29. Effect of Fibre Properties on Processing Performance: Top to Yarn

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Learning objectives

On completion of these two lectures you should be able to:

- an understanding of how and why greasy wool fibre properties affect topmaking
- an understanding of how and why top properties affect yarn properties and spinning performance
- an appreciation of the key drivers of specifications for tops and greasy fibres
- an understanding of, and reasons for, the relative importance of fibre properties in early stage processing

Key terms and concepts

See Lecture 1 of this Topic (Topic 28)

Introduction to the topic

See Lecture 1 of this Topic (Topic 28)

29.1 The spinner's demands

Spinners demand that a top meet a long list of technical specifications as well as a price. These are designed to ensure that the top will perform as expected in the spinning mill and also downstream in weaving or knitting to give the desired fabric at the best price. The fibre properties, diameter (D) and length (hauteur), are always specified and chosen according to the yarn being spun as they are the prime determinants of spinning performance. Most mills specify limits on the length distribution in terms of hauteur distribution (CV_H) or short-fibre content. Limits on diameter distribution (CV_D) are becoming routine but are not usually severe. Fibre strength of undyed top and curvature of top are not normally specified. Limits are set for colour and on the level of faults such as nep and pieces of vegetable matter (VM) and, for critical light-coloured fabrics, dark fibre levels will sometimes be specified. Limits on other contaminants, for example plastics, are not usually specified but when unacceptable levels are found in the fabric a claim is made against the spinner who will then make a claim against the topmaker. Evenness, regain and total fatty matter will usually be specified but top attributes such as quality of scouring and combing, and suitable lubricant and antistat, are difficult to determine from measurements of the top and the spinner, in part, relies on a good relationship with the topmaker.

Spinning performance and downstream yarn performance are critical because both spinning and weaving cost, typically, three to five times as much as all of topmaking. Yarn breaks are so expensive in terms of labour cost and lost productivity that it is common for less than one break every 50 km to be allowed (Plate 1990). For a fine worsted yarn being produced at 1 km/hr/spindle this equates to a maximum of 40 ends-down per thousand spindle hours.

29.2 Overview of processing route – top to yarn

The spinner converts top into yarn ready for the weaver or knitter (see Figure 28.1). The top sliver is progressively thinned down into a finer and finer strand for input to the spinning frame. This sequence of operations is called drawing. About half of all wool top is dyed as the first step in spinning. If it is dyed then it will always be gilled and re-combed before the drawing stage. However, it is now fairly standard practice for all fine wools to be re-combed before drawing. Drawing typically uses four to six passes on similar machines to the gill boxes of topmaking. At each stage the draft is higher than the number of slivers (ends) fed into the machine so that the weight of the sliver is gradually reduced. As the weight of the sliver is reduced the pinning used to control the fibres becomes finer and may be replaced by aprons or balloon rollers. In the final stage or stages, when the sliver is very light, then it must be given additional strength by rubbing or twisting. These machines are called the rover or flyer, respectively. The rubbing rover is more common with fine, pure wool, spinning and the twisting flyer is more common for blends with synthetics.

The roving (or flyer) packages are mounted, creeled, on the spinning frame. Spinning involves a further drafting step, with the fibres controlled by aprons, in which the roving strand is typically thinned down (drafted) by a factor of twenty. The drafted strand is then twisted to form a yarn. It is the twist that locks the fibres together and so gives the yarn strength. Twist is inserted by rotating a spindle carrying the whole yarn package, the bobbin, inside a balloon of yarn. The yarn passes through a metal loop, the traveller, which is free to slide around a lubricated metal ring. The traveller rotates slightly slower than the bobbin according to the rate at which fibres are fed and the yarn is wound onto the bobbin. More twist is needed for fine yarns and production decreases due to both the higher twist and lower weight. For a fine yarn some 500 to 1000 turns of twist per metre are needed to produce a well-locked structure, while the typical maximum spindle speed is about 10,000 rpm. The whole package must be rotated for every turn of twist inserted. Consequently, each spindle will only produce about 100 kg of fine yarn per year and some 3000 to 5000 spindles are needed to match the production of one drawing line.

