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FLAX

Cottonised fibre from linseed stalks

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Foreword

Flax, which is made into linen fabrics, is one of the oldest plant fibres known to be used for clothing. Flax, along with jute, hemp, ramie and kenaf, are bast fibres where the valuable fibre occurs in a re-inforcing cylinder around the plant stem. Linseed is a variety of flax grown for seed and oil production. Flax for fibre production is long-stemmed with little branching whereas linseed is short with considerable branching.

Sixty years ago flax was grown and processed extensively in Australia including in the Darling Downs region. Now there is almost none due to the advent of synthetics and to the heavy subsidies provided to European farmers. However, linseed production is increasing and the oil has valuable attributes, but the stalks are a low value waste stream.

Conventional flax processing aims to maintain long strands of bast fibre. It is labour intensive and most of the processing is done on antiquated machinery which has not been developed relative to the enormous investment and improvement in cotton processing machinery. There have been some efforts to “cottonise” flax by shortening it using cutting or enzymes but not linseed. However, the authors had observed that the component cellulose fibres of linseed were of similar fineness to cotton and could potentially be individualised for processing on high production open-end spinning equipment.

The aim of the project was to enhance the economic returns on bast fibre seed crops by turning the stalks into a source of high value fibre that could be processed on existing cotton machinery.

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Abbreviations

TFCA	The Flax Company of Australia
SDS	Sodium Dodecyl Sulphate
CTAB	Cetyl Trimethyl Ammonium Bromide
OFDA	Optical Fibre Diameter Analyser

Contents

Executive Summary

Attempts were made to convert the waste stalks of linseed, a shorter multi-stemmed variety of flax, into high value fibre that could be processed on cotton machinery into yarn and textiles. A tall variety of flax is used in the production of linen fabrics. Flax is a bast fibre which means that the good fibre comes from a ring of re-inforcing in the stem of the plant. The conventional flax processing system breaks the re-inforcing down into metre long strands of fibres. These strands are actually bundles of overlapping shorter finer fibres that are glued together. The equipment and processing steps to handle the long fibre is labour intensive and antiquated. The aim was to avoid all this by breaking down the linseed stalks into their finest components and then process the fibre on cotton machinery. Cotton is still the dominant fibre globally and its processing is the most advanced and automated and "cottonising" the linseed would potentially open up enormous opportunities.

The chosen route was to work in with the Flax Company of Australia who were commisioning some innovative machinery for shredding the stalks in a way that separates much of the woody core from the bast fibre. The stalks, as with conventional flax processing, had been allowed to ret, partially break down in the field, which aids separation. The aim was to establish a method for "cottonising" the linseed and to prepare fibre for a commercial cotton spinner (A.W. Spinning Pty Ltd) to turn into yarn on the rotor spinning system and have customers evaluate the suitability of the yarns.

Although a fibre that was judged as nearly spinnable was produced the efforts were eventually halted when it was found that fully individualised fibre of all the varieties examined was too short to be spun without blending with a long cotton or synthetic. It appeared likely that this fibre would also be more expensive than cotton and the production of suitable fibre in more than kilogram quantities would require further development and capital investment.

However, a number of achievements were made which could help improve linseed fibre, or other bast fibre, for use in alternative applications, or provide a means to produce higher quality "cottonised" fibre from flax or hemp. These included:

- methods and machinery to remove most of the woody non-fibrous contaminants while minimising fibre breakage using wool carding machinery
- a method to form the card web into a sliver strong enough for further processing
- chemical recipes to break down the glues and bleach the fibres without significant damage
- a rapid chemical treatment that could be carried out continuously with modest equipment
- means to greatly increase fibre individualisation by combining chemical and mechanical treatments
- the determination of suitable softeners for inhibiting re-glueing of fibres on drying.

These developments enabled the linseed stalks to be turned into a clean white product of excellent strength and of the finest diameter for bast fibre reported in the textile literature.

