a staple are clearly longer than the fine fibres (FG3). However, the length of the fine fibres always maintains a value of over 7 cm. This was confirmed in alpacas (McGregor, 2006).

1.6. Consistency of experimental and observational databases

Because of the conditions given in the area of llama fibre production, it is common to carry out research by observing populations, that is to say by working with flocks from breeders in different places that produce llama fibre under different circumstances. To create an observational database, the population structure is observed, fibre samples are taken and other characteristics are recorded. The observational database of the Fibre Laboratory has a very large number (*n*) of more than 2000 animals, their data come from different flocks and from productive circumstances similar to those of most of the breeders, so it can be considered representative for the Argentine llama population in general. It is a database that gathers many details regarding the study of the population structure, but it has a limitation typically related to observational flocks, which is that it is not possible to guarantee a continuous follow-up all along several years of the same animal since it can be sold, slaughtered or it can lose its individual identification, for example.

For this reason, it was pertinent to work with an experimental llama flock and to provide the necessary materials for the development of this thesis, that is to say to have a birth register, to follow several animals from their first year of life on and to have the possibility to take a fibre sample year after year. In this way, the experimental database was created, with animals identified in a reliable way and with a guarantee that they will remain in the flock.

The problem with this database is the low number (*n*): only 20 animals participated in the annual sampling, and for the first and last age classes the number is even lower because not all animals were sampled from their first year of life on and not all up to 11 years of life. Moreover, the results are not directly transferable to the rest of llama breeding in Argentina as the circumstances of the experimental flock are particular, especially in relation to their feeding. In other words, the information revealed is valid for these animals, but it is not representative for the llama population in general. Therefore, in Division 1.6 the experimental and observational databases are compared in relation to TMD and other variables to evaluate whether it is possible to verify their consistency.

Figure 25 plots the modification in the thoracic perimeter regarding the increasing age through a square regression. The two curves take its course in the same way and both have their peak in age class 6, which is a good basis for confirming the consistency of the two populations. The only difference is that the experimental data curve shows a higher thoracic perimeter than the observational curve, with a gap of approximately 10 cm. This indicates that the experimental flock is made up of larger animals or animals in better body condition. In fact, the feeding circumstances of the experimental flock are particular because it is a dense natural pasture including many forage species with high proteins, such as the white clover, and the climate has a fair amount of rainfall. This differs from the circumstances of the observational flocks of which only one is in similar circumstances to the experimental flock, while the other two flocks are situated in semi-arid areas (Anonymous, 2005).

For age classes from 1 to 6, the TMDv and TMDvo curves coincide in their trend and the two values corresponding to age class or category 6 overlap, so that the TMDv value covers the TMDvo value. From age class or category 7 onwards, the two curves start to separate from each other, but, anyway, both curves show the same biological effect, starting with a low initial MD, which increases until a certain age and stabilises. This is confirmed by the results of the two KWs which show similar letters, except that for the experimental data the stabilisation occurs one year later than for the observational data, that is to say that TMDvo and TMDv stabilise at 4 and 5 years respectively. The animal age at which the maximum value of TMD occurs varies depending on different bibliographical sources. For Australian alpacas, it was reported that TMD increased up to 7.5 years of age (McGregor & Butler, 2004), and for Argentine llamas, it increased up to 4 years of age (Frank et al., 2006a).

The TMDv curve of the experimental animals stabilises, but it does not start to drop during the age classes plotted, whereas the TMDvo of the observational animals decreases rapidly from 7 years old onwards. The letters of both KWs remain the same until age class 8, but the letter "B" appears for TMDvo age category 9 and it indicates the reduction of TMDvo at the end of the curve (Figure 26). Thus, consistency can be confirmed for TMD up to the age of 8 years old.

In the literature, there is a common denominator describing and confirming the TMD increase, but differences are recorded with regard to the age at which the maximum coarseness occurs. It can be concluded that the micron blowout exists as a biological effect, but that, depending on the llama flock, it may differ when the maximum TMD occurs regarding the animal's age.

The TMDvo curve fitted to a second-degree polynomial (R^2=0.48) has its maximum of 5.7 years according to the calculated first derivative. As specified in Division 1.1, the TMDv curve is fitted to a second-degree polynomial (R^2=0.30) whose first derivative equalled to zero gives a maximum of 8.8 years, that is to say, 3.1 years later. The shift of the curve peak of the experimental data (TMDv) with respect to the observational data (TMDvo) originates in the coarse fibres since the first derivative equalled to zero gives its maximum at 10.0 years for FG1 (MD1), while for FG2 and FG3, the maximum is given at 8.1 and 8.7 years respectively (MD2 and MD3). Furthermore, for the non-medullated fibres and the fragmented and interrupted medullated fibres, the peaks of the curves fitted to a second-degree polynomial occur at 8.5, 7.6 and 8.8 years respectively (MDA, MDF and MDI), while for the continuous and large medullated fibres, this maximum occurs at 10.2 and 12.8 years respectively (MDC and MDG). Once more, the coarsest fibres, which are the large medullated ("lattice") fibres, show the greatest shift of the maximum towards an older age class. This analysis confirms that the MD of the fibre type that differs most between the experimental and observational database is the large medulla fibre type.

According to the results of the Kruskal Wallis test (KW), the values of MD1 and MD3 show the first indication of lowering in age class 11 (Table in Figure 11). The phenomenon of the fibre MD reduction of the older animal of the experimental flock is also visually confirmed by the plotted curves of TMDw, TMDn, MD1, MD2, MD3 (Figure 8, Figures from 12 to 14) and the MD related to the fibre types (Figure 17), which show a reduction of the respective MD in the last age class.

It’s interesting to take a further step towards detailing the fibre types and the modification of their respective MDs regarding the increasing age. The experimental data were plotted in Figure 17 (MDA, MDF, MDI, MDC and MDG) whose content is repeated in Figure 27. In this last figure, the MD according to fibre type of the observational animals (MDAvo, MDFvo, MDIvo, MDCvo and MDGvo) is added to compare their respective curves. This comparison was done by pairing curves of the same medulla type, for example, curves of MDA and MDAvo, MDF and MDFvo, etc. These paired curves from experimental and observational data are very close or even overlapping in their path. Furthermore, a great consistency is observed in relation to the stepwise sequence of the curves corresponding to the same medulla type, starting with low values for the MD of the non-medullated fibres (MDA and MDAvo) and increasing up to high values for the MD of the large medullated fibres (MDG and MDGvo). The exception is a single clear difference that occurs for the large medullated fibres from age class 8 onwards. It can be concluded that the shift of the maximum of the coarsening towards a higher age class that is observed for TMDv with respect to TMDvo (Figures 26 and 8) is due to the difference in the MD of the large medullated fibres of both databases (MDG with respect to MDGvo).

It can be hypothesised that the experimental animals are so well fed, having protein-rich forages, that they can maintain a sustained growth of the coarser fibres, that is to say, of the large medullated fibres, whereas this is no longer possible from a certain age onwards regarding animals living in conditions with more limited forage. Whether this is an accurate assessment or not remains open, but it can be concluded that for the large medulla fibre types from age 8 onwards, the two databases do not show consistency.

Through the evaluation carried throughout the Figures 25 to 27, it can be summarised that, with the exception of the large medullated fibres from age class 8 onwards, the consistency of the experimental and observational databases was proven.

1.7. Final evaluation

The results of Sub-chapter 1 confirm a modification of the fleece structure regarding the increasing age that worsens the textile quality of llama fibre. In order to progress in the determination of possible solutions to this situation, Sub-chapter 2 analyses the possibility of rectifying this age effect through the textile process of the dehairing and, thus, achieving a higher value of the llama fibre within the textile chain.

To understand the llama fleece structure and morphology of the 3 FGs, it is useful to observe all variables at the same time, that is to say, looking at one FG across all figures in a cross-sectional manner. For example, a cross-sectional reading in relation to the fine fibres (FG3) reveals about the age class 1 that this FG is composed of superfine fibres of a MD of 20.6 µm (MD3 in Figure 14, Table 1), 10.8 cm of length (L3 in Figure 24), 93% of which are non-medullated or fragmented medullated (Figure 22, lower part), being the non-medullated fibres the most prevalent ones. They have a relatively high crimp frequency of 2.1 crimps/cm (CF3 in Figure 23) and represent the 68% of the staple weight (W%3 in Figure 15). The weight of coarse fibres of age class 1 is 23% (W%1 in Figure 15).

The age effect on the FG3 is revealed by making this same reading for a higher age class. For example, for age class 3, this group of fibres includes fine fibres with a MD of 23.5 µm (MD3 in Figure 14, Table 1), 9.2 cm of length (L3 in Figure 24), 96% of which are non-medullated or fragmented medullated (N%A3 and N%F3 in Figure 22, lower part), which have a high crimp frequency of 2.8 crimps/cm (CF3 in Figure 23) and which represent the 70% of the staple weight (W%3 in Figure 15). The weight of the coarse fibres remained almost the same as in age class 1 and it represents the 21% (W%1 in Figure 15).

There is a change in textile quality compared to age class 1, with the quality of the fine fibres of age class 1 being clearly higher. But, at the same time, it can be confirmed that the fine fibres of age class 3 are still of good textile quality. Accordingly, it can be considered that the selection of fleeces from animals up to 3 years old could be a good rudimentary criterion to select fleeces to be processed together and, in this way, achieve a first approximation to what could be a fleece classing regarding fineness in order to achieve raw material of better textile quality. In any case, there are fleeces from younger animals that are of poorer textile quality and fleeces from older animals that are of better textile quality.

Looking at the fleece structure for age class 7, it can be seen that FG3 is composed of medium fibres of a MD of 26.5 µm (MD3 in Figure 14, Table 1), 8.0 cm of length (L3 in Figure 24), having a high crimp frequency of 2.8 crimps/cm (CF3 in Figure 23) and representing 58% of the weight of the staple (W%3 in Figure 15). The fibre type remained at a high percentage of non-medullated or fragmented medullated fibres, at 94% (N%A3 and N%F3 in Figure 22, lower part), but reversing the presence of this fibre type to a higher percentage of fragmented medullated fibres. In addition, the presence of FG1 fibres increased with respect to the earlier age classes up to a value of 31% (W%1 in Figure 15).

A reading of the Kruskal Wallis test (KW) that results from Sub-chapter 1 also indicates that the inclusion of fleeces from animals aged up to 3 years of age could be a good option to achieve the desired raw material. For example, in Figure 11, the KW shows a result with no significant difference in MD1 and MD3 with respect to the first 3 age classes. This is repeated in MDA and MDG with respect to the first 3 age classes (Figure 17), although this is only true for the first 2 age classes regarding MDF and MDC. Nevertheless, these results support the choice of the materials for Sub-chapter 3, in which data from animals aged up to 3 years old were used only.

As described in Division 1.1 with regard to the fine fibres, it is questionable from age class 6 onwards whether a dehairing makes sense due to an increase in the MD of the fine fibres (MD3). But the animal's age is only a guiding datum because what defines the textile quality of a fleece is specifically the MD3 value which can be higher or lower with the same age, depending on the animal’s genetics.

In Sub-chapter 1 no progress was made with regard to the differentiation of the characteristics of different FTs structure. For each FT there was a very small amount of data and it becomes more relevant to resort to another database for the evaluation according to FT. This is done in Sub-chapter 3, in which the differences of the different FTs are discussed in depth in order to provide a useful basis for decision making related to the handling of fleeces of different types.

2. Dehairing effect on llama fibre structure

Sub-chapter 1 describes the phenomenon of llama fibre coarsening regarding the increasing age and the next step is to look for possible solutions to this problem. Beyond the details of up to which MD the fibre coarseness increases and at which age it occurs, the consequence is the devaluation of the fibre due to the increase in the MD and the increase in the prickle factor. In the case of knitted garments, there is the reference of the 3% coarse fibre threshold expressed in weight/weight (coarse fibre weight/total fibre weight) (Frank et al., 2014). Hence, there is a need to separate out the coarser or objectionable fibres. This means reducing the variability shown by the llama fibre with respect to its diameter, that is to say, beyond aiming at a reduction of the TMD, it also means achieving a more homogeneous textile material and a MD distribution that does not include fibres of a too high diameter corresponding to the objectionable fibres. The question that remains to be determined is whether dehairing is efficient in correcting the effect of the increase in diameter due to the increase in age.

The number of fleeces that were available to carry out the trials for this sub-chapter is small, but the corresponding results are nonetheless of indicative value and provide a basis to contribute to the decision-making process for the potential implementation of dehairing of a fibre lot. In addition, there is bibliographical support for the efficiency of the used technology, in the sense of the possible repeatability of the process efficiency if it is carried out industrially.

Regarding how to achieve a lower TMD between ages, there are two main possibilities, the genetic method, on the one hand, and the implementation of the dehairing, on the other hand. The genetic method involves selecting breeding animals by giving priority to animals having fine fleece and a reduced coarsening regarding the increasing age, particularly when selecting the breeder male for mating, and thus reducing the increase in the fibre diameter of the flock as the animals get older. However, for Peruvian alpacas, it was determined that it would be difficult to obtain quickly a better genetics through the selection of animals favouring a reduced micron blowout. (Munyard & Greeff, 2013). The genetic problem of reduced coarsening by age is the low heritability of the trait (0.18) which would imply a very slow response to selection (Munyard & Greef, 2013). On the other hand, research on Australian alpacas related to the micron blowout and selection concluded that there is an opportunity to improve the TMD and VC of alpaca fibre by the selection, but without quantifying the method (McGregor & Butler, 2004).

However, it should also be considered that the priority for each llama breeder is different and a selection in favour of fine fleece and reduced micron blowout animals may not necessarily be implemented, as the llama is a multi-purpose animal. The llama is described as an important element of cultural identity and main livelihood for small producers in the Central Andes of South America, including Argentina, providing meat, milk, fibre, transport energy and guano (Quispe et al., 2009). In addition to these traditional purposes, there are more recently developed purposes, such as tourism activities, either as an animal being part of sight-seeing and animal watching or for activities involving trekking and hiking accompanied by llamas, and even as a trained animal for therapeutic activities.

Therefore, it is pertinent to investigate solutions to achieve greater fineness regardless of the method related to genetic improvement and to produce the desired raw material from the llama population as it is. One possible measure to achieve this is the implementation of the dehairing, which allows to reduce the content of objectionable fibres to tolerable levels so as not to cause prickle and to reduce the mean diameter (Frank et al., 2014; Idem, 2019c). The understanding of the mechanisms at work during the textile process of dehairing that result in the separation of the different fibre types is justified on the basis of the dehairing theory (Singh, 2003).