When full, the yarn packages are removed (doffed) and, in most cases, will have their twist set in an autoclave steamer. The "singles" yarns are then wound onto larger packages on winding frames that have detectors for thick and thin (and sometimes coloured) places. Faulty yarn sections are removed and replaced by a splice. These singles yarns can be used directly in knitting or (sometimes) as a weft yarn in weaving. The yarn may also be package or hank dyed. However, to achieve a yarn that is strong and abrasion resistant enough to survive the stresses of weaving, or thicker, bulkier and of balanced twist for knitting, it is common to two-fold the yarn. Two singles yarns are twisted about each other in the opposite direction (or same direction for crepe yarns). This can be done by ring twisting, using a ring/traveller system similar to spinning, but it is now more common to use a 2-for-1 twister. The yarn cones are again steamed before being sent to weaving or packaged for sale.

Spinning is expensive because of the low productivity per spindle and the number of operatives needed to look after the operation. If the yarn breaks (an end-down) during spinning then an operator must piecen-up the broken end. Typically an operator will look after about 1000 spindles and the upper limit to the allowed end-breakage rate is about 40 ends-down per thousand spindle hours. The tension in the yarn and hence the number of breaks increases with speed, so the machine and thus productivity can be slowed if there are too many breaks. For very expensive (fine) yarns or in low labour-cost countries a higher rate of end-breakage may be tolerated, and more operatives used. The drawing and steaming operations are relatively cheap compared to the spinning step, the cost of two-folding can be almost as much as spinning, while dyeing and re-combing costs are moderate.

Light-weight fabrics require light-weight yarns and the weight of a yarn is the product of the average number of fibres in the yarn cross-section and the mass, per unit length, of the component fibres (i.e. proportional to fibre diameter squared). However, although we can control the average number of fibres we cannot control where each one is placed in the yarn. Thus, the statistics of random processes imposes a limit on achievable yarn evenness which is determined primarily by the average number of fibres in the yarn cross-section. There is no sensing or correction of the number of fibres on the spinning frame that would allow this random limit to be overcome. The yarn evenness, in turn, is the major factor in determining yarn strength as it influences the likelihood of thin or weak places.

The effect of average number of fibres in the cross-section is particularly dramatic on ends-down. For a fine weaving yarn reducing the average number of fibres in the cross-section from 35 to 30 can be expected to more than double the ends-down! The requirement of less than 40 ends-down per thousand spindle hours is incompatible with having much fewer than 35 fibres in the yarn cross-section. Hence, in Europe, where labour costs are relatively high, a spinning limit of 40 to 45 fibres is common except for expensive wools, but in China, where labour is cheap and the cost of the wool is the largest component of the yarn cost, the acceptable spinning limit may correspond to fewer than 35 fibres.

29.3 Effect of fibre properties on yarn properties and spinning performance

A very extensive review of the effects of fibre properties in processing was carried out in 1980 (Hunter 1980). Many of the publications reviewed went back to older spinning and drafting equipment, such as the Bradford system. Since that time the Continental system has dominated and the preparation route, the spinning frames, and their drafting arms have become very similar in all modern mills. However, the broad conclusions about the effect of fibre properties are thoroughly confirmed and quantified by more recent trials. The results presented below are solely for pure wool worsted yarns spun on modern ring frames. There are some other systems such as air-jet, friction and rotor spinning, but these have negligible market share for wool apparel yarns and the general conclusions should apply anyway. Recently there have also been some developments on the ring frame such as Sirospun, Solospun and compact spinning. These variants improve the binding of surface fibres, reduce yarn hairiness and can affect yarn tenacity slightly. However, the relative contributions of fibre properties are unchanged.

