WHY DO WE NEED STRONGER COTTON FIBRES?

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Abstract

Since the introduction of High Volume Instrument (HVI) testing it has become possible to screen every bale of a raw cotton delivery for fibre strength. This has opened up the possibility to devise, and to implement a premium and discount scheme for fibre strength within the cotton marketing system. With the introduction of these new pricing procedures, the way is open for the customers of cotton to send clear price signals to the producers in terms of their requirements for fibre strength. This has been hailed as a significant improvement to the cotton marketing system, and so it is. However, history teaches that such price signals can be a mixed blessing over the long term and can lead to so-called "Quality Traps". A Quality Trap is developed over a period of time whenever there is a direct or indirect negative association between two or more different fibre properties, only one of which is provided with a price signal in the market. Eventually there is a mismatch between the needs of the customers on the one hand and the reward system for the producers on the other. The purpose of the paper is to try to imagine whether any potential Quality Traps are likely to be created by the introduction of price incentives for higher cotton fibre bundle strength.

Introduction

The answer to the simple question "why do we need stronger cotton fibres" seems to be obvious. We need stronger cotton fibres for at least three reasons.

1. Because strong fibres can survive the rigours of ginning, opening, cleaning, carding, combing and drafting. If all fibres were strong, then we would presumably find a much lower percentage of short fibres in the ginned lint and in the drawframe slivers. Short fibres have a very bad influence on yarn strength and regularity.

2. Because we need stronger yarns. The stresses imposed on yarns are increasing year by year as spinning, winding, beaming, and weaving machines run at ever faster speeds. In this case, the average strength is much less important than the strength variation. Indeed, it can be (and has been) argued that the average yarn strength is of very little consequence to the efficiency of yarn processing and the quality of the final products; the dominant factors are the count and strength regularity and the level of imperfections. Nevertheless, a better average yarn strength always has been, and presumably always will be an important goal of the spinners. This is probably because, for a given raw stock, it is a simple, cheap, and direct indicator of how well the stock has been spun.

3. Because of the importance to many cotton woven fabrics of easy-care performance and control of shrinkage, both of which are most easily obtained by cross-linking (resin finishing). Cross-linking of cotton fibres causes a drastic loss in strength and abrasion resistance which, it is argued, can be offset by using stronger fibres.

Since the introduction of High Volume Instrument (HVI) testing it has been possible to screen every bale of a raw cotton delivery for fibre strength in a routine way. Over the last few years we have seen a rapid increase in the number of HVI lines installed and we now have the introduction of a premium and discount schedule for fibre bundle strength in US cottons. With the introduction of these new marketing systems, the way is now open, in principle, for the customers of cotton to send appropriate price signals to the producers in terms of their requirements for fibre strength.

The Concept of the Quality Trap

The cotton marketing system has always rewarded high strength in a generalised sort of way, by the identification of particular varieties and growing areas from which better than average strength could be expected. But now we are about to enter an era in which a systematic rewarding of quite small differences in fibre strength will presumably exert much more direct selection pressure upon cotton quality. To be more specific, the premiums and discounts will be tied to fibre bundle strength as measured by a particular test instrument.

History teaches us that such price signals can be a mixed blessing over the long term. In the early days, and for a long time after the introduction of marketing systems which established premiums and discounts for micronaire and grade, cotton producers and their customers made good use of the system in assigning value to cottons which were clean and mature. With the benefit of hindsight, we can see that the system had the built-in disadvantage that certain other fibre properties, of equal if not greater importance to the customers, were bound to be neglected in favour of grade and micronaire. Thus, whilst producers and ginners have pursued their legitimate interests in maximising the return on their large and risky investments, we have experienced a gradual increase in the quantity of short fibres, neps, and seed coat fragments which have a severe influence upon the value of the raw cotton, but which cannot easily be reflected in its price.

This situation represents a kind of "Quality Trap" in which there is a gap, or a mismatch between the needs of the customers on the one hand, and the reward system for the producers on the other. In a very real sense, the Quality Trap can be seen as an inevitable consequence of different rates of progress in different areas of technology.