1. Introduction

Historically, much of our clothing and other fabrics came from bast fibre crops (flax, hemp, kenaf, jute, etc.). The valuable fibre is contained in the outer stem of the plant where it is held by natural glues to provide a fibre-reinforcing. These plants were replaced to a great extent by cotton and, more recently, synthetic fibres but still retain some niche markets. Flax has diverged into two varieties – one, short and multi-stemmed, for seed (linseed) and the other, tall and straight, for linen fabrics (flax).

Part of the reason that flax has declined is that the traditional method for obtaining the fibre and producing the yarns has been very labour-intensive and required flax-specific machinery throughout. This has made it difficult to compete and the market has been too small for new machinery development to be funded. The traditional method has been to partially rot (ret) the plant stalks and to bundle and process them into long strands of fibre, which are really made up of strings of ultimate fibres. There then follows scutching, hackling and drawing on specialised machinery set up to handle very long fibres. Only at, or immediately prior to, spinning are the long strands partly broken down in a wet process.

At the end of the second World War there was an extensive flax growing industry in Australia, including on the Darling Downs, for both linseed oil and for linen. Hence, the agronomic know-how has been established for Australia. Seed flax is again being grown in the Toowoomba area which is particularly suitable for field retting of the stalks after harvesting which occurs in the normally humid summer. A group of growers with expertise in agronomics, development of machinery and marketing have formed the Flax Company of Australia and imported a unique bast fibre decorticating plant from the U.K. after the European Community greatly restricted subsidies. This plant was designed as a low labour alternative to the conventional route and while it is effective at breaking bast material into fibre strands these strands are relatively short compared to the long strands demanded by existing machinery for spinning preparation and the fibre was used for composites and geofabrics.

On a weight-for-weight basis both flax and hemp are known to be comparable to glass fibre in strength, and are the only common bast fibres (along with ramie) that have a fibre length (of the ultimate cells) longer than cotton. However, the key fibre property for textile processing is mean fibre diameter. The literature generally reports flax as the finest bast fibre (with mean diameter of 18 to 22μm), but the measured diameter and length are dependent on how well the fibres are broken down into their ultimate components and traditional long-line processing does not achieve complete individualisation. Physical and chemical processes, including some developed for blends of cotton and for bleaching of jute, were used to break down and bleach primary processed seed-flax fibre and to also inhibit the fibres from re-glueing on drying. Using an instrument, developed by CSIRO for wool, the distribution of fibre diameters was measured and it was discovered that the ultimate diameter was 12 to 13μm (comparable with a fine cotton). This made seed flax a potentially exciting and suitable fibre for processing on cotton machinery, although with the proviso that the processed fibre length of the ultimate fibres must be comparable to cotton. However, a priori, it can be expected that length and diameter will be correlated and that fibre length will be in some proportion to the length of stem sections.

Field retted linseed flax was processed in the laboratory to a state resembling ginned cotton and sufficiently individualised that a commercial cotton spinner could see a novel, niche market and agreed to evaluate the fibre once adequate quantities of suitable fibre could be prepared. The Flax Company of Australia Pty Ltd (TFCA) was growing several varieties of linseed and completing the commissioning of a unique plant for the primary processing of the stalks and agreed to supply decorticated fibre. The field retting and primary processing made the subsequent chemical (and physical) treatment more attractive by reducing the needed amount of chemicals and the reaction time.