What has changed since 1980 is the better incorporation of physical modelling into the analysis of experimental data and the validation of the quality of the resulting prediction algorithms using data from commercial mills. It had become very common to carry out multiple regression analyses on data from large experiments where there were numerous correlations between yarn parameters and fibre properties and no physical insight used to constrain the fits. Some of the pitfalls of such an approach have been illustrated (Lamb 1988). More recent trials, such as those seeking to elucidate the effect of diameter distribution, have used wools matched for most fibre properties but with wider than normal variation in the property of interest, and with the trial repeated at several diameters and for different yarn parameters. The data has then been fitted based on a physical understanding of expected behaviour (Yang & Lamb 1998).

It is then found that the normal spinning performance and properties, of a yarn of specified twist and thickness (linear density), can be accurately predicted from a knowledge of fibre properties (Lamb & Yang 1995b, 1996a, 1998). The reason for this ultimately lies in the fact that the broad limits are imposed by the statistics governing a finite average number of fibres, and that most mills have very similar spinning machinery. Therefore, it is possible to outline the effect of fibre properties with some confidence.

Diameter (D)

For a given yarn linear density, the mean number of fibres varies inversely as the square of the fibre diameter and it is the mean number of fibres (n) that determines yarn evenness and the number of thin places. Therefore, diameter is overwhelmingly important in determining the number of ends-down for a given yarn thickness and, hence, in determining the minimum fabric weight. The mean diameter is also the major factor controlling yarn bending stiffness and yarn strength and elongation.

Diameter distribution (CV_D)

The actual range of CV_D that occurs in tops is fairly limited (Naylor 1996). The effects of fibre diameter distribution have been carefully studied (Lamb, DeGroot & Naylor 1993; Lamb 2000a) using wools with a much wider than normal range of CV_D. The experimental results are in excellent agreement with theoretical expectations. If there is a wide distribution of fibre diameters, then the effect is as if the mean diameter were a little larger. The implication of this refinement, for typical Merino wools, is that a percentage change in coefficient of variation of diameter of 5 units is equivalent to a change of 1 μm in mean diameter. In other words, a 20 μm wool with CV_D=25% could be replaced by a 21 μm wool with CV_D=20% and the spinner will see negligible difference in yarn and fabric properties, spinning performance or, as it turns out, next-to-skin comfort. There is only limited recent data on the effect of CV_D on ends-down in spinning, but it is consistent with the expected effect.

It is likely that there will be a tendency for some wool buyers to put separate, and occasionally unreasonable, limits on both diameter and diameter distribution. Such a buyer will end up paying more than the astute buyer who is prepared to trade one attribute off against the other and end up with the desired spinning performance at a better price. Yarns from wools which have the same effective fineness, matched in terms of $D \sqrt{\{1 + (5\ CV_D/100)^2\}}$, as well as length and strength, will be indistinguishable. The above formula takes into account the fact that fibres with a wider range of diameters behave as if they had a higher mean diameter.

A given value of CV_D can arise due to along-fibre diameter variations or between-fibre diameter variations. In principle, when combined into a locked structure (yarn) the components are indistinguishable as the source of variation in yarn properties (except for the length scale of the variations). No studies have been made that try and distinguish effects on spinning from the two sources of diameter variation.

Hauteur (H)

The mean fibre length measured in top by the Almeter instrument is referred to as the hauteur. However, since the average number of fibres in the yarn cross-section is the prime determinant of evenness, the evenness is almost independent of fibre length. Only a small improvement in yarn evenness is observed with increasing fibre length. Fibres cannot contribute to yarn strength until their ends are bound by other fibres. Therefore, longer mean fibre length gives rise to increased yarn tenacity.

Ends-down and unevenness increase markedly at mean fibre lengths below 55 to 60 mm when the wool becomes too short for good fibre control on worsted drafting systems. It has been found that the spinning performance continues to improve with increasing hauteur out to at least 95 mm (Lamb & Yang 1996b). The machine settings (ratches) on the drawing machinery, but not the spinning frame, need to be increased for the longer wools, but this is a simple procedure. The one proviso is that the tops should not have a significant fraction of fibres longer than the drafting zone of the spinning frame. With current spinning frames, this is normally around 200 mm. For most Merino wools, fibres as long as 200 mm do not seem to occur unless the wool is overgrown, that is, there is more than a year between shearings.