2.1. Total mean diameter and mean diameter according to fibre groups (FG)

In relation to the dehairing effect, Figure 28 shows the trend of the total mean diameter (TMD) in its two variants, TMDwd and TMDnd. As the fibre passes through the dehairing machine (AM2) during the successive passes, the curve shows a large reduction in the TMD for the first 3 passes, then the reduction is smaller and shows a trend towards stabilising in the eighth or ninth pass. After the first 3 passes through the AM2, the TMDnd decreases by 3.4 µm (from 29.3 to 25.9 µm). This behaviour is consistent with cashmere dehairings in Australia (Singh, 2003; McGregor, 2018) and it is slightly different from what has been observed in previous trials on llama fibre with AM2 technology (Frank et al., 2009). After 7 additional passes, the TMDnd is lowered only by 1.0 µm (to 24.9 µm), which results in a total of 4.4 µm compared to the original TMD. The results of the Kruskal Wallis (KW) test show that the reduction of the TMD stabilises after the sixth pass. The TMD reduction through the dehairing was confirmed by the KW results as they are highly significant. Therefore, the veracity of the second specific hypothesis, related to an improvement of textile quality in relation to the TMD reduction, is confirmed.

In a dehairing trial of alpaca top with AM2 technology, it was found that the TMD decreased relatively little, from 22.4 to 21.9 µm, while the percentage of objectionable fibre (weight/weight) and the content of >30 µm fibres decreased more noticeably, from 4.88% and 9.1% to 2.2% and 3.6% respectively (Frank et al., 2019b). This confirms two concepts: on the one hand, even fine raw material can be improved through the dehairing as the coarse fibre content is reduced and, on the other hand, beyond the TMD reduction of coarse fleeces through the dehairing, it is important to pay attention to the reduction of objectionable fibres specifically. For the case of a top, the original raw material in the form of a fleece has already gone through the first step of the textile process which is carding and in which a small quantity of the objectionable fibres is removed by undergoing carding. Even so, this top contained a higher quantity of objectionable fibres than required for not causing prickle, which could be reduced to a level below the desired level of 3% by means of 6 passes through dehairing.

Frank et al. (2018) concluded that, for the Patagonian cashmere goat fibre dehairing with AM2 technology, the optimum would be not to exceed 4 passes and that a suitable quality of cashmere for international requirements was obtained carrying out this number of passes. It is expected that the dehairing product is obtained out of cashmere goat fibre with a lower number of passes than out of alpaca fibre since, in the case of cashmere, there is a greater difference in diameter, stiffness and crimp between the fine and coarse fibres, which makes the dehairing effect process easier (Wang et al., 2008).

It remains open for discussion how exactly the effect of dehairing is produced and how it modifies the fibre structure, for example, it is important to take into account that the dehairing is not only about reducing the TMD, but also about reducing the presence of objectionable fibres, which is discussed further below. Thus, determining an improvement in textile quality solely through TMD would be too simplistic because it is about reducing the inherent variability of the llama fibre, that is to say, improving textile quality means increasing homogeneity. Therefore, it is relevant to discuss the TMD reduction in the context which allows the Three Group Dissection, differentiating the three FGs, especially the reduction of FG1 that corresponds to coarse or objectionable fibres. Furthermore, in this thesis, the evaluation of the dehairing effect on fibre structure also includes other variables, for example, the crimp group of the fibres as to answer the second specific objective.

As in the corresponding graph in Sub-chapter 1 (Figure 8), the weight-weighted TMD is above the fibre frequency-weighted TMD, but, beyond that, both curves show the same trend. What calls the attention is that the TMDwd and TMDnd curves converge at the tenth pass. It would seem that the more the coarse fibre content falls (W%1d and N%1d in Figures 33 and 36 respectively) and, therefore, its influence on TMDw and TMDn decreases (Equations 2 and 3), both values overlap more and more. In a set of 52 dehaired lots of Australian cashmere, the difference between the measures is 70%, with the w/w being equally higher, whereas, in another trial, the author also finds the same difference even though the original objectionable fibre content was higher (McGregor, 2018). Another consistency shows a high variability of the variables, with a standard deviation of the same magnitude as the mean, which does not make these variables well qualified for use in the interpretation of the phenomenon (Frank et al., 2009).

Figure 29 shows the MD curves of the product and the subproduct (TMDnd and TMDns), both at the same time, as a way of demonstrating the dehairing effectiveness and the specific hypothesis of the second sub-chapter, since it clearly shows how the subproduct curve has a clearly higher MD than the product one, that is to say that it always contains coarser fibres. Thus, the modification of the fibre structure in the product towards a reduced TMD is evident, which is equivalent to an improvement of the textile quality of the fibre.

Beyond this, it remains open whether the TMD reduction always guarantees that the textile quality of the dehairing product is suitable and has the sufficient quality to produce fine garments. This is demonstrated when the TMDwd curve decreases below the 26 μm line in the seventh pass and the TMDnd one does it in the fourth pass (Figure 28). The subproduct plotted in Figure 29 remains above 30 μm until the seventh pass and only decreases to 28 μm thereafter. This indicates that it also purifies from intermediate fibres (FG2) in agreement with Wang et al. (2008). Furthermore, it remains to be determined whether or not the distribution of MD includes a too high percentage of objectionable fibres.

Fine fibre group (FG3) and its MD in the raw material before dehairing:

In order to clarify some aspects related to fine fibres, that is to say, to the fibres desired for fine garment production, and how to achieve an increase of their presence in the dehairing product, it is useful to give some considerations that combine what was seen in Sub-chapter 1 with the results of Sub-chapter 2. The TMDnd curve in Figure 28 is repeated in Figure 30 to show it in the context of the MDs of the three FGs (MD1d, MD2d and MD3d). The design of this graph is analogous to Figure 11 in Sub-chapter 1 in the sense that it shows the TMD together with the MD of each FG. But it should be taken into account that the analogy between Figure 11 and Figure 30 is only given for the 0 (zero) pass because this corresponds to the whole fleece before dehairing. As soon as the fleece enters into the dehairing process, that is to say, from the first pass onwards, the fleece structure is transformed and it turns into a different structure, which is described by the fibre structure inherent to the fibre found in the textile process.

To summarise, it should be highlighted that for pass 0, the MD of the fine fibres (MD3d in Figure 30) is analogous to that one of the fine fibres of the experimental animals (MD3 in Figure 11), and TMDnd (Figures 28 and 30) is analogous to TMDn (Figures 8 and 11). But, what Figure 30 expresses about pass 1 onwards is already different because in the case of the experimental animals and Figure 11, the FG3 always remains a part of the whole fleece, which is taken as equivalent to the dehairing product, whereas the FG3 in Figure 30 is simply a part of this dehairing product. Thus, MD3d and MD3 are no longer analogous to each other from the first pass onwards, but the group of fine fibres of fleeces in their original and whole state (MD3 in Figure 11) becomes analogous to the total mean diameter of the dehairing product (TMDnd in Figure 28) because, logically, it is precisely those fine fibres of a fleece with its MD3 the ones that end up accumulating in the dehairing product that has its TMDnd. The analogy of MD3 in Figure 11 with TMDnd in Figure 28 becomes stronger as the dehairing becomes more complete and only the fine fibres of the dehaired fleeces remain in the dehairing product. In the graph in Figure 28, this would correspond to the TMDnd of passes 8 to 10, but having the limitation in this trial of not being able to thoroughly separate all coarse fibres, that is to say, the group of fine fibres in the dehairing product (W%3d in Figures 33 and 34) does not constitute 100% of the fibres but, instead, it constitutes a value of about 90%.

But beyond that, the idea of observing Figures 11 and 28 at the same time is to better clarify the potential of the dehairing effect. For example, what would happen if the fleeces plotted in Figure 11 for age classes from 1 to 3 were taken to dehairing separately? What would happen if, instead, these fleeces were the ones of age classes from 4 to 7 or age classes from 8 to 10? These could be three different lots of raw material that were taken for dehairing. The TMDn of the fleeces to be dehaired would be around 26 µm for the first case, between 28 and 31 µm approximately for the second case, and around 32 µm for age classes from 8 to 10 (Figure 11). Assuming a dehairing of these three lots of fleeces separately, within three different trials, the TMDn of each lot would correspond to the TMDnd in pass 0 of Figure 28.

Then, when these fleeces are dehaired, their groups of fine fibres (MD3 in Figure 11) are the ones that will accumulate in the dehairing product (TMDnd from the eighth pass to the tenth pass in Figure 28). So, if the MD3 curve in Figure 11 is divided into 3 parts, age classes from 1 to 3 have a MD3 of about 22 µm, age classes from 4 to 7 have a MD3 of about 26 µm and age classes from 8 to 10 have a MD3 of about 27 µm (Figure 11). Fibres with these respective MD3 become part of the product of a potential dehairing with a TMDnd (Figure 28) of around 22 µm, 26 µm and 27 µm respectively, and it is clear which fleeces have the highest capacity to provide a high-quality textile dehairing product. This is the basis for highlighting the need to find and implement a process to dehair only those fleeces that justify their dehairing. In this respect, the classing of fleeces regarding fineness will be evaluated in the Sub-chapter 3.

Fine fibre group (FG3) and its MD as characteristic of the fleece structure:
The bunch of 16 fleeces used for the dehairing trial constitutes a possible marketed fibre lot, intended for the textile industry and, with respect to TMD, it has a value similar to the fleeces of the experimental animals in age class 5:

TMDnd = 29.3 µm at pass 0 (zero) (Figure 28 and 30) and
TMDn = 29.1 µm at age class 5 (Figure 8 and 11).

However, the fleece structure of the fleeces used for the dehairing trial differs somewhat from that of the fleeces of the experimental animals, as the coarse fibres are coarser than those of that age class and the fine fibres are finer:

MD1d = 46.7 µm at pass 0 (zero) (Figure 30 and 31) and
MD1 = 43.2 µm at age class 5 (Figure 11).
MD3d = 24.6 µm at pass 0 (zero) (Figure 30 and 31) and
MD3 = 25.6 µm at age class 5 (Figure 11).

This means that, taking the fine fibres as reference (FG3), because that FG corresponds to the dehairing product, the lot of dehaired fleeces corresponds to the age class between 3 and 4 of the experimental animals:

MD3d = 24.6 µm at pass 0 (zero) (Figure 30 and 31) and
MD3 = 23.5 and 25.1 µm at age classes 3 and 4 respectively.

It is important to discern this, because what determines the potential of a fibre lot is the fineness of the FG of fine fibres, not the coarseness of the coarse fibres. It is something secondary if the coarse fibres are coarser because they will be separated from the fibre lot during the dehairing process anyway. It may even be better if they are coarser because a greater difference in diameter between coarse and fine fibres increases the possibility of being dehaired (Wang et al., 2008).

Fine fibre group (FG3) and its MD in the dehairing product:

With regard to the group of fine fibres (FG3), it was observed that the MD3d curve plotted in Figure 30 only decreases slightly, 1.1 µm altogether, taking as a reference the lowest point of the MD3d curve which occurs in the eighth pass and in which it has a value of 23.5 µm. At the end of the second pass, MD3d is 0.7 µm lower than the initial value, decreasing from 24.6 to 23.9 µm. After that, MD3d remains between 23.5 and 24.0 µm until the end of the tenth pass. Taking the average of 23.9 µm of passes from 2 to 10 as a reference, MD3d is reduced by 0.7 µm. Therefore, it is important to point out that the dehairing effect on the fibre structure related to the fine fibres and their MD is very limited, which is confirmed by the not significant KW result. This is in line with the result of an Australian study on cashmere fibre dehairing which confirmed that the MD of cashmere in the dehairing product, that is to say, the fine fibre part of the original fleece, did not change appreciably as successive passes of the dehairing process are carried out (McGregor, 2018). Two concepts are confirmed: on the one hand, that fine fibres have a certain MD that is practically not reduced by dehairing and, on the other hand, that “the Three Group Dissection works" because if the group of fine fibres (FG3) is separated from one lot of fibre over and over again, that is to say, "always the same group" is measured, it leads to "the same result". The capability of the Three Group Dissection to reveal the textile value of the llama fibre has been described previously (Brodtmann et al., 2018).

The fact that the dehairing effect does not include a refining of the fine fibre group (MD3d) shows a limitation of that textile process and means that, in order to obtain a satisfactory dehairing product, it is necessary that the fleeces provided to the dehairing actually contain fine fibres of sufficient fineness. This simply indicates that the dehairing of a fleece lot whose finest fibres are not truly fine will result in a dehairing product of just the same MD and not much lower. For example, a fleece with a group of fine fibres of a MD3 of 27 µm, which are medium fibres according to the specification given in Table 1, may come from a fleece that has a TMDn of approximately 32 µm (TMDn and MD3 curves for age classes from 8 to 10 in Figure 11). If, when dehairing such a fleece, the MD of the fine fibres decreased by 0.7 µm, as in the case of the dehairing trial, it cannot be expected that textile raw material suitable for the production of fine garments would be achieved. Therefore, it is crucial that another measure is implemented prior to dehairing to ensure a high degree of fibre content of sufficient fineness in the fibre lot to be dehaired.

Fine fibre group (FG3) and its W% and N% in the dehairing product:

Thus, one implication of this discussion about the MD of the fine fibres of the dehairing product (MD3d) is that the main function of dehairing is not to make this MD finer, but the main objective is to separate the coarse fibres, the objectionable fibres, from the dehairing product and to achieve as high a percentage of these fine fibres as possible (Figures 33 and 36, variable W%3d and N%3d). This is nothing new, but it is pertinent to point it out in the context of this discussion because there is often confusion about it. It emphasises the need to avoid the usual practice of gathering raw material as unsorted fibre and providing all fibre together to the dehairing process, as this production step does not have the capacity to provide a high-quality product, regardless of the quality of the fleece lot provided. In other words, it is evident that the dehairing process can only provide a high-quality product, that is to say, fine fibres, if these fibres are contained in the fleeces before they are dehaired. Furthermore, they must be contained in as high a percentage as possible to improve the dehairing yield. Therefore, classing the raw material regarding fineness before being dehaired should be considered as a step prior to the dehairing.