Currently, the tonnage of seed flax in Australia, primarily for use in bread and industrial oil, is about 6,000 tonnes while linen flax is negligible. A small amount of flax yarn is imported for woven fabric production, primarily upholstery. However, world trade in linseed is hundreds of thousands of metric tonnes and the demand is expanding rapidly for natural floor and paint products and in high omega-3 nutritional products. New varieties of seed flax, such as Linola, have also been developed with improved oil qualities. The growth potential of the industry is significant with the considerable recent pressure for "greener" products and, for example, the move in Europe to have cars recyclable has already led to significant quantities of bast fibres being used in fibre-reinforced composites. The Flax Company of Australia has begun producing bast fibre products for the geofabrics and fibre composite industries. Further processing into a high value fibre would enhance the utilisation of what is a waste stream to seed production, and it is estimated that the return on the stalks for the production of high value fibre, could effectively double the gross margin received by the producer. This improved economic opportunity could provides a real incentive for growth of a well-known broad-acre crop, without the need for extensive agronomic studies. By improving the downstream processing a synergy with the Australian Cotton Industry could be developed to offer unique blended yarns that might be cost competitive on the world market and if even only 1% of the world cotton market was captured it would rival the whole Australian Cotton Industry. If the fibre could feed into existing cotton machinery it could penetrate and utilise the majority of world textile machinery and design facilities, and give an Australian supply chain the opportunity to test market a "natural" substitute for existing furnishing, sheet and canvas products and new products such as a cotton/flax denim. A.W. Spinning Ltd examined samples of prepared fibre and agreed to be involved in the assessment of the potential of the yarns that could be spun on their equipment. The Textile, Clothing, Footwear & Leather Centre assessed bast fibres as a potential growth area in Australia and new techniques that allowed linseed to be processed on cotton machinery might be applicable (with some modification) to other bast fibres. However, the benefits cannot begin to flow until the demonstration of product opportunities justifies investment in secondary processing of the bast fibres. Any equipment would have to be based on existing equipment for textile processing and would need to represent only a small investment relative to the existing investment in cotton equipment and its fashion and marketing arms.

It would need to be demonstrated that the processing is feasible, that the fibre and yarn meet acceptable commercial criteria (strength, evenness, colour, hairiness, freedom from contamination etc.), and that attractive products can be produced at an acceptable price. There is a current market for flax yarns in woven products although the shorter fibre and cotton route means that any yarns may be more suitable for knitwear. The second part of the equation will be price which will influence potential routes and the needed investigations. The price will be very dependent on, for example, the number of drying steps, the number of processing steps or passes, the yields, and the capital cost of equipment.

The use of bast fibres is attractive from the point of view of improved sustainability by enabling plant fibre to substitute for man-made fibres (some based on petrochemicals), by replacing some cotton production by a plant with lower water, herbicide and pesticide requirements, and by improving the usage of an existing waste stream. There will be some negative environmental effects from the chemicals used to break down the fibre glues, primarily because neutralisation of a strong alkali will produce salts. The chemical recipes would need to be optimised. In the long run, biological alternatives may be found and the effluent could be returned as fertiliser.

2. Objectives

The aim of this project was to convert waste stalks from linseed production into a high value fibre suitable for processing on the cotton system, and to demonstrate that there was potential demand for fabrics made from the fibre. The principle was to use field retted and decorticated linseed from a new processing enterprise and upgrade the fibre stream for use in a high value application. When an appropriate processing route was established then yarns would be spun by a commercial partner and the fabric making customers asked to assess the market potential. The key requirement for commercialisation was seen as establishing convincing evidence that a satisfactory product could be produced at an acceptable price such that there would be investment in secondary processing.

The new process was to be compared with the conventional high-labour cost processing – the long-line system – currently used for producing flax yarns. Potential cultivars, growing and retting conditions were to be assessed in terms of the achievable fibre properties.

3. Methodology

The underlying aim was to individualise fibres as completely as possible by removing the gums that hold the ultimate fibres together, without excessively reducing the strength of the ultimate fibres. This was based on the understanding from conventional staple fibre spinning that the quality and fineness of yarn that can be spun will almost exclusively depend on the mean diameter of the component fibres, provided the length of the ultimate fibres is comparable with cotton, but the performance and quality will be degraded by the extent of unindividualised bundles or other thick contaminants. Preliminary experiments had shown that the ultimate fibres were similar in diameter to a fine cotton and of an acceptable fibre length, but under conditions that had not fully individualised the fibres.