A consistent effect of evenness and hauteur (H) on tenacity has been seen in experiments. For a fine yarn the effect of a 25mm increase in H on evenness is similar to that of a 1 μm reduction in mean diameter, while for tenacity and ends-down a 10 mm change matches 1μm, although the exact trade-off is dependent on the average number of fibres.

Results from the Pricemaker® analysis of the premiums and discounts paid at auction, and other studies (Swan, Piper & Purvis 2000) have revealed a peak in the price paid as a function of staple length (with the peak being much more marked at finer fibre diameters and with the position of the peak increasing from about 83 mm for 16μm to 95mm for 23μm wools). In other words, the market has actually penalised "over-long" wools. A more recent study (Lamb & Curtis 2004) has shown that there is now a plateau rather than a marked turn down at long staple length except for superfine wools, particularly those of high staple strength. This appears to be partly due to a belief by some spinners that a wool can be too long. Recent trials have not found any evidence to support such a belief. In one trial (Lamb & Yang 1996b), an especially long top (98.4 mm hauteur) of 22 μm mean fibre diameter was processed. No troubles were encountered in drawing and spinning with only the ratches of gill boxes and rover being adjusted. The wool spun well, despite having an average of only 31 fibres in the cross-section. Moreover, it was possible to spin with a lower than normal twist level and still get good spinning and excellent weaving performance, thus improving production as well as making a marginal improvement to fabric softness. A commercial trial using two long tops processed in five mills around the globe gave performance in good agreement with the claimed advantages of longer hauteur (Lamb & Oldham 2000).

The negative belief in "overlong" wool seems to be strongest amongst fine wool spinners. The most likely explanation is that a spinner will set up the machinery settings for the standard short wool and when the longer wool is gilled or roved without adjustment the long fibres are too strongly held and do not draft well. Longer wool also needs different settings in re-combing.

Length distribution (CV_H)

There is a widespread belief that can be found in some training manuals, that there is an optimum distribution of fibre length in top, corresponding to a CV_H of about 40%, for minimum yarn unevenness and best spinning performance. However, a careful examination of the literature and recent trials shows no concrete evidence for this assertion (Lamb & Yang 1995a; Lamb & Oldham 2000). However, CV_H can also partly reflect the extent of fibre breakage in processing and the staple strength (SS) of the input wool. It is also strongly correlated with H, with high CV_H corresponding to shorter H.

This lack of any substantial dependence of yarn properties on CV_H has been confirmed in results from leading Italian mills. However, the belief of an optimum CV_H of around 45% is very widely held and most topmakers will have difficulty in selling a top with a CV_H greater than 50%. It is possible that the belief may have arisen partly from mill experience when processing tops which had been put together from extremes of short fine and long coarse wools. These tops would have often had a high CV_H and would have processed more poorly than expected. However, a measurement of CV_D would have explained the poor performance. As stated, high CV_H is also associated with short hauteur and high short fibre content. These values are also likely to be relatively large if combing has been poor or the fibres have been particularly weak. Thus the conclusions about the lack of importance of CV_H assume that combing has been good and that differences in other fibre properties have been taken into account. A trial in five Indian spinning mills with two tops matched for fibre properties other than CV_H showed no differences in performance (Lamb et al. 2002).

A high CV_H occurs most readily in long (e.g. fleece) wools with a weak point about one-third of the way along the fibre. It also tends to be associated with low staple strength. Upper limits on CV_H may therefore contribute to the penalty for long length and low staple strength in superfine wools where a penalty for high mid-breaks has also recently appeared (Lamb & Curtis 2004). The CV_H limits also tend to prevent a wide range of fibre lengths being blended. It seems that there is currently a market opportunity for purchasing long staple length, low staple strength wools as these can be under-valued or over-penalised.