For example, progress in manufacturing technology increases the relative importance of certain fibre properties. When competition demands, and production technology allows spinning machinery to run much faster, then the economic consequences of stoppages become intolerable and the relative importance of those factors which lower productivity or yarn quality rises drastically. However, the reward system for producers cannot be changed unless and until the technology of rapid instrumental testing for the particular fibre properties in question has advanced to the stage where every bale can be tested in a matter of ten to fifteen seconds.

Maybe now is the time that we should be trying to look forward to see whether we can imagine a Quality Trap which is inherent in the systematic rewarding of increased fibre strength. Such a trap would be signalled by the drift of other, important fibre properties towards less favourable levels as a result of the pressure which will be exerted on cotton breeders, farmers, and ginners to deliver ginned lint having higher HVI fibre bundle strength.

Of course, imagination is a much less powerful analytical tool than hindsight and it is not possible - certainly not within the confines of today's presentation - to make a comprehensive analysis of where any potential Quality Traps may lie. All that is intended, at this stage, is to make the point that this is an area where those who have the power to influence future marketing systems should perhaps be directing some of their attention, and to indicate a few aspects of the problem where particular study might be fruitful.

An important aspect of Quality Traps is a negative association between two or more different fibre properties, only one of which is provided with a price signal in the market. For example, there is a clear link between grade and short fibre content because, in order to improve the grade, it is necessary to clean the cotton intensively which can lead to fibre breakage. Thus, in order to imagine Quality Traps based on fibre strength, we need to be aware of the relationships between fibre strength and other important fibre properties which might be affected by attempting to deliver ever-higher HVI bundle strength values.

Improving Fibre Strength

Presumably, there are at least three mechanisms by which the average fibre strength can be improved.

1. Genetic Selection

By deliberate breeding programs which seek to improve:

a. the intrinsic strength of the fibres, by altering the fibre structural characteristics, or

b. the basic uniformity of the fibres within bolls, within plants, and between plants.

Strategy (a) raises the tensile strength of all of the fibres, without necessarily changing the strength variation. Strategy (b) does not change the intrinsic strength but reduces the number of weak fibres.

2. Agronomic Selection

By changes in farming techniques which might tend to maximise a given genetic potential. For example, mature fibres are stronger than immature fibres. Any farming technique which increased the average maturity of the crop should also increase the average strength. Increasing the average maturity would increase the value of the crop in other ways also, but these are currently given no reward by the marketing system.

3. Technological Selection

By empirical evolution of machine and process technology. For example, imagine a change in the ginning process which resulted in the breakage of all fibres whose strength was less than a certain value, but their retention in the ginned lint as short fibres, thus maintaining the ginning outturn. If the weak fibres are now too short to be represented at the break point in the HVI bundle strength test, and do not depress the Upper Half Mean length significantly, then a situation might arise in which the additional premiums for lower trash content and higher average strength might more than offset any discount for length or weight.

Whilst remembering that imagination is a far less powerful analytical tool than hindsight, it is nevertheless difficult to imagine serious Quality Traps which are associated with those breeding programs or agronomic strategies whose objective is to improve the uniformity of the crop. For example, it may well become more economical to develop new varieties, or exploit existing varieties of cotton which are much more determinate in their habit and which display more uniformity from boll to boll across the plant. It is already known that the lowest quality fibres come from the last few percent by weight of the crop to develop. If the last few percent of the producer's reward can be obtained through strength uniformity then maybe less emphasis will have to be laid on absolute yield. Such developments would appear to be wholly benign and it is to be hoped that the breeders and farmers will find one or more of such strategies which are capable of significantly increasing their reward from the new marketing system.

On the other hand, it is just as difficult to imagine the results of technological selection for higher strength being anything but perverse. This is because any mechanical procedure which succeeds in completely removing all of the weak fibres from a raw cotton containing a relatively large proportion of such fibres, will be heavily penalised by losses in ginning outturn. The only successful strategy for the ginner in such cases will be to convert the long weak fibres into short ones and to keep them in the lint. If this should prove to be a rewarding strategy for the ginner and farmer, then the result will be to provide a reinforcement of the unfortunate trend already started by the financial inducement for the ginner to produce clean cotton.

Therefore, those of our colleagues who are able to test the possible existence of such potential Quality Traps, either experimentally or by constructing computer simulations of the effect of single fibre strength distributions upon fibre breakage, and the consequent effects upon HVI bundle strengths, are urged to examine the dangers which may await us as a result of the introduction of premiums and discounts for HVI strength.