The planned steps were to: 1) establish base fibre attributes by measuring diameter and length distributions; 2) process quantities of prepared fibre on both wool and cotton cards and establish the effectiveness of the removal of non-fibrous contaminants; 3) optimise chemical treatment recipes, using small quantities of part-processed fibre, in terms of individualisation into ultimate fibres and to bleach the fibres to acceptable whiteness, and measure any degrading of fibre strength; 4) test the effectiveness of means to enhance fibre individualisation and reduce fibre breakage in further processing; 5) take larger sample quantities of fibre through the optimised individualisation and then via cotton processing machinery into yarn via both ring and rotor (open-end) systems at CSIRO and a commercial spinner, and compare these with conventional flax and matched cotton yarns.

The stalks could be pulped, as is done for paper production. However, pulping systems use high pressure and temperatures and rely on huge throughput to overcome the high capital cost of the equipment. They also tend not to be concerned with minimising entanglement or maximising fibre length. The aim was to concentrate on a processing route that could be introduced via a small-scale low-cost operation that would fit in with the production of a textile mill. A biological route, controlled retting or breakdown with enzymes, was only considered in the context of achieving improved fibre separation with little damage, in order to be able to produce useful fibre for the spinning trials.

3.1 Conventional long-line system

The traditional method has been to grow tall varieties of the flax plant with little branching. The plants have been selectively bred to maximise fibre production and are usually harvested before the seed is ripe. The whole stalk is pulled from the ground and stacked or tied into bundles. These stalks are allowed to partially rot (ret), that is to be attacked by micro-organisms that degrade the gums holding the fibres together. Historically, this was done in water but water retting had to be abandoned in Europe because of the pollution load and foul smell, and it is now normal to use dew retting. The bundles of plant stalks are then beaten in a process known as scutching to free the fibres from the light woody core, called hurd, of the plant. The bundles are then further cleaned and broken down into long strands of fibres by holding one end and drawing sets of pins repeatedly down along the bundles in a process called hackling. The long strands of fibre up to 1m in length, made up of strings of ultimate fibres, are then overlapped to form a sliver. The sliver undergoes several drafting stages using pinned gills to control the fibres and then a final stage of drafting on a flyer rover which inserts a small amount of twist into the strand. All this uses specialised machinery set up to handle very long fibres. A similar processing sequence and machinery to that used for wool is also used. The scutched tow passes through a breaker card followed by a finisher card. The sliver is then processed by intersecting gills and may be combed before being drawn into a roving.

In both cases the roving packages will normally be treated chemically to remove the gum and bleach the fibres but may go straight to the spinning frame. The roving is then passed through a bath of cold water with additives before being immediately drafted and spun. The bath must be close to boiling if the flax has not been chemically treated. This wet spinning is unique to bast fibres but is essential for the production of fine yarns by allowing drafting of the component fibres of the original long strands.

Because of its small share of the global market, flax processing machinery has fallen progressively further behind in technology and automation, and the production costs relative to cotton, in particular, have increased. This has further eroded the market for linen products and meant that processing has progressively moved to the low labour cost countries of Eastern Europe and Asia, particularly China and India. Currently, there are significant agricultural subsidies for the growing of flax in the EEC and more than 100,000 tonnes of fibre is still grown annually (Rupp 2000).

3.2 Alternative processing routes

There have been efforts in both Europe and North America to find a more mechanised, less labour-intensive, route for processing both flax and hemp. Generally, the fibres are dew retted and mechanically harvested, with less attention to retention of length or even with cutting to more manageable lengths, then mechanically decorticated. One such decorticator machine, developed in the U.K., was the Silsoe decorticator. This is the basis of the machine installed in Toowoomba by TFCA. For use in textiles the fibre must be further individualised. Methods that have been explored include steam explosion (Kessler et. al. 1994), chemical retting, ultrasonic retting (von Drach et. al. 1999) and organic retting (Leupin 2000). The latter method proposes field decortication as part of the harvesting process and aerobic processing using naturally occurring micro-organisms. It is claimed (Leupin 2000) that the steam explosion and ultrasonic retting methods are much more expensive than the price of cotton ($2 to $2.50/kg) that would make the fibre uneconomic relative to cotton.