It has also been shown recently that the value of CV_H determined by the Almeter can be seriously in error when there is a marked variation in along-fibre diameter profile, such that very high values of CV_H are most likely due to thin-in-the middle profiles and very low values due to thick-in-the-middle profiles.

Short-fibre content

A few mills specify an upper limit on short fibre-content, e.g. that the % (by number) of fibres <30mm be less than 10%. Short-fibre content is strongly correlated with CV_H and H and its Almeter-measured value can be substantially in error if the along-fibre diameter profile varies (Brims 2002, 2003; Lamb 2003; Lamb 2004). In principle, short-fibre content is a check on the quality of combing, which is designed to remove all short fibre, although some breakage will also occur during combing. Re-combing typically only reduces the Almeter-measured short fibre content (%<30mm) by about 20% e.g. from 10% to 8%, so at this stage the measurement must be considered as suspect. Short fibres are less well controlled in drafting but when their measured total by weight (shorter fibres being lighter) is so tiny (typically <2% for fibres <30mm) and they are randomly spread through the sliver, they should not have a significant effect on yarn evenness or yarn faults. Re-combing has been observed to improve yarn evenness and reduce yarn faults but this is believed to be due to improved fibre individualisation and improved fault removal.

Strength

Bundle strength in top, using a short gauge, is a measure of the mean strength of the fibre keratin complex. It should be distinguished from staple strength which measures the weakest point along the whole staple of greasy wool and whose value primarily reflects changes in diameter due to nutrition or environment. The variation in the bundle strength of ecru wool tops, made from single sale lots, has been observed to be small, with a co-efficient of variation of only about 10% although the variation is partly associated with mean diameter. Chemical treatments, such as severe dyeing or shrinkproofing can damage fibres, reducing bundle strength and yarn tenacity and elongation. Such chemical damage appears to be much more important than differences between ecru (undyed) wools.

Yarn strength will vary directly with average fibre strength measured at a gauge over which fibres are bound by twist to share the load. This has been confirmed in trials using the same wool damaged to varying degrees by dyeing. Studies have shown that incorporating bundle tenacity (BT), as measured using Sirolan-Tensor (Yang et al 1996; Yang, Schütz & Lamb 1997), significantly improves the prediction of yarn tenacity. It is estimated that a 10% decrease in fibre bundle tenacity will increase ends-down, near the spinning limit, by about 50%. In rough terms, a 10% change in fibre bundle tenacity trades-off against a change of about 6 to 9 mm in hauteur. However, it has been found that intrinsic fibre strength (measured at the point of break) and staple strength do not relate closely to bundle strength (Lamb 2004) although very low SS was correlated with a small reduction in bundle strength. Apart from this small correlation it is not currently possible to select wools that will give inherently stronger tops.

Crimp/curvature

By lower crimp is meant lower crimps per cm or crimp frequency as opposed to depth of crimp or the clarity or definition of the crimp structure. More than half of the original crimp, in terms of fibre curvature, is lost in processing from raw wool to yarn, though relative rankings remain. However, until the fibres are dyed or locked in a fabric structure, most of the crimp can be recovered by a wet relaxation. On the other hand, crimp definition, which is primarily a measure of whether groups of fibres curve together, is largely lost in scouring and carding.

Lower curvature is associated with improved yarn evenness and better spinning (Lamb, Robinson & Mahar 1996; Lobb et al. 1997; Kurdo, Whiteley & Smith 1986; Lamb 2000b; Lamb, Purvis & Robinson 2000) but it is difficult to separate the effects of hauteur and curvature. Curvature only has a small effect on hauteur but, because faster growing wools have lower curvature, there is a marked relationship in most studies between hauteur and curvature. The effects of curvature have generally been found to be small once strong correlations with other fibre properties, such as diameter and hauteur, have been taken into account. One trial (Dolling 2002) has seen relatively large effects on yarn evenness and tenacity/elongation and improved spinning performance but this trial also found differences in hauteur of more than 12mm, which easily account for the observed differences in yarn properties and spinning performance. Some studies (Stevens & Mahar 1995; Haigh & Robinson 2002) have failed to see significant differences when only small quantities of yarns have been measured. The more thorough spinning studies have indicated that a decrease of 7°/mm in curvature of the top (equal to a reduction of 10°/mm in the greasy, or -1 crimp/cm) is equivalent, for evenness, to an increase of 8 mm in H.