An exception to this statement would be, for example, if the purpose is the production of carpets, in which case coarse fibres are also desired fibres and the dehairing is implemented to separate the vegetable matter and other impurities in order to improve the quality of the yarn and the final product. Quispe et al. (2015) indicates through research related to the manual dehairing of Peruvian llama fibre that, after the dehairing, the appropriate use of fine llama fibre would be the production of high-quality clothing, while coarse fibres should be used for the production of carpets or the handmade production of everyday utensils.

The effectiveness of the dehairing is confirmed by the KW performed for fine fibres which shows significant differences for the relative weight of the FG of fine fibres (W%3d, Figure 33) and the relative fibre frequency of the fine fibre group (N%3d, Figure 36), that is to say that it shows a significant increase in fine fibres within the product, which confirms the veracity of the second specific hypothesis related to an improvement of the textile quality in relation to the increase in N%3d. According to what the KW results show, the fine fibre content within the product stabilises from pass 6 onwards for N%3d and from pass 8 onwards for W%3d.

Coarse fibre group (FG1) and its MD in the dehairing product:

At the end of the second pass, MD1d is 2.2 µm lower than the initial value, it decreases from 46.7 to 44.5 µm, and then moves between 44.4 and 39.2 µm until the end of the tenth pass. Taking the value at the end of the tenth pass as a reference, the MD1d is reduced by 7.5 µm, it decreases from 46.7 to 39.2 µm. This confirms a MD reduction of the coarse fibres as a dehairing effect, as it is confirmed by the KW result which is significant. On the other hand, the few FG1 fibres remaining within the product after the tenth pass are still coarse and have to be considered as objectionable fibres. So, the discussion with regard to the coarse fibres, beyond the MD, has to be completed with the relative weight and relative fibre frequency variables of the coarse fibre group (W%1d and N%1d) to confirm whether the dehairing shows a satisfactory result, which is done below.

The MD2d curve in Figure 30 does not show a very consistent behaviour, especially because the MD2d is higher than that of the whole fleece at the end of the first pass, and the MD2d at the end of the last pass is also higher than that of the previous pass. This shows that the intermediate fibre group (FG2) is difficult to define and differentiate. This may be due to a difficulty in implementing the Three Group Dissection, in which it is easier to identify the fibres belonging to FG1 and FG3. It often happens that FG2 fibres are included in this FG by discarding them, in other words, because they do not coincide with the characteristics of either FG1 or FG3. In any case, the MD of the intermediate fibre ranges between 33.8 and 29.1 µm for the 16 dehaired fleeces, that is to say, just below the 30 µm threshold, and it can be considered that FG2 should not be included within the dehairing product. An important piece of information is that there are few FG2 fibres (Figures 33 and 36), thus they are not the ones that determine the fibre structure. Therefore, in Table 3, only the coarse fibre group (FG1) was analysed. Specialists in cashmere already objected to the incidence of intermediate fibres (FG2) in the dehairing process, but with the technology of Scottish origin (Dawson Ltd.) (Smith, 1988), however, the latest trials with a technology similar to AM2 do not refer to this difficulty (McGregor, 2018).

It is interesting to see that the value of the MD of the FG1 of the subproduct (MD1s) of the tenth pass (44.1 µm) is lower than the MD of the FG1 of the product (MD1d) of the first pass (45.2 µm), as this confirms that through the successive passes through the dehairing machine, finer and finer fibres are separated. In other words, in each pass the coarser fibres are separated from the fibre lot that enters into the dehairing machine, and, if the MD of the dehaired fibre is finer, the fibres separated because of their coarseness, which form the subproduct, become less coarse. This means that the coarse fibres are not coarse according to a fixed value of coarseness, but they are coarse in relation to the fine fibres forming the product. This is also widely verified in cashmere (McGregor, 2018) and in alpaca top (Frank et al., 2019b).

Coarse fibre group (FG1) and its W% and N% in the dehairing product:
In relation to the discussion about implementing dehairing in order to achieve a raw material suitable to be used for the production of fine garments, it is necessary to evaluate whether the dehairing separates coarse fibres in a satisfactory way. In this regard, the variable of coarse fibre percentage expressed in weight/weight (coarse fibre weight/total fibre weight) was determined to be one of the thresholds that panellists who participated in tests to evaluate the ability to produce prickle on the skin detected, and it stands at 3.23% for yarn and 4.57% for fabric surface (Frank et al., 2014). By taking the threshold of 3% as the maximum acceptable threshold in relation to the presence of coarse fibre expressed as a percentage, the horizontal line of that value was included in Figures from 33 to 35, which are related to the presence of fibre expressed in weight/weight. In Figures from 36 to 38, which plot the variables related to the presence of an FG expressed in relative fibre frequency, the percentage of 3% was also taken as a reference threshold.

However, in McGregor (2012) and with respect to cashmere, it is reported that for cashmere from the commercial dehairing and cashmere tops, the mean value, the standard derivation and the variability of the residual guard hair, which corresponds to FG1, are: 0.5%; 0.7% and 0 to 3.7% weight/weight for the dehaired cashmere, and 0.4%; 0.5% and 0.1 to 1.5% weight/weight for the cashmere top (McGregor, 2000; McGregor & Postle, 2004). The incidence of measured fibre in dehaired cashmere was predicted by origin of cashmere and TMD, coefficient of mean diameter variation and interactions by origin and characteristics of TMD (McGregor, 2000), so the dehairing trial was standardised as much as possible, for example, by separating according to fleece type. The variability with respect to residual guard hair reflects differences in the ability of commercial dehairing companies to remove the guard hair from raw cashmere, as well as differences in raw fibre characteristics that affect dehairing efficiency and the dehaired fibre characteristics (McGregor & Butler, 2008b). The objectionable fibre decrease (difference between dehairing and top: 0.5 to 0.4), the great variability in the measurement and the wide range of a non-normal distribution oppose to the use of this data as a reference. It seems to be the mohair (more similar in diameter to these llama fleeces) which provides better information since there are no data of its own. Washed material having a 2.18% of objectionable fibre ("kemp") reaches 1.7%

after the carding, a 20% reduction (Kruger & Albertyn, 1966). In a trial with similar, but combed (worsted) material, the "intersected" top contained 2.37% coarse fibre and decreased to 1% after the last combing (top) (Kruger, 1966). It could be then assumed that the level of dehairing achieved in terms of percentage of objectionable fibres could be discounted from what the literature reports and would be well below the detected threshold of 3% weight/weight (Frank et al., 2014).

Figures 33 and 36 clearly show the dehairing effect through the continuous trend towards reducing the presence of coarse fibres (W%1d and N%1d) and intermediate fibres (W%2d and N%2d) in the product, that is to say, lowering their percentage, which is confirmed by a very significant KW result for these variables. Furthermore, Figures 34 and 37 provide an interesting illustration by showing the curves of the product and subproduct variables on the same graph: for example, the curves related to FG1 (W%1d and W%1s curves in Figure 34, on the one hand, and the N%1d and N%1s curves in Figure 37, on the other hand) are very far apart from each other and illustrate the effectiveness of dehairing in relation to the separation of coarse fibres from the product and their accumulation in the subproduct.

In relation to FG2 (variables W%2d and W%2s, on the one hand, and N%2d and N%2s, on the other hand), the curves differentiate little and the dehairing effect is poorly defined. However, as FG2 contains a very small quantity of fibres, both in the product and in the subproduct, it is an FG that has very little influence on the fibre structure and it is not considered necessary to deepen the discussion in this respect.

Even if the dehairing effect is confirmed, the question is whether the presence of coarse fibres can be lowered below the desired threshold. Figures 35 and 38 provide a clearer picture of the dehairing effect in relation to coarse fibres. In both figures the coarse fibres (FG1) of each fleece are plotted separately and each of the 4 graphs shows the data for only one fleece type. A clear reduction of coarse fibres is shown for each of the dehaired fleeces, but the W%1d value is below the 3% threshold only for 5 fleeces at the end of the 10th pass. The values are lower for N%1d and they are below the 3% threshold for 8 fleeces at the end of the tenth pass, however, this already happens for some fleeces from the sixth pass onwards. In any case, the results of the dehairing trial do not show entirely satisfactory results in this respect. It is important to complete this discussion by including the results differentiating not only the FG, but also the fibre type contained in each FG, which is done at the end of Division 2.2. In this respect, it was confirmed that FG1 is composed of fibres of coarse and continuous medulla (Figure 42, upper part).

In this context, Figures 44 and 45, which are related to fibre length, also provide important information. There is a clear trend that the fibres included in the subproduct are the shortest ones. The few coarse fibres of FG1 that remain in the product until the tenth pass are on average more than 10 cm long. Possibly, this great fibre length is the origin of the problem: the long objectionable fibres are difficult to dehair and tend to remain in the product instead of being included in the subproduct, as it would be desirable. Likewise, they become a problem in those lots which have a shearing interval longer than one year, since it is common for camelids being sheared after more than one year of fibre growth (Seghetti Frondizi, D.G., personal communication.).

Coarse fibre group (FG1) and differences according to fleece types:

With regard to the trial carried out in this research, it can be summarised (Figures 35 and 38) that the best results are shown for the DC fleece type and the most objectionable results are shown for the Lustre fleece type, for which the W%1d value remains high (10 and 6% in Figure 35) after the tenth pass. The Lustre fleeces included in the trial had a W%1d of 40 and 51% before being dehaired, that is to say that it is higher than the one of other fleece types, for which the value was between 10 and 34%. This implies that the results of this trial show the convenience of classing fleeces regarding fleece type and that one possibility is to select only DC fleeces for the dehairing process or, in any case, to combine this fleece type with IC and SC fleeces, but definitely Lustre fleeces must be separated. This conclusion is in accordance with what Frank et al. (2011a) confirmed, in which the classing regarding fleece type is recommended, given a different behaviour during the dehairing of the different types and a less satisfactory behaviour for fleeces of a lustre type. Frank et al. (2012b) describes the modification of textile raw material coming from llama fleeces and confirms the removal of coarse fibres through the dehairing having a generally weaker response from lustre fleece types.

Furthermore, it is interesting to observe the initial percentage of the relative weight and the diameters within the group of DC, IC and SC fleeces: for the 5 fleeces whose coarse fibre percentages are reduced below the 3% threshold, the initial values of the relative weight are between 20 and 23% (W%1d), the total mean diameter between 26.3 and 32.7 µm (TMDnd) and the mean diameter of the coarse fibres between 39.7 and 51.7 µm (MD1d). On the other hand, for fleeces whose coarse fibre percentages remain above the 3% threshold, the initial values vary between 10 and 34% (W%1d), 22.9 and 32.6 µm (TMDn) and 37.6 and 50.1 µm (MD1d) respectively. This confirms that the initial value of W%1d, TMDn and MD1d variables is not conclusive as to whether or not a W%1d below the 3% threshold is achieved after the tenth pass. There appear to be other factors that may help to ensure that such an objective can be achieved, and further trials need to be undertaken to address this issue.

The yield for dehairing is shown in Figure 33 since the variable used to calculate the yield is the weight of fine fibres (FG3) in relation to the whole fleece: at pass 0 (zero), that is to say before the start of the dehairing process, the FG3 relative weight is 65%, which corresponds to the potential yield for dehairing. However, in order to deepen the discussion on yield, it would be important to differentiate between fleeces of different fineness (see Division 3.10 of Chapter IV).

Coarse fibre group (FG1) and the reduction estimation by means of regressions: Through the polynomial equation used to describe the reduction of coarse fibres within the product as successive passes are carried out, the quantity of passes necessary to reach a minimum of coarse fibres in the product was estimated (W%1 and N%1 in Table 3). This polynomial equation can be used for a real situation in which dehairing is implemented and provides support for the decision making with respect to how many passes would be necessary to reach the minimum value of coarse fibre weight and maximum value of fine fibre, and the magnitudes of these values, although the behaviour during the dehairing depends on many variables, such as the degree of felting, fibre length, among others, and a large number of dehairing trials would be necessary to be added to the results of this thesis. However, the coefficient of determination indicates a value between 60 and 80%, depending on the number of passes through the machine, for the coarse fibres and is higher for the fine fibres, while the intermediate fibres showed a lower value. The noticeable difference between the two variables (W% and N%) in all three FGs had been already discussed above in relation to work on cashmere (McGregor, 2018) and it is observed here as well. The similarity in behaviour with a similar technology, but in Australian cashmere, is important. The decrease in the relative amount of objectionable fibre at each pass is between 15 and 20%, with a noticeable decrease from the fourth pass onwards (Singh, 2003). The fine fibre recovery rate in the case of Australian cashmere is no more than 65% (McGregor, 2018), which is higher in this trial involving llama fibre. Calculations not included in this thesis, but partly carried out with the same samples and observational data from commercial dehairing, place this value between 65 and 75%, depending very much on the condition of the fleeces (Frank, E.N., personal communication). Although they had been undertaken using a different method than McGregor’s (2018), in the original validation trials of the AM2 technology (Frank et al., 2009), a value similar to that of cashmere had been obtained for llama fibre. Also, regarding the alpaca fibre, the value was very similar to that reported here (70%).

The results of this trial show a different behaviour depending on the fleece type. The minimum estimation for the coarse fibre group expressed in relative weight and relative fibre frequency (W%1d and N%1d) is reached at passes 12 and 10 for DC fleeces, passes 10 and 8 for IC fleeces, passes 11 and 9 for SC fleeces and passes 15 and 9 for Lustre fleeces, which means that it is confirmed that DC, IC and SC fleeces show a similar behaviour with respect to the relative weight of the coarse fibre group (W%1) and the number of passes needed to reach the minimum, while Lustre fleece behaves differently and needs more passes for that purpose. Even the fact that the quadratic term is not significant confirms a linear behaviour. This confirms that, for the dehairing process, it is detrimental to mix lustre fleeces with the other fleece types. Therefore, in order to achieve an optimal process performance, it is advisable to process DC, IC and SC fleeces together, and lustre fleeces separately. According to industrial assessment, lustre fleeces can be dehaired *at infinitum* (Seghetti Frondizi, D.G., personal communication.). Thus, it is necessary to implement a classing regarding fleece type before starting the dehairing process (Frank et al., 2007).