Hopefully, the practical effects of such a strategy can be shown to be unrewarding to the ginners and farmers but, if they cannot, then the already urgent need for a rapid instrumental test method for short fibre content becomes critical.

This leaves the route of genetic selection for higher intrinsic fibre strength by altering the average fibre structure. To see whether we can imagine a Quality Trap inherent in this strategy, it might be useful to consider the structural origins of fibre strength.

Structural Origins of Fibre Strength

The cotton fibre is composed of highly crystalline micro fibrils which themselves are probably extremely strong in the axial direction - values in the region of 130 g/tex can be deduced from theoretical studies [1]. The strength of the single fibre depends on the way that these microfibrils are arranged in a helical pattern and the way that the direction of the fibrillar helix reverses from time to time along the length of the fibre. The spiralling arrangement of the fibrils gives rise to convolutions, or twisting of the fibre. The periodic reversals in the direction of the fibrillar helix cause the convolutions also to reverse their direction. These and other structural features have been summarised by Hearle and Sparrow [2, 3, 4] in a generalised explanation of the fractography and the extensibility of cotton fibres.

What is important for our discussion is the crucial role which is played by the presence of the reversals and the convolutions, their frequency, and, especially, the uniformity of their distribution along the fibre length. In brief, and grossly simplified, the tensile strength of a normal fibre (i.e. a fibre of normal maturity and without gross defects) is governed firstly by the uniformity of spacing of the reversals and secondly by the cross-sectional uniformity of the fibrillar packing.

This is because the initial effect of a tensile load is to untwist the convolutions. On either side of a reversal zone, the convolutions are untwisting in opposite directions so the reversal zone is the centre of rotation. If the length of the fibre segments between each reversal zone is roughly the same, then stress concentrations are shared more or less equally between all reversal zones. However, if some segments between reversal zones are relatively short, then all of the twist will be removed from such segments before other, longer segments have been fully de-twisted. Stress will begin to concentrate close to the reversal zone, causing the fibre first to split along the fibrillar helix, and then to fracture. Thus, a tensile failure is actually the result of cracking under torsional strain, so the torsional stiffness and the uniformity of structure over the cross-section are vital influences.

How quickly the fibre will fail beside such reversal zones, and at what stress, will depend on the underlying uniformity of the fibrillar packing at the places near the reversals and how well the rapidly concentrating stresses can be distributed over the cross-section and back through the length of the fibre segment. Kassenbeck [5] has shown how the uniformity of fibrillar packing over the fibre cross section is influenced by the maturity and by the way that the fibre collapses when it first emerges from the boll and dries out in the field.

In a normal fibre, this general tensile fracture mechanism is probably the main source of the well-known effect of the tensile test gauge length upon fibre strength [6, 7, 8]. The longer the test length, the more likely it contains a region of unbalanced twist, where stress can concentrate.

An important consequence of this fracture mechanism is that the breaking extension is governed by the number of convolutions in the shorter fibre segments. Under low loads, extension of the fibre is largely the result of deconvolution - the greater the number of convolutions, the greater the extension. Deconvolution ceases either when the fibre breaks or when all of the segments having one twist direction are fully untwisted.

If the convolutions are removed, for example by mercerising under tension, then the extension at break is drastically reduced although the strength is generally significantly increased. The increase in strength is probably partly because there is no longer such a strong concentration of stress adjacent to particular reversal zones, but also because of the improved distribution of fibrillar packing across the fibre cross section. The pronounced drop in both fibre strength and extensibility which is caused by chemical cross-linking (for example in easy-care processes) is probably partly due to an increase in the torsional stiffness of the fibre, which makes it more difficult to untwist the convolutions, and partly due to irregularities in the fibrillar packing being "frozen" into the structure so that stresses are concentrated into a smaller length of the fibre.

When cotton fibres are evaluated for their strength in the marketing system, they are not measured as individual fibres but as bundles. Bundle testing exaggerates the effects described above - since there is a greater likelihood of finding "weak" places - but also adds its own complications. These are to do with differences in the orientation of the different fibres within a bundle and also different levels of crimp. The smaller the differences in orientation and crimp which are present between different individual fibres in a bundle, then the higher will be the bundle strength. Likewise, the smaller the differences in strength between different fibres (i.e. the greater the uniformity among fibres) the better will be the bundle strength.