The OFDA, but not Laserscan, provides a measure of CV(Curvature). It has been argued that this is a measure of whether all fibres have the same curvature and hence may be related to crimp definition, however, one study found that variation in curvature did not reflect crimp definition (Crook, Nivison & Purvis 1999). This is not surprising as the path of a single fibre snippet on a slide is roughly sinusoidal with the curvature oscillating either side of zero. As far as is known the measurement is not considered in top specifications.

Neps, contaminants (VM, dark and medullated fibre), residuals, weathering

Neps, small entanglements of fibre, mostly arise on the card and are pulled tighter in gilling. Their number increases as the wool becomes finer. The vast majority are removed in combing. Any remaining will be removed by a re-combing but new ones gradually appear in further processing. In general, they are too small to affect spinning performance but their level appears to be correlated with the number of faults cut out of the yarn, which suggests that the mechanisms that give rise to new neps are similar to those giving rise to larger thick places (Lamb 1996; Prins & Robinson 1996).

Large contaminants, such as pieces of eyelash burr, can probably cause a spinning break on occasions, but their major impact is in holes in knitting and the cost of removing them in mending. Poor scouring, shown by high residuals, and excessive fibre damage from strong alkaline scouring have been shown to degrade spinning performance. However, these are not properties inherent to the wool on the sheep. Weathering can lead to more losses during topmaking and it seems that most weathered tip does not get through to the top. UV damage to the whole fibre should show up in terms of reduced hauteur and bundle strength. All these properties are difficult to measure on the top. For example, it is difficult to distinguish between grease left after scouring and lubricants added in processing. Improved measures of cleanness and lack of damage would be desirable but are not considered further here as they are not seen as inherent properties of the wool fibre.

29.4 The relative importance of fibre properties

The theoretical understanding of the expected effect of fibre properties together with results of CSIRO and commercial mill trials have led to a series of prediction algorithms within a user-friendly computer program (Sirolan-Yarnspec, Lamb & Yang 1996a).

The relative importance of fibre properties for yarn properties and spinning performance, which is encapsulated in these algorithms, can be summarised in a few simple statements:

- mean diameter is overwhelmingly the most important top fibre property
- mean fibre length is the next most important and 10 mm of hauteur can be traded-off against 1 μm in mean diameter in terms of its effect on yarn tenacity and ends-down in spinning. For evenness, about 25 mm trades off against 1 μm. Neither trade-off applies to fabric handle because fibre diameter, rather than tenacity and evenness, affects stiffness and softness
- the importance of fibre length distribution CV_H, on yarn properties and spinning performance, is small and over-rated
- the importance of diameter distribution CV_D is as expected, with approx. 5% in CV_D trading-off against 1 μm, for yarn and fabric properties and spinning performance
- a 10% change in fibre strength, in the top, trades off against 6 to 9 mm of hauteur, for yarn strength and spinning performance, but average fibre strength in the top is hardly related to staple strength
- higher curvature is associated with slightly poorer yarn evenness.

These messages are not meant to imply that, for particular end-uses other attributes such as dark fibre, contaminants, colour and even neps are unimportant, but, in general they do not directly affect spinning performance.

The above ranking for relative importance primarily ranks fibre properties in terms of their impact on costs in processing, and independent of any correlations between fibre properties e.g. between diameter, hauteur and curvature. A finer diameter fibre may entangle more in scouring and will lead to a shorter top and more neps. It may also be processed through drawing at a lower production rate and lead to a yarn with different bulk (after allowing for curvature) but, when matched with another top differing only in mean diameter, it will give a stronger, more even, and less stiff, yarn with better spinning performance.