The dehairing processes carried out in cashmere show a similar quantity of passes to reach that level of coarse fibres, 9 for Singh (2003) and from 9 to 12 for McGregor (2018). This does not confirm the typical statement that the fibre to be dehaired should have a ratio between coarse and fine fibre diameter of at least 4 times. Also, in the case of Australian cashmere, it was claimed that its dehairing was not efficient because, in addition, their coarse fibres were shorter than their fine fibres (Smith, 1988), which the Australian trials themselves were responsible for "demystifying" (Singh, 2003; McGregor, 2001; Idem 2018). In the latter work, a considerably lower yield is obtained at dehairing in the only lot of double coated cashmere which was used (Cashmere length/coarse fibre length ratio of 1:12). This had also been demonstrated incipiently on alpaca fibre (Wang et al., 2008) and conclusively with AM2 technology on tops of alpaca from the Peruvian industry (Frank et al., 2019b).

This conclusion is also in line with a study on linear density ("title") and the spinning regularity carried out by Frank et al. (2019c) with llama fibre in which it is concluded that the behaviour of different fleece types during the dehairing differs from each other and the need to implement classing regarding fleece type before dehairing is said. Despite being a shorter fibre, the yarn is less hairy ("hairiness") due to the fact that thicker fibres protrude less. This would happen because in the spinning process (high speed of the continuous spinning), the coarse fibres are expelled towards the edge of the yarn by the centrifugal force, but they got "pinched" or trapped at the other end in the yarn centre, where they were initially located (Miró, A., personal communication).

2.2. Mean diameter according to fibre type

Figure 39 shows that the non-medullated fibres (MDAd) do not reduce their MD through the dehairing, but they remain around 22 µm (ranging from 21.9 to 22.5 µm). The MD of fragmented medullated fibres (MDFd) is not reduced either, but it remains around 26 µm (ranging from 25.7 to 26.4 µm). That is to say that no dehairing effect is observed on these two variables. This implies that if a superfine or fine dehairing product is required, it is necessary to provide, for the dehairing, fleeces containing fibres of the desired fineness. Furthermore, the almost constant MDAd and MDFd values confirm that the method used in this thesis, whereby each sample is first dissected into 3 fibre groups and then the MD of a fibre type is weighted from the MD and the frequency of each FG (Equation 5, Figure 5), provides consistent results, since by measuring always the same fibres, the same result is reached.

Figure 40 shows the dehairing effect on the relative frequency of non-medullated and fragmented medullated fibres (N%Ad and N%Fd). Non-medullated fibres, which are the desired fibres having the highest textile value, clearly increase their presence (N%Ad) within the product, which is confirmed by the significant KW results. This confirms an improvement in the textile quality through the dehairing process. The frequency of fragmented medullated fibres (N%F), which are also desired fibres within the product, remains high throughout the successive passes.

In relation to the dehairing and the behaviour of different types of mohair, alpaca and Angora fibre, McGregor (2012) comments that it is highly likely that methods that result in reducing the TMD in alpaca fibre lead directly to a reduction in the incidence of medullated fibre, in the same way it was seen in mohair fibre. In Lupton et al. (1991), it was reported on 20 µm mohair without medullation. However, in Australian alpaca fibre with an TMD measured at an average flank height of 20 µm, the medullated fibres represent a 10% in relation to fibre frequency and these have a MD of 30 µm. This incidence of medullated fibre in Australian alpacas corresponds exactly to the quantity of skin follicles of 9 secondary follicles per each primary follicle. Specifically, the ratio of secondary/primary follicles in alpacas was less than 9:1 (Ferguson et al., 2000), what implies that all primary follicles and some of the secondary follicles are producing medullated fibres (McGregor, 2012). For high quality dehaired cashmere, the incidence of medullated fibre should be <0.2% (McGregor, 2000; Idem 2001; McGregor & Postle, 2004).

For Angora fibre, the high incidence of medullated fibre reduces the average specific density to approximately 1.20 g/cm^3, which is lower than that of other animal fibre types of 1.31 g/cm^3, since Angora possibly has several parallel medullas within the fibre. Variations in the specific densities of Angora fibre possibly affect blending ratios as well as other characteristics of Angora textiles (Blankenburg & Philippen, 1988). Differences in specific density and medullation between Angora fibre samples of different origin were reported.

In raw Australian mohair having 4.3% of large medulla (kemp) and 6.5% of total medullated fibre, the incidence of large medulla (kemp) fibres was reduced to 1.9% and total medullated fibre was reduced to 4.2% by laboratory washing and carding on a Shirley Analyser (McGregor, 2010). This instrument was presented as having potential for dehairing in Australian cashmere (Couchman & Holt, 1990).

In Figures 39 and 40, it can be seen that the fibre structure does not change much with respect to the MD of the different fibre types. Instead, the dehairing effect and, thus, the modification of the fibre structure is mainly determined by a change in the relative weight and relative fibre frequency (W% and N%) of the three FGs (Figures 33 and 36). Furthermore, Figures 41 and 42 show which fibre types compose each FG. FG3 is composed of the non-medullated and fragmented medullated fibres (Figure 42, lower part) and this remains the case throughout the dehairing process. FG3 is only modified by increasing the presence of non-medullated fibres and thus reducing the presence of fragmented medullated fibres. FG2 contains mostly continuous and fragmented medullated fibres (Figure 42, central part), but it is nevertheless an FG that has low incidence in the fibre structure due to its reduced frequency (Figures 33 and 36). Finally, FG1 is composed of continuous and large medullated fibres (Figure 42, upper part). This composition is kept throughout the dehairing process. FG1 only clearly changes in the tenth pass, where the presence of large medullated fibres decreases and therefore the presence of continuous medullated fibre increases. Generally speaking, this was also observed in alpaca fibre (Frank et al., 2019b).

With respect to the MD, Figure 41 shows curves that confirm what was seen in Figures 30 and 39: an almost constant MD of the non-medullated and fragmented medullated fibres, corresponding to FG3, and a reduction of a few microns of the continuous and large medullated fibres, corresponding to FG1.

The MD curve of the interrupted medullated fibres (MDId in Figure 39) shows an inconsistent behaviour along the successive passes, but its presence is so low (N%Id in Figure 40) that further discussion is not considered necessary. A dehairing effect is reported for the MD of the continuous and large medullated fibres (MDCd and MDGd in Figure 39) as there is a slight downward trend of the MD. However, the comparison made by the KW test shows no significance. The MDCd drops from 37.3 to 36.1 µm, so it decreases 1.2 µm, and MDGd drops from 53.7 to 50.3 µm, decreasing 3.4 µm over the ten passes. This value of a reduction of only a few microns is consistent with the TMDn reduction value of 4.4 µm (Figure 29).

Figure 40 shows the dehairing effect on the relative frequency of continuous and large medullated fibres (N%Cd and N%Gd) with a clear trend to be reduced, which is confirmed by the significant KW results. This implies a strong modification of the fibre structure and an improvement of the textile quality. According to the KW results, the reduction of the N% for continuous medullated fibres (N%Cd) stabilises from the sixth pass onwards, while it shows a significant difference until the last two passes for large medullated fibres (N%Gd). In this respect, the continuous medullated fibres could be a problem because they seem to be still present in the product even after more passes.

The percentage of large medullated fibres alone is 2.6% at the end of the fifth pass (N%Gd in Figure 40), that is to say that they are already below the 3% threshold, and from the seventh pass onwards, it remains clearly below this threshold. It is interesting to verify that large medullated fibres are noticeably thicker than continuous medullated fibres: the MD of large medullated fibres is 53.8 µm before the dehairing process and decreases up to around 50 µm at the end of dehairing, while the MD of continuous medullated fibres is 40.2 µm before the dehairing process and 38.0 µm at the end of it (Figure 41, upper part). Evidently, the increased coarseness of large medullated fibres helps them to be separated more quickly, whereas continuous medullated fibres could be a problem in this respect.

2.3. Crimp frequency

The few coarse or objectionable fibres that remain within the product after successive passes keep the low CF. And the fine fibres keep the high CF. No clear effect on this fibre characteristic is observed due to the dehairing process.

2.4. Crimp groups

When comparing the CGs of the product and the subproduct (upper and lower parts of Table 4 respectively), the modification that the dehairing produces in a fibre lot is observed because, for all FTs, the table shows a clearly higher presence of CG4 fibres in the subproduct than in the product. CG4 is the typical CG composed of objectionable fibres and the fact that more of this CG is found in the subproduct indicates the effectiveness of the dehairing process. This would happen due to the higher elasticity of the crimpier fine fibres, and the stiffness and straightness of the coarse fibres (Singh, 2003).

Furthermore, in the case of showing a modification (column 4 with respect to column 3 as well as column 6 with respect to column 5), this is, for the product, towards a CG that is usually of finer fibres and, for the subproduct, towards a CG that is usually of coarser fibres. This can be observed due to a modification towards a CG of higher crimp in the case of the product and a CG of lower crimp in the case of the subproduct.

With respect to the modification of the fleece structure throughout the successive passes, a modification occurs for DC, IC and SC fleeces towards CGs of higher CF, that is to say, from CG4 to CG3 and from CG3 to CG2. In contrast to this result, no modification occurs for the Lustre fleece, which confirms a different behaviour. This can be explained by the low crimp frequency and the long shape of the crimp of the fine fibres that conform this fleece type (Frank et al., 2007). It can be concluded that it is not advisable to process all fleece types together, but rather to implement a classing regarding fleece type before dehairing and to join DC, IC and SC fleeces, on the one hand, and the lustre fleece types (HL and Lustre), on the other hand. Similar characteristics of the processed fibres guarantee a similar behaviour during the dehairing process and thus a more feasible adjustment of the dehairing machine, leading to a better performance of the dehairing as well as of the subsequent production process (Frank et al., 2007; Idem, 2011; Seghetti Frondizi, 2014).

2.5. Fibre length

The dehairing effect shows a shortening of the fibres. Clearly, the fibres belonging to FG3 are the shortest ones, but they remain above 7 cm even after the tenth pass, which is a good length for spinning the fibre by a worsted process (Alexander, 1995). Figure 45 plots the length of the fibres of the 3 FGs contained in the subproduct and shows that, from the first pass on, the shortest fibres are included in the subproduct.

2.6. Final evaluation

The dehairing effect can be observed by a cross-sectional reading of all figures with respect to the initial fleece structure (pass 0) and the modification observed in the fibre structure of the dehairing product (passes from 1 to 10). A cross-sectional look at the fine fibres (FG3) allows the textile quality of the raw material to be assessed before the dehairing (pass 0) since the fibres of this FG are the ones that should be gathered in the dehairing product. It is revealed that this FG is composed of fine fibres with a MD of 24.6 µm (MD3d in Figure 30, Table 1), 36% of which are non-medullated and 58% of which are fragmented medullated fibres, making 94% (N%A3d and N%F3d in Figure 42, lower part). These fibres are 9.7 cm long (L3d in Figure 44), have a high crimp frequency of 3.8 crimps/cm (CF3d in Figure 43) and represent the 65% of the staple weight (W%3d in Figure 33). The weight of the intermediate and coarse fibres of the fleece before the process is 11% and 24% respectively (W%2d and W%1d in Figure 33).

Already after the first pass, the modification of the fibre structure can be observed, which keeps changing with each pass. At the end of the first pass, a relative weight of fine, intermediate and coarse fibres of 68%, 11% and 21% respectively is recorded, which changes to 83%, 7% and 10% respectively at the end of the fifth pass, and to 89%, 5% and 7% respectively after the tenth pass (Figure 33). Fibre length is 8.5; 10.3 and 12.0 cm respectively after the first pass, it is reduced to 7.8; 9.3 and 10.8 cm respectively after the fifth pass and then stabilised for FG2 and FG1, while it is still slightly reduced with respect to FG3, not significantly, however, according to KW (Figure 44). In other words, a significant modification is observed in relation to these variables, while the MD only modifies with a clear trend for FG1, reducing itself (Figure 30), and the modification of the CF does not show a clear trend either (Figure 43).

In other words, the results confirm a modification of the fibre structure through the dehairing, which means an improvement in the textile quality, mainly due to the effective separation of the coarse fibres from the product, with the greatest impact being achieved during the first few passes. At the same time, a limitation is observed, which is given by the fact that the quantity of coarse fibres weight/weight, despite being very close to the 3% threshold, does not manage to decrease below this threshold.

Furthermore, it was confirmed that it is not advisable to implement the dehairing for fleeces whose fine fibres have too high a MD since it was shown that the dehairing effect has a limitation with respect to the ability to reduce the MD of fine fibres. It was also verified that different fleece types respond differently to the dehairing process. To summarise, it can be said that, in order to achieve an improvement in the textile quality, the dehairing is a fundamental component of the solution, but it is limited on its own since its effectiveness is conditioned by the raw material that is provided to the dehairing. As an additional measure to be evaluated, the classing of fleeces regarding fineness and/or fleece type is proposed, which is analysed in Sub-chapter 3. The need to implement the classing with respect to specific criteria for developing an industry based on animal fibre is in line with what was concluded in Frank et al. (2017a) in relation to Patagonian cashmere. It was also confirmed that, it is essential to implement a prior classing regarding fleece type for processing llama fibre since different fleece types do not behave in the same way during the process (Frank et al., 2011a).

3. Effect of classing and of dehairing on fibre textile quality

The results included in Sub-chapter 3 were published in Brodtmann et al. (2018) and complemented with additional analyses, mainly as detailed in Division 3.9.

In Sub-chapters 1 and 2, real data were evaluated, obtained from the annual follow-up of breeding animals on the one hand, and from the fibre textile process in a dehairing machine on the other hand, that is to say, from the reality of fibre production and processing. Sub-chapter 3 complements the research by providing a reference regarding the theoretical potential of the dehairing being a measure to increase fibre homogenisation as well as for fleece classing, which is another measure that has a homogenising effect on the structure of a fibre lot intended for textile use. In other words, neither fleece classing is carried out, nor fibre is dehaired on a dehairing machine, but the data revealed from fibre samples were taken and, through a simulation of classing and dehairing carried out by means of mathematical analysis, it was evaluated and verified whether such measures could theoretically have the desired effect of homogenising a fibre lot and thus the textile quality. From these theoretical references, it will be possible to complete the discussion on the age effect as well as of dehairing.

Classing can be implemented regarding fleece type as well as fineness. This measure consists of assessing one fleece after the other, classing each fleece according to what has been assessed and separating fleeces into different lots according to this classing. On the contrary, during the dehairing, the different fibre types of the same fleece are separated, mainly in order to separate objectionable fibres that reduce the high quality provided by fine fibres as a textile raw material. In this context, coarse fibres are referred to as "undesirable" or "objectionable” since they are not suitable for the production of fine textiles. This separation of fibre types corresponds to the separation according to fibre groups as provided by the Three Group Dissection.