From this, admittedly rather superficial analysis, we can deduce that, in principle, cotton geneticists and breeders can increase the average strength of the fibres by one or more of the following strategies.

1. Improve the uniformity of distribution of reversal zones. In particular there should be no cases of reversal zones which are relatively very close together. This will help to spread the tensile load over a greater number of reversal zones.

2. Improve the uniformity of fibrillar packing over the fibre cross section in such a way that stresses are more easily dissipated across the section and along the length of the fibre.

3. Reduce or eliminate the convolutions. This is achieved by reducing the average helix angle and improving the orientation of the microfibrils. In the ultimate, the fibre becomes almost straight, like mercerised cotton or linen, with a low helix angle.

The consequences of the first two approaches seem to be wholly beneficial. What we appear to get is a more uniform basic fibre structure with no penalty in terms of reduced extensibility or increased torsional stiffness. There is even a chance that the response to cross-linking might be improved. Such an improvement will presumably be signalled by a change in the shape of the curve which describes the effect of test length upon bundle strength. Zero-gauge strength will change little, if at all, but that at 3 mm will be significantly higher.

On the other hand, the consequences of the third approach may be drastically reduced elongation and an even worse response to chemical cross-linking treatments, as the fibre becomes stiffer and more brittle. In addition, the spinning folklore has it that the convolutions are an important factor in determining drafting efficiency. One can also imagine that the convolutions are an important aspect of that indefinable "pleasant, comfortable" feel of cotton products. This type of strength improvement will presumably be signalled by significant increases in both the zero gauge and 3 mm bundle strengths.

Why do we Need Stronger Cotton Fibres?

At this stage, it is perhaps appropriate to return to the question which is posed in the title of this presentation and rephrase it to read "why should we be encouraging breeders, farmers, and ginners to deliver ginned lint with higher HVI bundle strength values when it might lead them straight into a Quality Trap, where the price for higher strength is a reduction in value of the crop?"

As already admitted, it is not possible today to undertake an exhaustive discussion of the Quality Traps which might be awaiting us as a result of strong price signals from the market in favour of stronger cottons.

We can suggest that there is a danger of producing stiffer cotton fibres with fewer convolutions and lower extensibility. We can also suggest that there is a danger of increasing short fibre and nep content. We can finally suggest that there is a danger of producing cottons which possess an even worse response to easy-care cross-linking treatments.

If any of these are the consequence of price incentives for strength, then we do not need stronger cotton fibres!

However, it also seems that there may be ways for the breeders and farmers to improve the average fibre strength which will also improve extensibility, will reduce short fibre and nep content, will give better dyeing performance, and may even give us a better response to cross-linking. This is achieved by improving the uniformity of their cottons.

In the first place, uniformity means the underlying structural uniformity of the fibre in terms of distribution of reversal zones. This is the (probably extremely difficult) job of the geneticist and the breeder. In the second case, uniformity means constancy of the fibre cross-sectional geometry and this means uniformity of fineness and maturity from boll to boll and from plant to plant. This is partly the job of the breeder but also places a heavy responsibility on the farmer.

If improved uniformity is the main long-term consequence of price incentives for strength, then the sooner the better!

If we want to avoid the potential Quality Traps (not all of which have been identified here), then we must do at least two things.

Firstly, we must stay alert to the changes which may be occurring over the next decade in the balance of properties of our raw cotton deliveries so that an undesirable drift in, say short fibre content or the number of seed coat fragments can be spotted in good time.

Secondly, we must encourage the development and introduction of rapid and reliable instrumental test procedures for the other important fibre properties, especially maturity and short fibre content, which will allow them to be included in the marketing system to correct any potential adverse drift.

It would also help if those few remaining laboratories that are still able to indulge in basic cotton fibre research could continue the good work done in the sixties and seventies (but abandoned in the eighties), which was slowly elucidating the fibre structural foundations of strength and abrasion resistance in cotton products. As a simple example, it would be useful to know how many of the weak fibres in a sample are simply immature, how many have an unfortunate distribution of convolutions, and how many are abnormal in the sense of having growth deformities or having been attacked and degraded by micro-organisms.

Literature

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