In order to illustrate the trade-offs, some of the Yarnspec (Version 5.20) predictions for yarn evenness and ends-down are presented below. The exact trade-off will vary according to the actual yarn and spinning conditions and other fibre properties, but the examples used are fairly representative for a medium to fine weaving yarn. The yarn evenness (CV%) and ends-down in spinning of such a yarn are shown as a function of fibre diameter in Table 29.1.

Table 29.1 Yarn evenness (CV%) and ends-down in spinning as a function of fibre diameter. Adapted from: Lamb (1997).

Diameter μm	19	20	21	22	23
No. of fibres	44	40	36	33	30
CV% (evenness)	19.0	19.9	20.9	21.8	22.7
Ends-down/1000 sp. hrs.	27	38	53	77	111

(Using: Nm 59, 17 tex, 675 tpm, CV_D=21%, H=70 mm, Curv. =75°/mm, fibre tenacity = 10.51cN/tex, re-combed, spun at 9000 rpm with #29 traveller on 50 mm rings.)

The spinning performance varies very rapidly with mean diameter. Forty ends-down per thousand spindle hours is about what is just commercially acceptable in high labour cost countries such as USA, Japan and Europe. For the middle wool with a mean fibre diameter of 21μm, the effect of CV_D is shown in Table 29.2.

Table 29.2 Effect of CV_D on yarn evenness (CV%) and ends-down in spinning. Adapted from: Lamb (1997).

CV_D%	19	20	21	22.5	24
CV% (evenness)	20.5	20.7	20.9	21.1	21.5
Ends-down/1000 sp. hrs.	47	50	53	59	67

The extremes, which cover 90% of the range observed in sale lots of 21μm wool, show an effect roughly equal to that which would be achieved by a shift of 1μm in mean diameter. However, a mill is unlikely to encounter values of even this range in consignments of 21μm wool, unless wools of grossly different diameter have been blended together.

The effect of hauteur is illustrated in Table 29.3 for the yarn of Tables 29.1 and 29.2 with D = 21μm and CV_D = 21%. Longer fibres lead to slightly more even and significantly stronger yarns and so to substantially fewer ends-down in spinning.

Table 29.3 Effect of hauteur on yarn evenness (CV%) and ends-down in spinning. Adapted from: Lamb (1997).

Hauteur mm	50	60	70	80	90
CV% (evenness)	21.5	21.2	20.9	20.5	20.2
Ends-down/1000 sp. hrs.	119	76	53	39	30

For the wool and yarn of Tables 28.3, 4 and 5 with D = 21μm, CV_D = 21% and H = 70mm, the effect on ends-down of 10% changes in bundle tenacity is shown in Table 29.4. The evenness is not shown because it is unaffected by bundle tenacity.

Table 29.4 Effect of bundle tenacity on ends-down in spinning. Source: Adapted from: Lamb (1997).

Bundle Tenacity cN/tex	9.5	10.5	11.5
Ends-down/1000 sp. hr.	71	53	43

Comparison with Tables 29.2 and 29.3 indicates that a 10% change in bundle tenacity (BT) has a similar effect to a 7.5 mm change in hauteur or a change of 3 in CV_D%. However, as already noted, it is not possible at present to select greasy wools on the basis of their bundle strength in top.

It is important to realise that it is not being recommended to spinners that a specification for a 21μm wool should have, for example, H > 90mm, BT > 11.5cN/tex and CV_D < 19%. Such overtight specification necessarily leads to a higher-priced top as the topmaker has a more limited choice of wools and must insure against the increased risk. Instead, improved knowledge of the relative importance of fibre properties should allow the topmaker and spinner to optimise the top purchase for the desired product and performance.

The aim is not to buy the "best" wool but the most suitable. This probably equates to the cheapest top that will perform to requirements (Lamb 1997).