Furthermore, this sub-chapter provides complementary criteria in relation to the understanding of the differences among fleece types and thus provides an innovative line of thought for the process of classing fleeces regarding fleece type. Although llama fleece types have been clearly and unmistakably described in detail (Frank, 2001; Frank et al., 2007a), this does not always mean that it is easy to distinguish one fleece type from another, for example, in a rural context. The description of the fleece types was issued through the description of the fibre types and the corresponding fibre characteristics. However, when shearing, the whole staple is better observed than the individual fibres and it is convenient that the existing description of the fleece types is complemented by other ways of describing them. The purpose of this is to identify the fleece type in an easy way, for example, in order to separate the animals regarding fleece type before shearing or to classify the fleeces regarding fleece type after shearing.

In the same way that the llama fleece consists of a set of fibres of different types that are arranged in a specific structure, a specific structure of the set of fibres is also formed when, among many fleeces, a lot of llama fibres is assembled to be used in the textile industry. In that sense, the llama fleece is nothing but a very small fibre lot.

The intrinsic order of the "llama fleece structure" provided by the animal is very specific and is composed of parallel fibres, whereas the "llama fibre structure", in principle, will never be so specific because it consists of a blend of many fleeces and they are not parallelised at the beginning of the production process. On the other hand, when one of the first steps of the textile process, which is the carding, is implemented, the parallelisation of the fibre is achieved again, that is to say that the fibre structure becomes more orderly again.

The results analysed in Divisions 3.3 to 3.9 represent those of a lot of raw material that could have been purchased at a given time. The fibre structure of a hypothetical lot composed of many fleeces as a whole is revealed. In order to distinguish the effect that can be achieved by implementing the measure of classing fleeces and/or through the textile process of dehairing, it is essential to detail and reveal the fleece structure in general, and the differences among the structures provided by the different FTs in particular. This assessment should help in the decision making as to whether it makes sense to implement these measures at the beginning of the textile process chain or not.

It is the structure provided by a fibre lot that defines its capability of being dehaired as well as its behaviour during the whole textile process chain. The structure, ´estructura´ in Spanish, is so important that the initial letter of that Spanish word was chosen to identify the variables in Sub-chapter 3. In this sub-chapter, it is evaluated, based on a conceptual analysis and through a simulation, how the implementation of classing and/or dehairing modifies the initial structure provided by the fleece, as it is produced by the animal. Furthermore, it is evaluated whether these two measures are able to improve the fibre structure within a lot of llama fibre at the "hinge point" between the primary production and further process within the textile industry. By mentioning the expression “to improve", we automatically mean "to homogenise" since it is essential for the textile industry to receive a textile raw material that is as uniform as possible. This is in line with the findings about llama fibre in Hick et al. (2013) in relation to the need for a classing process in order to obtain homogeneous commercial lots and thus establish a differential pricing scheme for the different fibre qualities.

3.1. Schematic and conceptual description of the FTs

Beyond the frequency of certain fibre types, the mere presence of these fibre types is what defines a FT (Frank et al., 2007a). This is very strong finding, which has the implication that by analysing a small fraction of a staple, that is to say, only a few fibres, one can already differentiate one FT from another. It also implies that the combination of certain fibre types, regardless of how many of each type there actually are, defines the FT and also a characteristic structure. For example, the combination of fine crimpy fibres with coarse straight fibres forms a certain structure, whereas if the coarse fibres are also crimpy, the structure changes. Another decisive circumstance in relation to the structure of a fleece is whether all fibres have the same crimp type or not.

This knowledge leads to a schematic description of the FTs and to the development of conceptual thinking to describe them. The four morphological characteristics of the fibres that describe the five FTs and lead to their definition are length, coarseness, crimp type and lustre type (Frank et al., 2007a). It is important to point out that these four characteristics are macroscopic, being the only condition that it is not necessary to have an exact evaluation of the coarseness or fineness of the fibres, but that making a broadly differentiation is suitable to define the FT. Since this is the case, this means that by visual examination alone the fibre types can be evaluated well enough to differentiate the FTs clearly and reliably.

The five FTs were drawn schematically in Figure 46 and they were described conceptually in Tables 5 and 6. In this way, the existing work performed by Frank (2001) and Frank et al. (2007a) is summarised. While what has been described is not innovative, the work developed by implementing the Three Group Dissection was the starting point for arranging the existing knowledge and deepening FT-related research. This need also became evident because of the importance of being able to communicate the existing knowledge more effectively and clearly, for example, when training new personnel working with llama fibre, whether in a fibre laboratory, for fibre production in the agricultural sector or within the textile industry using camelid fibre.

Like any schematization, it helps to summarise, but at the same time, it simplifies so much that it does not include or convey the whole reality. For example, the coarse fibres of the DC fleece type are not so straight in all cases, but they may also include some curve or several irregular curves in their path. Another aspect of the drawing in Figure 46 that is not so realistic is that, in reality, the fibres of a Lustre fleece are placed much closer to each other, being placed closely and "tightly" to each other along the whole length of the staple. This cannot be drawn in this diagram because the different fibres would not be distinguishable. Moreover, the staple is twisted on itself and this three-dimensional arrangement is not represented in this diagram either.

3.2. FT differentiation according to opposite characteristics

In the context of Division 3.2, the diameter is not taken into account because a high diameter range is inherent to all fleece types and therefore does not help to distinguish them. The same can be said in relation to the fibre length which differs little according to FTs. Among the fibre characteristics diameter, length and crimp type, the latter is the decisive one in relation to whether a fleece is double coated or not. The coexistence of two clearly different crimp types within a single fleece does not allow all fibres to be arranged in a unified way as it does happen with a fleece with a single coat, that is to say, a simple coated fleece.

According to the way of describing the llama fleece structure shown in Figure 47, the different FTs are summarised in a single graph. The particular logic of this graph is that each FT is described in a specific way. They are not described by means of absolute values of fibre characteristics, but through values that are relative to each other. In relation to the CF, the DC fleece is positioned at an intermediate place because it contains very waveless fibres (almost straight) and, at the same time, very crimpy fibres. The IC fleece is positioned somewhere in between the DC and SC fleece. The HL fleece is similar to the Lustre fleece, especially in relation to its visual appearance, only that it contains some fibres of intermediate CF.

The limitation of the conceptualisation and schematization of FTs is given by the strong simplification of the fleece structure. On the one hand, the conceptualisation makes sense to clarify certain typical aspects, but, on the other hand, it is not able to describe many other aspects due to its lack of detail. For example, in the diagram shown in Figure 46, it is necessary to include a new aspect by introducing the three FGs since there seem to be only two in the schematization, the two FGs with the most extreme characteristics. This is useful in a certain context, in order to simplify the description of the FTs, but when dissecting a sample, a group of intermediate fibres are clearly defined because fibres are found that, due to their characteristics, cannot be included in the group of fine fibres neither can they be included in the group of coarse fibres. Divisions from 3.3 to 3.9 describe the fleece structure in more detail according to different fibre characteristics. The analysis is based on the three FGs, that is to say that it includes the fibre group of the intermediate fibres (FG2) since it is based on the findings of the Three Group Dissection.

Classing regarding FT:

The process of reducing the high variability of llama fibre in order to improve its textile potential can be well illustrated by looking first at Figure 47 and then at Figure 46. If a classing of fleeces regarding its type is carried out and only DC, IC and SC fleeces are selected, the lower right part of the graph in Figure 47 is set aside. The next step could be the classing regarding fineness in order to reduce the MD variability. For the selected fleeces, which are the finest ones, the next step could be the dehairing process. The dehairing product would then be composed only of the crimped fibres of the DC, IC and SC fleece types. Figure 46 illustrates how similar these fibres are. This could be a recommended sequence of production steps in order to obtain a lot of fine fibres with a high degree of homogeneity, which adds value to the llama fibre by offering a higher potential as a textile raw material.

As described above, the main FTs, which are DC, IC and Lustre, can be easily distinguished. On the other hand, it may be more difficult to distinguish between DC and IC as much as between IC and SC because the differences are gradual. But this does not matter if the classing is carried out by leaving DC, IC and SC together in a lot.

What would be a major problem in this case, is that an IC fleece could possibly be confused with an HL fleece or vice versa because, in both cases, we are dealing with an intermediate TV. A certain similarity between IC and HL fleeces with respect to their structure is revealed by their close position within Figure 47. In this context, a useful differentiating factor is the quantity of CG4 fibres present in the fine fibre group, which is larger for an HL fleece. In addition, it helps what is described in the first paragraph of Division 3.4 within Chapter V that, for the different FTs, the FG1 fibres show very different crimp patterns, even though they all belong to CG4. In that paragraph, only the three main FTs are described, but it can be taken into account that the IC fleece is intermediate between DC and SC, and the HL fleece is intermediate between SC and Lustre, but more similar to Lustre. In addition, the different type of lustre, which is more noticeable in the whole staple than in a separate fibre, is also an important differentiating factor.

Effect of the FT on dehairing:

The dehairing process is entirely mechanical and relies on morphological differences between fibre types. Logically, larger differences between the fibre types present in a fleece facilitate the capability of being dehaired. It was found that the dehairing of alpaca fibre is not as effective as the dehairing of cashmere because fine and coarse alpaca fibres differ less with respect to diameter, stiffness and crimp (Wang et al., 2008). McGregor & Butler

(2008b) showed that white fleece colour, longer raw cashmere, higher fibre curvature, lower vegetable matter content, normal guard hair length and the absence of visible felting were associated with more efficient process and/or the production of longer cashmere. Cashmere is a denomination which refers to the fine fibre part of the raw fleece and/or the dehairing product that gathers these fine fibres. Furthermore, raw cashmere with a higher cashmere content (by weight/weight) and a larger fibre diameter was processed less efficiently than raw cashmere with a lower cashmere content and smaller fibre diameter. According to this thesis, the DC fleece type, which is positioned on the left side of Figure 47, should show a better behaviour during the dehairing process. This was confirmed by Frank et al. (2011a).

Another important aspect related to the dehairing effectiveness is that the fibres passing through the dehairing machine must arrive one by one at the place within the machinery where separation of the fibres takes place, rather than entangled with each other, for example, because they are entangled with each other due to felting. Therefore, before they reach the dehairing point, the staples must be opened to separate the fibres from each other. The first report on the dehairing of llama fibre was made by Townend et al. (1980) and is related to mechanical aspects and the problem of felting with respect to the behaviour of the raw fibre, but it does not refer to the specific behaviour of the different fleece types. In this thesis, an aspect was evaluated, an existing aspect that goes beyond the felting problem and that is related to the different fleece structures whose behaviour during the dehairing process differs. Logically, it is easier to open a fleece when it has a structure with larger bulk, while the more closed the structure of lustre fleeces is, the more difficult it becomes to separate the fibres. Figure 47 shows which fleece types have a more open fleece structure, that is to say, with larger bulk: the fleece types situated in the upper part of the figure. Although the DC fleece type is situated only at an intermediate height, it has an open structure because for the fine down fibres alone the bulk is similar to that of an SC fleece. This confirms the convenience of joining DC, IC and SC fleece types when implementing a classing regarding fleece type.

When taking into account the two characteristics of fleece structure that favour the capability of being dehaired, a larger bulk and a higher degree of differences among fibre types, the DC fleece type is the most benefited, followed by the IC and the SC fleece types. Again, this is confirmed by Frank et al. (2011a). Therefore, a more rigorous classing regarding fleece type could be carried out by selecting DC fleeces only because this fleece type meets both characteristics which benefit the capability of being dehaired.

3.3. Crimp frequency according to FT

The description of the llama fleece structure in Divisions from 3.3 to 3.9 was focused on the objective of Sub-chapter 3, which is mainly related to the mean diameter (MD). Therefore, the analysis is the most detailed for this variable. But also, the variables related to fibre crimp, which are the crimp frequency (CF) and the crimp group (CG), have a decisive influence on the homogeneity of the fibre. MD, CF and CG are considered as the main characteristics and are analysed in detail in order to evaluate the suitability or necessity of classing regarding fleece type and fineness as well as of implementing a dehairing, while fibre length (L) is only briefly mentioned.

Group of coarse fibres (FG1):

The CF is a typical characteristic to differentiate between DC and SC fleeces. For more than 60% of DC fleeces, the CF of FG1 is <1 crimp/cm, which is equivalent to a straight or almost straight fibre, while for SC fleeces the percentage of fleeces with such a reduced CF is low because the fibres of an SC fleece always show a crimped pattern, even the coarse fibres (Figure 48). This is the reason why the SC fleece has a position at the top of the graph in Figure 47. It’s typical for Lustre fleeces to have the reduced CF for FG1 and it is relatively reduced even for the other two FGs, which leads to be situated in the lower part of Figure 47.

In the middle of Figure 48 graph about the SC fleece, it can be seen that only about 20% of the fibres of FG1 showed a CF of < 1 crimp/cm, that is to say, a clearly lower percentage than the DC and Lustre fleeces. Furthermore, 1 crimp/cm was measured for almost 50% of the fibres, 2 crimps/cm were measured for almost 30% of them and there are even coarse fibres with 3 crimps/cm. This confirms the typical crimpy fibre pattern of SC fleece. It also confirms that within that crimped pattern there are varied CFs, that is to say that the fibres show a sinuosity of different sizes, as it can be seen in Figure 48. Therefore, the fibres cannot unite with each other and a very airy structure is formed. Furthermore, it must be taken into account that these coarse fibres are the ones that have the main force in defining the shape of the staple because they are the most rigid ones due to their increased coarseness.

In the case of the Lustre fleece, as seen in the graph on the right within Figure 48, the crimp of the coarse fibres is <1 or 1 crimp/cm, which is accompanied by a long, regular, helix-shaped crimp, that is to say a three-dimensional crimp. This leads to the typical shape of the Lustre fleece staple, which is a very extended crimp and has a greater cohesion. The intermediate and fine fibres are crimpier, but they nevertheless accompany the structure composed by the coarse fibres because they do not have the strength to counteract. Moreover, they are much less crimpy than those of the DC and SC fleeces.

For the FG1 fibres of the DC fleece, the graph on the left within Figure 48 shows a curve almost identical to that one of the Lustre fleeces, but even so, these fibres form a very different structure. This is due to the irregularity of the fibres in relation to their CF which does not allow a cohesion among them and, in addition, the fine fibres show different CFs and an airy structure, similar to that of the SC fleece.

An issue concerning the measurement of the CF of very irregularly crimped fibres, especially the coarse fibres of the DC fleece, is that the result differs depending on the fibre section in which the CF is measured. In that sense, the method chosen in this thesis to measure the CF can be questioned. A method described by McGregor (2007) was chosen, in which the number of crimps per centimetre is measured and it is randomly chosen in which section of the fibre to measure. Another method to measure the CF could be the one implemented by Frank (2001) in which the full length of the fibre is taken into account, that is to say that the CF results from the division of the number of crimps ("valleys" or "summits") by the fibre total length. The CF of the DC fleece would have been possibly lower than that of the Lustre fleece if that method had been used in this thesis.

Group of fine fibres (FG3):

With respect to the FG3 fibres, the observed CF of the DC, IC and SC fleeces was almost identical, while the FG3 fibres of the HL and Lustre fleeces showed a different, lower frequency crimp, which can be seen in Figure 48. With respect to the classing regarding fleece type, this indicates the convenience of gathering the HL and Lustre fleeces, on the one hand, and the DC, IC and SC fleeces, on the other hand.

3.4. Crimp groups according to FT

Group of coarse fibres (FG1):

With respect to coarse fibres, Figure 49 to Figure 51 show that the three FTs plotted have in common that almost all FG1 fibres are gathered in one single CG, which is the CG4. But, when classing regarding fleece type, it is important to take into account that FG1 fibres show important differences in relation to their crimp pattern, even though they belong to the same CG. In order to classify them correctly it is helpful to keep this in mind. For DC fleeces, the CG4 pattern shows a high irregularity since it changes from long to sharp curves which are followed by very straight parts of the fibre. For SC fleece, the CG4 pattern is similar, but it does not contain straight parts, which leads to a higher CF. For a Lustre fleece fibre, the typical CG4 pattern is a long and very regular crimp, similar to the shape of an extended corkscrew helix.

To discuss the typical structure of DC fleeces, it is revealing to look at Figure 49 at the same time as Figure 48: it can be seen that this is the FT that shows the greatest difference with regard to FG1 and FG3. In fact, this is the reason for the isolated position of the DC fleece on the left side of Figure 47, as the noticeable difference with respect to the fibre crimp type of FG1 and FG3, both in terms of CG and CF, leads to a double coated fleece.

For the Lustre fleece type, the typical extended crimp staple without volume stands out. This is formed by the presence of many fine fibres which belong to CG4 and which accompany the coarse fibres which always belong to this CG4. In addition, the fine fibres of Lustre fleeces show the same regular crimp pattern as the coarse fibres. Both characteristics allow the fine and coarse fibres to come very close to each other and to be arranged in very tight staples.

Group of fine fibres (FG3):

If FG3 is taken as equivalent to the product of the dehairing process and the aim is to achieve the greatest possible homogeneity in order to improve the behaviour of the llama fibre during the textile process, this implies responding to the need to gather together FTs having the same characteristics, specifically in that FG. As a conclusion, the same can be said as for CF since it is convenient to gather DC, IC and SC fleeces together, on the one hand, and HL and Lustre fleeces, on the other hand. This statement is also reinforced by looking at Figure 49 and Figure 50, which represent the DC and SC fleeces, and have a very similar appearance.

3.5. Fibre length according to FT

The wide range of lengths from 4 to more than 20 centimetres can be attributed to the presence of different shearing gaps and, in addition, to the presence of animals that have never been sheared. This variability can be reduced by means of the annual shearing.

The results related to fibre length are described only in brief since through the three main characteristics, which are TMD, CF and CG, the potential effect of classing and dehairing can be evaluated. For the same reason, the data analysis does not include medulla type, stiffness, flake height and presence or absence of lustre, although these characteristics may be of interest to the textile industry.

3.6. Mean diameter according to FT

The group of coarse fibres (FG1) represents the so-called objectionable fibres, while the group of fine fibres (FG3) represents the desirable fibres which have the potential to be used for the production of fine textiles and, in this context, are equivalent to the dehairing product. The FG2 fibres represent an intermediate position between these two extremes and they are not analysed in detail.

Group of coarse fibres (FG1):

Table 8 shows that the DC fleece has the coarsest fibres within FG1 and its MD (MD1e) is clearly above the mean of the coarse fibre's MD of all FTs, which is 45.5 µm, as shown in Table 15 (column 2, row 1). Furthermore, the standard deviation value of the DC fleece (SD1e) is clearly the highest one, being more than 8 µm. The IC fleece follows the DC fleece, which is logical according to the description of the IC fleece which specifies that it is an intermediate type between DC and SC. The fact that the FG1 fibres of the DC fleece are coarser than those of the other fleece types does not make much difference in relation to the presence of objectionable fibres and the need for dehairing because an average of approximately 40 or 41 µm, which was calculated for the Lustre and SC fleeces, also confirms the presence of coarse fibres which are capable of producing prickle on the skin. This leads to the conclusion that if the aim is to produce fine garments, all FTs need to be dehaired.

Group of fine fibres (FG3):

FG3 can be evaluated as equivalent to the product of the dehairing process. Table 9 includes the results for all fleeces, that is to say that no fineness classing has been implemented, and the MD of FG3 (MD3e) shows that the SC and Lustre fleece types provide finer FG3 fibres. The mean MD of the fine fibre group is 24.4 µm (Table 15, column 26, row 1), that is to say that SC and Lustre fleece types with a MD3e between 22 and 23 µm are below this value. However, the addition of MD and SD of the fine fibre group (MD3e + SD3e) for both FTs adds up to a fibre micronage of around 26 µm, which shows the need to improve the fineness in order to provide a raw material of sufficient textile quality. This indicates the need to implement an additional measure in addition to the dehairing to reduce the MD, which could be the classing regarding fineness. This is evaluated in the following paragraphs.

3.7. Mean diameter according to FT with and without classing and/or dehairing

Group of fine fibres (FG3):

After implementing a fleece classing regarding fineness, the result changes with respect to the MD of the FG3 (MD3e), as it is shown in Tables 10 and 11. In this case, the MD3e of the DC fleece type does not show significant differences to that one belonging to the other FTs. This confirms that if a fineness classing with subsequent dehairing is implemented, it is appropriate to gather the DC, IC and SC fleece types together as proposed in the last paragraph of Division 3.3 and the last paragraph of Division 3.4 of Chapter V, which are related to CF and CG respectively.

What is striking is that a much higher percentage of DC and IC fleeces had a high TMDne and they had to be removed from the analysis in order to simulate keeping only fine fleeces in the "dehairing" lot. This can be seen by evaluating the quantity of fleeces analysed in column 2 of Tables from 9 to 11. In order to select the DC and IC fleeces with TMDne<28 µm, the 63% and 64% of the fleeces of each type were set aside respectively, while only 26%, 43% and 17% of the SC, HL and Lustre fleeces were set aside respectively.

3.8. Mean diameter with/without classing and/or dehairing

In this division, the analyses were performed on all samples together, that is to say that differences among FTs were not distinguished.

Fibre coarsening regarding the animal age is a well-known phenomenon (McGregor & Butler, 2004; Frank et al., 2006a). Therefore, it was decided to include only data from young animals for this analysis in order to determine whether, in that way, diameter variability could be satisfactory. Furthermore, the results of Sub-chapter 1 confirmed that fleeces from classes 1 to 3 showed the best textile quality. This corresponds to a selection of only young animals for shearing in order to assemble a lot of relatively fine fleeces. The age limit was set at only three years old. To this free-range classing, it was added the simulation of yet another type of classing, which consists in the fact that the sampling area is located on the flank of the animal, that is to say on a part of the animal's body where the fleece has its best quality. This is equivalent to a fibre classing regarding body sites (Frank et al., 2007b) which is carried out during or after shearing where claws and other coarse fibre parts are removed.

Even so, the TMDne distribution shown in Figure 53 includes a wide range of diameters, which shows that even including what has been mentioned in the previous paragraph, it is necessary to implement measures to set aside too coarse fibres if the purpose is the production of fine garments. In this light, it is illustrative to see how the TMDne distribution opens up into three distributions, one representing each FG (MD1e, MD2e and MD3e). 31% of the fleeces analysed showed a MD3e in the 23.5 µm range and 25% in the 20.5 µm range (ranges defined in Table 1). The problem is that, within the llama fleece, this segment of fine fibres coexists with another segment of objectionable fibres. The latter ones are mainly represented by the distribution curve of MD1e in Figure 53. But the distribution of MD2e also shows a high percentage of fleeces with coarse FG2 fibres, which means that many of the intermediate diameter fibres are coarse.

Column 1 of Table 15 shows the magnitude of the MD reduction that is achieved through the classing regarding fineness. This varies between approximately 2 and 4 µm, depending on the quantity of fleeces that has been excluded. The question is whether classing as a single measure can be said to be sufficient to provide raw material for the production of fine textiles. The value of 25.0 µm at the bottom of the column indicates that there is a limitation, especially since this value is the mean value and includes a SD of several fibre micronages, that is to say that it indicates that a dehairing needs to be implemented after the classing.

Group of coarse fibres (FG1):

The coarse edge of the TMDne distribution consists of the presence of FG1 fibres. These are plotted by means of the MD1e distribution in Figure 53 and it can be seen how coarse the FG1 fibres can be. Taking into account that fibres with a diameter higher than 30 µm are coarse, then more than half of the FG2 fibres are also objectionable, which is illustrated by the MD2e distribution. After classing, including only fleeces of TMDne<31µm or TMDne<28µm, the percentage of coarse FG2 fibres decreases somewhat, as it can be seen in Figures 54 and 55 as well as in Columns 4 and 5 of Table 15.

The prickle produced by textiles is determined by the quantity of fibres that are coarser than a certain threshold value of the diameter. This threshold is around 30 µm and information about the shape of the coarse edge within the diameter distribution is not necessary (Naylor, 1992b). According to this, the presence of objectionable fibres can be seen in all fleeces, also in the finest TMDne fleeces, since the fibres of FG1 are always coarser than this threshold value. Therefore, the finest fleeces also require dehairing.

Taking the percentage of FG1 fibres as a reference, the same finding is made regarding the presence of objectionable fibres. This threshold was defined at 3.23% (weight/weight) of objectionable fibres (Frank et al., 2014). Taking the FG1 fibre weight as equivalent to objectionable fibres, all fleeces analysed are above this threshold and therefore need to be dehairing: on average the fleeces contain 17% (weight/weight) of objectionable fibres, with a minimum of 3% and a maximum of 55%.

Another aspect that is in line with what has been said in the previous two paragraphs with respect to the need for dehairing is shown in Figure 54. It shows that the classing regarding fineness is not capable of replacing the dehairing since, after classing, the MD1e<31 still keeps a very high coarseness. This observation is confirmed by an even more rigorous classing in which only TMDne<28µm fleeces are included, as it is shown in Figure 55. The result is almost the same: the MD1e distribution still covers a range from 30 µm up to above 50 µm. Furthermore, through classing, the mean of the MD1e distribution only decreases from 45.5 to 41.1 µm (Table 15, column 2). The distributions of FG1 with and without classing are also plotted in Figure 56: it shows that the distributions of MD1e, MD1e<31 and MD1e<28 are shifted to the left, but only very slightly, that is to say that they keep a high coarseness. Generally speaking, this means that fine fleeces can provide finer fine fibres, but the coarse fibres remain coarse. Consequently, it can be said that the classing regarding fineness almost fails to reduce the MD1, that is to say, the presence of objectionable fibres. This means that, after classing fleeces regarding fineness, dehairing is still necessary as a process capable of reducing the diameter variability and adding value to llama fibre as a textile raw material.

In addition, special attention should be paid to processes in which partial dehairing is carried out and it is important not to confuse this with a complete dehairing, which is necessary to start the production chain to produce fine textiles. For example, if no dehairing is carried out before the raw material is taken to carding, but instead raw fibre is taken directly to carding, this results in a partial dehairing, since many of the very coarse fibres are gathered together with vegetable matter in the carding shoddy waste. This means that some of the FG1 fibres have been separated, but it is far from a complete removal of the objectionable fibres, that is to say, from a complete dehairing. This type of process is equivalent to the removal of the coarse edge of the FG1, that is to say, to a partial dehairing.

In order to further develop what has been outlined above, it is useful to look at Figure 55 since it can be clearly seen what the situation would be if one were to argue that to produce fine textiles it would be sufficient to implement a classing including fleeces of TMDne<28µm and a partial dehairing that is carried out by a carding machine. The MD1e distribution shows that the coarse edge is situated at approximately 45 to 53 µm. If through a partial dehairing only this coarse edge were removed, the major part of the objectionable fibres would be retained in the carding staple and thus in the yarn as well, which would mean that the problem of prickle sensation on the skin would persist.

Group of fine fibres (FG3):

Figure 53 plots the MD3e distribution on the left side of the graph. Although the maximum peak of this curve is in the range of 23.5 µm, its mean shifts further to the right at 24.4 µm, given the bulky edge of coarse fibres observed at the right of the curve. This coarse edge shows the existence of 17% of fleeces with a MD3e within the 29.5 and 32.5 µm range, that is to say that fleeces in which the finest fibres are not "fine" according to the ranges established in Table 1, but "medium" or "coarse". For these fleeces, a dehairing would not be indicated since the dehairing product would still be coarse and therefore not suitable for the production of fine textiles. Due to this fact, it is confirmed that classing regarding fineness is a necessary step prior to dehairing in order to only dehair fleeces that actually provide fine fibres.

Figure 54 shows the result of the simulation of a classing that includes only TMDne<31µm fleeces. Here, the segment of coarse MD3e fibres is removed and the MD3e is lower than 28 µm for 99% of the fleeces and it is lower than 25 µm for 80% of them. This confirms the effectiveness of the classing regarding fineness since the presence of fine fibres within a fibre lot increases.

The fineness degree of the textile to be processed influences the decision as to how low the TMDne threshold used when classing regarding fineness should be. In addition, the SDe should be taken into account. For example, for fleeces having a TMDne within the range of 28 to 31 µm, the MD3e varies between 18 and 28 µm. This confirms the known fact that, in order to determine the textile quality with respect to fineness, the MD is not the only variable, but it must be complemented by the SD (Dolling et al., 1992).

The average yield at dehairing was calculated at 69% and it could be higher for fine fleeces. The variable used to define the yield is the weight of the FG3 in relation to the weight of the dissected whole staple (Frank et al., 2009).