29.5 Residual effects of greasy wool properties

It has been well established that good predictions of yarn properties and spinning performance can be made on the basis of measured top properties. There do not appear to be residual effects from greasy wool properties other than via measured differences in top properties. A review of staple strength (Lamb 2004) has shown that there is little evidence for effects beyond topmaking other than that due to the differences in hauteur that are associated with differences in staple strength. Downstream effects of differences in intrinsic fibre strength are expected, it is just that variations in staple strength are primarily due to other factors. Staple length influences hauteur which can then be used as the key length property. CV_H replaces CV(SL) as a measure of length variation but CV_H is not significantly influenced by CV(SL). The percentage of mid-breaks has an effect on hauteur but the position of the thin place is not expected to have additional effects and any remaining effects due to the severity of the thin place should be accommodated by the dependence on CV_D. The fibre diameter and CV_D of the top reflect the greasy wool input and remain unchanged by further processing as fibre losses are small. Crimp, as measured by fibre curvature, is further altered during spinning and the effects in spinning appear to be small. Other Style attributes such as crimp definition, tippiness, weathering, and staple shape are removed in topmaking or make small contributions via differences in hauteur or fibre strength. The evidence is that tops perform according to their properties, as measured in the top. The main areas of uncertainty are in the ongoing contributions of staple strength, reliable measurement of fibre damage, and there is disagreement between mill purchasing practices and the measured importance of CV_H.

Readings

The following readings are available on CD

1. Lamb, P.R. and Curtis, K.M.S. 2004, Identifying customer needs and addressing process and product opportunities, Discussion Paper, Australian Sheep Industry CRC.
2. Lamb, P.R., Curtis, K.M.S., Humphries, W. and Pant, N., 2002, 'Opening up specifications', *Wool Technology and Sheep Breeding.,* vol. 50(2), pp. 679.
3. Lamb, P.R. and Oldham, C.M. 2000, 'The advantages of long hauteur', *Proceedings of IWTO Technical and Standards Committee Meeting,* Report No. CTF 03, Christchurch, May.
4. Lamb, P.R. and Yang, S. 1995, The effect of fibre length distribution in worsted spinning, CSIRO Div. of Wool Technology, Report WT95-01.

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Summary

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In terms of improved quality of yarn and spinning performance, the key quality attributes of wool top are, in order of importance, fibre diameter, length, strength, diameter distribution and curvature. Because of its impact on processing and on the desirability of the products, diameter is overwhelmingly important. Longer length in the top is better up to mean fibre lengths of at least 95mm but settings in drawing may need to be adjusted. The length distribution has little or no effect but a wide distribution is associated with more breakage in topmaking, shorter hauteur, and greater along-fibre diameter variation and thin-in-the middle profiles. For undyed wools the strength of the top is relatively constant and only a little weaker if the staple strength is very low. Diameter distribution has well-established effects which can be accurately summarised by 5% in CV_D being worth 1μm. Curvature is related to the crimp frequency of the greasy wools and it appears that high curvature gives rise to marginally poorer performance. In addition, the biggest non-wool quality attribute is freedom from contamination in all its forms. Contamination is still the greatest complaint of the processor

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Glossary of terms

Bulk	Volume occupied per unit mass of fibre under given load
Commission processing	Processing, e.g. topmaking, of wool owned and selected by another party e.g. spinning mill
Creel	To mount input packages (rovings) on spinning frame
Doff	To remove full bobbins of yarn from all spindles on spinning frame
Dust penetration	The extent to which dust has penetrated down into the staple (it is not the same as dirt content which measures the mass of dirt and may be held near the tip by grease)
Intrinsic tenacity	The inherent strength (peak load per unit of linear density) of the material (fibre)
Re-combing	A second combing, similar to the first, but usually carried out by the spinner after dyeing or for fine diameter wool
Weathering	Damage caused to the outer ends (tips) of the fibres mostly by UV radiation