3.9. Classing and dehairing potential

In this division, the analyses were performed on all samples together, that is to say that differences among FTs were not distinguished.

MD reduction through classing (without subsequent dehairing):

The KW test in Table 12 shows the modification of the TMDne that is achieved through classing, without carrying out a subsequent dehairing. Delimiting the included fleeces to those having a TMDne lower than 31 µm confirms a significant difference in the mean TMDne. And lowering the TMDne threshold by 3 µm more, down to 28 µm, also shows a significant difference. The effectiveness of the fleece classing regarding fineness is confirmed. It is interesting to note that a TMDne reduction of 3 µm leads to a MD3e reduction of 1.5 µm. But, even though a significant reduction of the mean TMDne is confirmed, this result is not necessarily satisfactory in relation to the textile quality achieved. On the one hand, the value of 25.0 µm for the mean TMDne is at the upper end of the range of "fine" fibres, so that a higher fineness should be achieved. On the other hand, as the dehairing was not carried out, it contains objectionable fibres. The latter aspect would not be solved either by classing even more rigorously because, as mentioned above (Division 3.8, FG1 in the second paragraph), the fleeces with the lowest TMD also contain objectionable fibres.

MD reduction through dehairing (without prior fleeces classing):

Table 13 shows the reduction of the MD achieved through the dehairing, without having implemented first a classing of the fleeces regarding fineness. The mean TMDne of the non-classified fleeces has a value of 28.7 µm which, through the dehairing, is reduced to a mean MD3e of 24.4 µm. This FG3 value is considered as equivalent to the dehairing product. The KW test confirms a significant change with respect to the MD and the effectiveness of the dehairing is also confirmed. However, it would not be correct to automatically interpret that this result means that, just through the dehairing, a homogeneous textile of sufficient textile quality for the production of fine textiles can be achieved: it will be finer, but this does not imply its textile quality is fine enough. In other words, the MD of the FG3 is always finer than the rest of the sample and, in that sense, the result of this statistical test can be said to be correct, but it is not necessarily considered "fine" according to the classing in Table 1 where "fine" fibres are in the range between 22 and 25.9 µm. The MD3e value of 24.4 µm lies in the middle of the range of "fine" fibres, but taking the SD3e into account, the MD3e value can exceed this range towards a higher coarseness. In fact, for the production of fine textiles not only a "fine" fibre raw material is aimed at, but also at "superfine" and "ultrafine (Baby)" fibres, as far as possible.

Figure 53 illustrates the MD distribution of a fibre lot that is composed of fleeces for which a classing regarding fineness was not implemented. What can be seen in this graph is a dehairing by assuming that the dehairing product is represented by the distribution of MD3e. Visually, the reduction in fibre diameter appears to be approximately of 3 µm, which is illustrated by means of the gap between the distribution of TMDne and MD3e. The calculated reduction from the mean of the TMDne distribution (28.7 µm) to the mean of the MD3e distribution (24.4 µm) obtained through the dehairing is 4.3 µm, as seen in column 8 of Table 15. However, as stated above (Division 3.8, FG3, first paragraph), dehairing would be recommended only for fleeces of a certain fineness. Furthermore, the obtained mean of the MD3e distribution of 24.4 µm with a SD3e of 4.1 µm is not satisfactory to provide raw material for the production of fine textiles.

MD reduction through a combination of classing and dehairing:

Based on what has been developed in this division, it can be concluded that if both measures to reduce the MD, classing and dehairing, are implemented on their own, they are not satisfactory. It remains to evaluate the possibility of implementing these two measures, which have the potential to reduce the variability with respect to the diameter, one after the other.

After classing regarding fineness and dehairing, the MD reduction is even greater. According to the KW test in Table 14, a more rigorous classing (TMDne<28µm) followed by a dehairing results in a significant difference compared to a basic classing (TMDne<31µm) followed by a dehairing. It is confirmed that classing regarding fineness improves the result of the subsequent dehairing process.

Column 9 of Table 15 shows that the mean of the TMDne distribution of a lot of non-classified and non-dehaired fleeces of 28.7 µm is lowered by implementing a classing which selects fleeces of TMDne<31µm and by a subsequent dehairing. The MD3e distribution is lowered to a mean of 22.8 µm, that is to say that the reduction is 5.9 µm. When selecting TMD<28µm fleeces and dehairing them, the reduction is 7.1 µm. At the top of column 9 there is no value because it corresponds to the non-classified MD.

Figure 57 shows how the distributions of MD3e move toward finer diameters after classing and dehairing. Classing is represented by the sequence of the three distributions situated in the central part of the graph plotting the total mean diameter: TMDne, TMDne<31 and TMDne<28 and corresponds to Column 1 of Table 15. The distributions that include a classing, TMDne<31 and TMDne<28, show an abrupt drop on their right side since no fleeces in the 32.5 and 29.5 µm ranges, respectively, are included. The dehairing process, with or without prior classing, is represented by the sequence of the three curves situated on the left side of the graph, that is to say, by the distributions that correspond to the dehairing product: MD3e, MD3e<31 and MD3e<28. These three distributions are summarized in columns 6 and 7 of Table 15.

As seen in Figure 57, the MD3e distributions of TMDne<31µm and TMDne<28µm fleeces include a high percentage of fibres of between approximately 20 and 24 µm. For the least rigorous classing (TMDne<31µm), the percentage of fleeces having a MD3e lower than 25 µm was 81% and the one having a MD3e lower than 22 µm was 40% (MD3e<31). For the most rigorous classing (TMDne<28µm), these values were 96% and 58% respectively (MD3e<28), or, in other words, almost all FG3 fibres were found to be "fine" according to the range designation in Table 1, and more than half of them were found to be "superfine". As shown in columns 6 and 7 of Table 15, the mean MD3e distribution of the TMDne<31µm and TMDne<28µm fleece group was found to be 22.8 and 21.6 µm respectively, with a SD3e of 3.8 and 3.7 µm respectively. Taking the samples of this sub-chapter as a reference, this fibre segment represents the potential of llama fibre as a textile raw material for the production of fine textiles.

The results of the different Kruskal Wallis tests indicate that the specific hypothesis of Sub-chapter 3 is confirmed since both the tests made with respect to an implementation of classing (Table 12) and dehairing (Table 13) have a significant result with respect to the MD achieved. Moreover, the addition of these two measures shows a significant result with respect to the MD achieved (Table 14).

CHAPTER VI. CONCLUSIONS

GENERAL CONCLUSIONS:

Age effect:

The study of the age effect related to llama fleece structure reaffirmed the existence of the well-known phenomenon of fibre coarsening due to the increasing age, which is known as "micron blowout". In addition, it was observed that all fibre types show this biological effect, but the contribution to the total (TMD) coarsening is more noticeable for coarse fibres, especially for large medulla fibres, as these are the ones that increase their mean diameter the most and increase their frequency. That is to say that a change in the fleece structure, unfavourable from the point of view of textile quality, was confirmed, which occurs with the increasing age of the animal, and it is concomitant with the increase in body size (surface area).

Dehairing effect:

The study with respect to the llama fibre structure found within the dehairing process reaffirmed a favourable modification implying an improvement with respect to the textile quality of the fibre. It was confirmed that, firstly, it is due to the separation of the coarse fibres that are included in the subproduct and, at the same time, it is due to the increase in fine fibres in the dehairing product, thus reducing the TMD of the product and the prickle effect due to the reduction of objectionable fibres.

From the description in the previous paragraphs, it was confirmed that the general hypothesis is validated, as the age of the animal modifies the fleece structure unfavourably from the textile quality point of view, what is rectified with the dehairing process. However, this can only be validated up to approximately the first 5 years of the animal's life and depends on the required textile quality. Regardless of the age at which this limitation occurs, the general hypothesis must be refuted for those fleeces of which the finest fibre group is too coarse, since these fibres are the ones that constitute the product content and their mean diameter is hardly reduced by dehairing, so that the loss of textile quality cannot be rectified.

Furthermore, it arises the need to place the general hypothesis within the existing context of fibre production which includes fleeces of varied textile value, including coarse fleeces whose fine fibres are not fine enough. It was therefore concluded that, for the production of fine textiles, dehairing alone cannot guarantee a sufficiently fine dehairing product, but it must be implemented after the fleeces have been classified regarding fineness.

Likewise, another limitation to the general hypothesis was verified, which is related to the content of objectionable fibres, because, although the dehairing process always improves textile quality, it is not always able to separate all objectionable fibres from the dehairing product and further studies are needed to verify which factors can improve the separation of these fibres.

Classing and dehairing effect:

The need to implement a classing regarding fineness was confirmed through the analyses carried out in each of the three sub-chapters. At the same time, it was observed that classing alone is not sufficient to achieve the desired raw material since, although fine TMD fleeces include a high percentage of fine fibres of high textile quality, these are intermingled with objectionable fibres that have the capacity to produce prickle on the skin. This means that, besides the age effect, the need to implement a dehairing to improve the textile quality of llama fibre from the first shearing of one-year-old animals was confirmed because, even for these young animals, the content of coarse (objectionable) fibres in their fleece is higher than the acceptable one. Finally, it was verified that if both measures, classing regarding fineness and the subsequent dehairing, are implemented, llama fibre becomes a raw material of high textile value.

Likewise, through the analyses carried out in each of the three sub-chapters, the need to implement, in addition to the classing regarding fineness, a classing regarding fleece type prior to the dehairing process was confirmed. Based on the study of fleece structure in Sub-chapters 1 and 3, it was verified that, in order to achieve textile raw material of the highest homogeneity with respect to crimp frequency (CF) and crimp groups (CG), it is desirable to implement the classing regarding fleece type and to gather DC, IC and SC fleeces on the one hand and HL and Lustre fleeces on the other hand. Furthermore, through the dehairing process carried out in the context of Sub-chapter 2, the convenience of this separation of fleece types was verified since DC, IC and SC fleeces showed a similar behaviour while lustre type fleeces (HL and L) showed a different behaviour.

This means that it is not advisable to process all fleece types together, but rather to implement a classing regarding fleece type before dehairing. Similar characteristics of the processed fibres guarantee a similar behaviour during the dehairing process and thus a more feasible adjustment of the dehairing machine, leading to a better performance of the dehairing as well as of the subsequent production process.

SPECIFIC CONCLUSIONS:

1. Age effect on llama fleece structure

Modification regarding the age:

The study of the fleece structure reaffirmed the existence of an age effect that produces a coarsening of the total mean fibre diameter (TMD), which has been described in the literature already published. Furthermore, it was confirmed that this biological effect originates in an increase in all the mean diameter (MD) variables analysed, both in the ones belonging to each fibre group and to each fibre type. These MDs show the same biological effect, which involves a low initial MD that increases until it stabilises at a certain age and, then, it starts to decrease.

Although fibre coarsening is present in all fibre groups and all fibre types, the contribution of the coarse fibres (FG1) to TMD coarsening is higher than that of the other two fibre groups, since FG1 increases significantly with respect to its relative fibre frequency (N%1), while the fibre frequency of FG2 (N%2) is almost stable and that one of FG3 (N%3) is low. In turn, FG1 is composed of continuous medullated and large medulla fibre types and these latter fibres are the ones that contribute most to TMD coarsening. This is because the actual coarsening of the large medulla fibres (MDG) is greater than that of the other fibre types and, at the same time, because their relative fibre frequency (N%G) increases significantly regarding the age.

It was determined that, after the initial increase, the TMDvo of the fleeces belonging to the observational flocks stabilises from age class 4 onwards, with the maximum peak of the curve of this variable fitted to a second-degree polynomial having its maximum at 5.7 years. For the experimental flock, the stabilisation of TMDv, TMDw and TMDn was determined between age classes 5 and 6 although their maximum peaks of a second-degree polynomial are between 8.8 and 10.3 years respectively, depending on the different ways of expressing the TMD. It was observed that the greatest contribution to the shift of the TMD curve of the experimental animals towards older age is due to the group of coarse fibres (FG1) and, within this fibre group, it is due to the large medullated fibres. It was confirmed that the age at which the maximum TMD occurs may differ depending on the age distribution in the llama flocks.

Textile quality defined by the objectionable fibres:

It was shown that FG1 consists entirely of objectionable fibres and that this is true from age class 1 on. This means that also in the case of fleeces coming from a first shearing at one year of age, the need to implement the dehairing process in order to achieve high textile quality raw material was confirmed.

Textile quality defined by the group of fine fibres:

Taking the group of fine fibres (FG3) contained in a staple as an indicator of the textile quality since it is equivalent to the product of potential dehairing, it was confirmed that the highest textile quality can be expected from fleeces corresponding to age classes from 1 to 3, that is to say, fleeces coming from animals aged up to 3 years of age. It was observed that in these three initial age classes, the FG3 fibres are superfine or fine (MD of 20.6 to 23.5 µm), that is to say that these are fleeces containing raw material of high potential, which are suitable for dehairing and it was confirmed that the llama fibre can provide high textile quality. It was shown that the selection of fleeces from animals up to 3 years of age can be considered a good rudimentary criterion to select fleeces to be processed together and, in this way, achieve a first approximation to what could be a fleece classing regarding fineness in order to achieve raw material of better textile quality.

It was observed that even for age classes 4 and 5, the MD of FG3 is below the threshold of 26 µm, thus confirming that also these age classes provide fleeces that can be considered for dehairing, depending on how high the requirements of the final product are. It was also confirmed that, when using fleeces coming from animals of 6 years old or older, and if the aim is to achieve fine raw material, special attention has to be paid to the fine fibres contained within the fleece (rather than to the coarse fibres), since the question is whether these fibres are fine enough to be able to provide raw material of sufficient fineness. Thus, it was found to be important to make a differentiated use of fleeces containing fine fibres if the purpose is the production of fine textiles, e.g. by means of classing regarding fineness with a subsequent dehairing.

From what has been described in the previous paragraphs, the 1st specific hypothesis was validated since it was confirmed that, from the point of view of textile quality, the age effect has an unfavourable impact on the llama fleece in relation to the mean fibre diameter (MD) and to the relative fibre frequency (N%). This unfavourable effect originates in a modification of the fleece structure, which is described in the following paragraphs.

Fleece structure:

It was stated that FG1 is composed entirely of coarse or very coarse fibres, which are of very low crimp frequency and they all belong to crimp group 4 (CG4). It was verified that all of them are objectionable fibres. In relation to FG2, the great variability of the fibre types and their respective MDs stands out: unlike FG1 and FG3, it is composed of all fibre types and these are of varied diameter. It was observed that FG3 is mainly composed of non-medullated and fragmented medullated fibres, and that this remains true even when the animal grows. An increase in medullated fibre was observed regarding the increasing age.

It was determined that during the first three age classes, the yield at dehairing, which is equivalent to the relative weight of FG3, averages 68%; it is around 61% for age classes 4 and 5; and then it drops to approximately 50%, what calls into question up to which age of the animal such a textile process is justified.

It was observed that the large medullated fibres contained within FG1 constitute almost the total of the large medullated fibres contained in the whole staple. Continuous medullated fibres were found to be present in all three FGs, although the MD clearly changes from lower to higher between FG3 and FG1. In addition, it was found that interrupted medullated fibres are very rare in all the three FGs and that fragmented medullated fibres are found in FG2 and FG3. Finally, it was determined that non-medullated fibres within FG3 make up almost the total of non-medullated fibres contained in a staple.

With regard to fibre length, it was observed that it decreases regarding the age of the animal and stabilises at age class 5. This was observed in all three FGs equally. Furthermore, it was verified that the length of the coarse fibres (L1) of a staple is clearly longer than that one belonging to the fine fibres (L3), but that, nevertheless, the length of the fine fibres always keeps a value above 7 cm.

The analysis of the crimp frequency (CF) confirmed that the three FGs clearly differ with respect to their CF; FG1 being the one with the straightest fibres, FG3 being the one with the most crimped fibres and FG2 being the one with intermediate values, and this differentiation is maintained throughout the animal growth. With regard to the crimp groups (CGs), clear differences were also spotted among the three FGs and the modifications with respect to age are quite minor. The CGs study confirmed that, in order to obtain more homogeneous raw material, it is convenient to implement the classing regarding fleece type and to join together DC, IC and SC fleeces on the one hand and HL and Lustre fleeces on the other hand.

Three Group Dissection:

What was confirmed through the discussion about the different FGs and their characteristics is that the implementation of the Three Group Dissection, and the resulting formation of the three FGs, makes practical sense since it reveals fundamental information with respect to the textile quality of a fibre sample. Furthermore, the Three Group Dissection stands out as a method that, due to its simple implementation, can be used both in a rudimentary context location and in free-range.

2. Dehairing effect on llama fibre structure

Modification regarding the dehairing:

Through the study of llama fibre within the dehairing process and the analysis of its fibre structure, it was reaffirmed that the dehairing effect produces a reduction of the total mean fibre diameter (TMD), which is commonly described in the relevant literature. It was confirmed that this effect is linked to a reduction in the MD of the coarse fibre group (MD1d), while the evolution of the intermediate fibres is not well defined (MD2d) and the MD of the fine fibre group (MD3d) remains almost constant. In turn, the information provided by the relative fibre frequency confirmed that the dehairing effect is clearly linked to the continuous trend of reducing the presence of coarse fibres (N%1d) within the product as well as intermediate fibres (N%2d), while the presence of fine fibres (N%3d) within the product increases. Furthermore, it showed that the fibre structure is determined by the groups of fine and coarse fibres (N%3d and N%1d) since the frequency of intermediate fibres (N%2) is very low.

The study of the dehairing effect related to fibre types and its impact on the fibre structure revealed a constant MD of the non-medullated and fragmented medullated fibres (MDAd and MDFd), corresponding to FG3 (MD3d), and a reduction of a few microns of the large medullated fibres (MDGd), corresponding to FG1 (MD1d). With respect to the presence of interrupted medullated fibres (N%Id), it was observed that it is so low that it does not impact on the fibre structure. It was revealed that the fibre structure is determined by the non-medullated and fragmented medullated fibres on the one hand, which are the desired fibres with the highest textile value, and by the continuous and large medullated fibres on the other hand. There was a constant increase in the non-medullated fibres (N%Ad) during the successive passes, and a high and continuous presence of the fragmented medullated fibres (N%Fd). Continuous (N%Cd) and coarse (N%Gd) medullated fibres showed a clear tendency to reduce their presence in the product.

The dehairing effect is more pronounced during the first 6 passes approximately since the TMD reduction stabilises from the sixth pass onwards and the fine fibre content within the product stabilises from the sixth pass onwards in relation to the relative fibre frequency (N%3d), and from the eighth pass onwards in relation to the relative weight (W%3d). On the other hand, the estimated minimum for the coarse fibre group expressed with relative weight and relative fibre frequency (W%1d and N%1d) is reached from pass 8 to pass 15, depending on the fleece type, which is why it is recommended to process lustre fleeces separately.

With respect to the 2nd specific hypothesis, the description in the previous paragraphs confirmed that this hypothesis is validated since the dehairing produces a reduction in the total mean diameter (TMDwd and TMDnd), a reduction in the diameter of coarse fibres (MD1d), an increase in the content of fine fibres within the dehairing product (W%3d and N%3d) and a reduction in the content of intermediate and large medullated fibres within the product (W%2d, N%2d, W%1d and N%1d). Therefore, it can be stated that, from the point of view of textile quality, the dehairing textile process modifies the fibre structure favourably in relation to the mean fibre diameter (MD), the relative weight (W%) and the relative fibre frequency (N%).

However, two limitations to the 2nd specific hypothesis became evident. This means that, on the one hand, the 2nd specific hypothesis can be validated because the textile quality clearly improves in relation to several variables, but, on the other hand, it remains open whether the improvement is always sufficient in relation to the textile quality achieved and whether it is always suitable for the production of fine textiles. In this regard, the two specific determining aspects are characteristics of the dehairing product: on the one hand, a mean fibre diameter which is sufficiently fine (TMDnd) and, on the other hand, a content of objectionable fibres which is sufficiently low (W%1d).

Textile quality defined by the group of fine fibres:

It became evident that, in order to achieve a reduced mean fibre diameter within the dehairing product (TMDnd), it is necessary that the fine fibre group (FG3) of the fleeces provided to the dehairing has to have a reduced mean diameter (MD3), that is to say that the dehairing can only provide fine fibres if these fibres are contained in the fleeces before they are dehaired. This means that the dehairing process can be considered a fundamental and important component of the solution, but that the dehairing alone is limited, since its effectiveness is conditioned by the raw material that is provided for the process. Therefore, it was concluded that it is indispensable to avoid the usual practice of gathering raw material as unsorted fibre and providing all fibre together to the dehairing process since, in this case, also fleeces whose FG3 have a too high MD3, are included. Therefore, the need to implement a classing of fleeces regarding fineness as an additional measure prior to the dehairing process was confirmed.

Textile quality defined by the objectionable fibres:

With respect to the objectionable fibres, which are represented by the coarse fibre group (FG1), it was revealed that the dehairing process clearly reduces this variable for all dehaired fleeces, but the relative weight (W%1d) is not reduced below the desired threshold of 3% for all of them. In other words, the results of the dehairing trial do not show entirely satisfactory results in this respect. It was confirmed that the initial value of the variables such as total mean diameter (TMDnd) as well as mean diameter and relative weight of the coarse fibre group (MD1d and W%1d) do not influence whether or not a W%1d below the 3% threshold is achieved at the end of the dehairing trial. And it was concluded that other factors can apparently help to achieve this aim. In addition, it was noted that the large medullated fibres that are very coarse are separated more effectively, whereas coarse continuous medullated fibres are more problematic in this respect and it was also noted that further trials need to be undertaken to address this issue.

Fibre structure:

It was determined that FG1 is composed of coarse and continuous medullated fibres and that this composition is maintained throughout the dehairing process. With respect to FG2, it was observed that it contains mostly continuous and fragmented medullated fibres, but it is nevertheless an FG that has low incidence in the fibre structure due to its reduced size. In addition, FG3 was found to be composed of non-medullated and fragmented medullated fibres, which is maintained throughout the dehairing process. The yield at dehairing was determined to be 65%.

In relation to fibre length, it was observed that the dehairing effect shows a shortening of the fibres belonging to the three fibre groups (FG1, FG2 and FG3) and a clear trend to include the shorter fibres in the subproduct. In addition, it was verified that the FG3 fibres are the shortest ones, but they maintain their length above 7 cm, which is a good length for spinning the fibre.

With respect to the dehairing effect on the crimp frequency (CF), no clear effect was observed. However, in relation to the crimp group (CG), a modification was verified, which was similar for the DC, IC and SC fleeces, while there is no modification for the Lustre fleece. This confirmed a different behaviour according to fleece type and means that, in order to achieve an optimal process performance, it is advisable to process Lustre fleeces separately from DC, IC and SC fleeces. Thus, it is necessary to implement a classing regarding fleece type before starting the dehairing process.

Three Group Dissection:

During the dehairing process, it was observed that the MD of the non-medullated and fragmented medullated fibres remained constant, which leads to confirm that the method used in this thesis, the Three Group Dissection, provides consistent results since when measuring similar fibres from the same fibre group, the same result is obtained. It can be said that they are similar fibres since they are obtained from samples extracted from the same fibre lot and they are dissected in the same way in order to obtain the fine fibre group, which contains the non-medullated and fragmented medullated fibres.

3. Effect of classing and of dehairing on fibre textile quality

Textile quality defined by the group of fine fibres:

Llama fibre has potential as a textile quality raw material for the production of fine garments. If classing regarding fineness is implemented within a fleece lot by selecting only fleeces with a total mean diameter (TMDne) of up to 28 or 31 µm and a subsequent dehairing process is implemented, the dehairing product can provide raw material with a mean diameter (MD3e) of 21.6 or 22.8 µm respectively. That is to say that taking the samples of Sub-chapter 3 as a reference, this fibre segment represents the potential of llama fibre as raw material.

Classing and dehairing:

It was confirmed that both measures to reduce the mean diameter (MD), classing and dehairing, contribute to the reduction of the raw material MD achieved by implementing them, but, at the same time, it was found that both measures implemented on their own are not satisfactory. The implementation of a classing prior to the dehairing increases the effectiveness of the dehairing process since classing regarding fineness is essential to ensure the presence of superfine and fine fibre as well as their higher proportion in the raw material provided to the dehairing process. In addition, it was found that the classing regarding fineness almost fails to reduce the MD of the coarse fibres (MD1e), that is to say, the presence of objectionable fibres. This means that, after classing fleeces regarding fineness, dehairing is still necessary as a process capable of reducing the diameter variability and adding value to llama fibre as a textile raw material.

Furthermore, it was confirmed that in one fleece lot the MD of the fine fibre group (MD3e) is distributed over a wide range of diameters, which means that there are many fleeces which are so coarse that even their finest fibres are not fine, but medium or coarse. If a high textile quality raw material is sought for these fleeces, a dehairing would not be indicated since the dehairing product would still be coarse and therefore it would not be suitable for the production of fine textiles. Due to this fact, it was confirmed that classing regarding fineness is a necessary step prior to dehairing in order to only dehair fleeces that actually provide fine fibres.

Additionally, the present research showed that, in order to provide raw material of high homogeneity with regard to crimp groups (CGs), it is necessary to implement the classing regarding fleece type prior to the dehairing process. It is advisable to separate the fleeces, leaving fleece types DC, IC and SC on one side, and fleece types HL and Lustre on the other side.

For fleeces of all fleece types, it is necessary to implement the dehairing process since they all contain objectionable fibres. The fleece types DC, IC and SC respond best to the dehairing. In addition, it was highlighted that special attention should be paid to processes in which partial dehairing is carried out and it is important not to confuse this with a complete dehairing, which is necessary to start the production chain to produce fine textiles.

From what has been described in the previous paragraphs, the 3rd specific hypothesis was validated since it was confirmed that the implementation of the classing of fleeces regarding fineness and/or fleece type plus the dehairing process modifies the fibre structure, that is to say, the composition of llama fibre as a textile raw material, and increases its textile quality in relation to the mean fibre diameter (MD).

CHAPTER VII. RECOMMENDATIONS

From what has been studied in this thesis and from the extensive information gathered (both personal and bibliographic), it is possible to specify pending points of be studied and recommended practices to ensure that the conclusions of the study are favourably applied to the production of Argentine llama fibre. In order to further study the phenomenon of the increase in mean diameter regarding the age, the following points are still pending.

1 Clarify the true effect of increasing animal size regarding the follicular density. Although there is already evidence for this, it should be extended to spatial studies that may even find new sources of variation which can be used as possible genetic parameters. There is still an unanswered doubt about the fact that the phenomenon fails to be verified in vicunas, and this could be due to its very high follicular density.

2 To remove the effect of nutritional status and handling in general from the phenomenon, taking into account the findings in other fibre-producing species. It is possible that, as in sheep, there is not such a noticeable increase in underfed animals from the dry altiplano, particularly from the province of Catamarca.

3 Disseminate the findings of this thesis on the phenomenon, emphasising that delaying shearing does not modify it, urging producers to shear adult animals annually and crias before they are one year old.

4 Develop dehairing trials with emphasis on correcting the fleece felting problem, taking into account that handling practices in altiplano conditions are unlikely to be modified, at least in the short term.

5 Carry out optimisation studies with existing technology that tends to achieve more efficient dehairing in terms of yield and degree of fibre breakage. Complement the dehairing trials by combing and spinning the dehaired fibre in order to be able to demonstrate their benefits besides diameter reduction and reduction of objectionable fibres. The higher quality of the yarn has been demonstrated, but trials should be extended to all process systems (carding, semi-combing and combing) regarding different titles and even regarding different blends with other animal fibres.

6 Carry out genetic studies on the phenomenon to better understand it, differentiating the decrease in the mean diameter according to fibre type and relating it to the dehairing capacity of the fibre, in order to be able to justify the investment in genetic improvement. In order to achieve a better dehairing product, the priority is a reduced mean diameter of the fine fibre group corresponding to the dehairing product and to improve the dehairing capacity. The latter tends to improve with a greater difference in the mean diameter of the fine fibre group and the coarse fibre group.

7 Obtain organic traceability systems for the dehaired fibre, e.g., extracted from plants, in order to be able to identify it in the fabric or clothing marks and thus justify its higher value. Evaluate the possibility that this can be combined with environmentally friendly insect (moth) repellents.

8 Highlight by all means the application of the dehairing technology regarding its direct textile benefits and the environmental benefit that arises from the use of unwashed fibre which is freed from foreign elements (vegetable matter) without the use of chemical components (sodium salts).

CHAPTER VIII. BIBLIOGRAPHICAL REFERENCES

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