3.3 Cottonised fibre

Bast fibres constitute a cylinder of re-inforcing elements near the outside of the plant stem. The fibres are glued strongly together by both gums (polysaccharides) and lignins. There appears to be a hierarchy of bonding so that the component or ultimate fibres can be broken first into bundles or long strands of overlapping fibres by mild retting. The aim of the conventional long-line system is to maintain the length of these long strands (around 1m) for as long as possible. The shorter strands are collected as scutching tow or combed out in the hackling process and are considered a lower grade product. These shorter fibres can also be produced by more violent opening processes and can be used to produce slivers that are processed on the conventional semi-worsted or worsted (wool) systems.

Cotton is also a cellulose fibre but grows as individual fibres attached to the seeds of the plant. The average length of the fibres is about 15mm but ginning and cleaning removes a lot of the shorter fibres. A typical good quality cotton will have a quoted length of 32mm (1¼ inches) but this measurement actually refers to the “effective length” which is closer to the average of the longest 40% of fibres. Cottonising of flax fibre involves reducing the length of the fibres to that suitable for cotton machinery. This is normally done by cutting. It can be done on long-line sliver but it appears to be more common to use the waste tow from the hackling process as this fibre is of lower value and may be more individualised. Cottonised flax fibre is also available by the mechanical processing equipment developed by Laroche, Temafa and Rieter.

Cottonised flax has been available for about ten years (Scholz 1994) to spin in blends on rotor spinning frames, but the opening systems have needed improved trash separation. The Belgian company Procotex has developed an “E-lin” yarn based on rotor spinning technology (Rupp 2000). Work in Poland has produced a cottonised flax fibre of 0.9 tex that could be spun on BD200S rotor spinning machines into a 30 tex yarn in a 50:50 combination with a fine cotton (Czekalski et. al. 2000). This fineness was claimed to be better than the fineness of cottonised flax obtained commercially, yet 0.9 tex corresponds to a mean fibre diameter of approximately 29µm, which is very coarse relative to Merino wool or cotton.

3.4 Proposed processing route

The proposed route to turning the waste stalks into high value fibre was to mechanically and chemically fully individualise the bast component into its ultimate fibres. This needed to be done in conjunction with nearly complete removal of any non-fibrous contaminants, notably the hurd, but minimum fibre breakage because the fibres were likely to be borderline for length. Any chemical treatment needed to have only a modest effect on the strength of the fibres because high strength is a positive attribute of flax yarns and will be particularly needed if the fibres are short. According to the literature, the ultimate fibres of conventional flax had a mean diameter of 18 to 21µm and a mean fibre length of around 50mm, which would mean that full individualisation might still leave some fibres that were too long, whereas this seemed unlikely for the linseed. The general problem encountered by others was that any wet treatment led to the glueing of fibres on drying and consequent breakage in further processing. However, some promising products to reduce the re-glueing had been identified in preliminary trials.

3.5 Mechanical separation

There are many patents and commercial machinery for decortication – the separation of the bast fibre from the hurd. These opening and cleaning systems have generally been directed at fibre varieties of flax. They aim to remove the hurd with minimal breakage of the bast fibre strands. Because many of the fibre bundles are still strongly glued together heavy mechanical opening can break the bundles rather than individualise the fibres. Anthony 2002 investigated the effectiveness of cotton gin machinery in the separation of fibre from seed flax straw after chopping the stalks into 51mm lengths and achieved moderate efficiency (68%) and purity (86%), otherwise there seems to be little published work on processing of seed varieties of flax.

There is considerable literature on the chemical and biological treatment of fibre flax but little on how to best mechanically individualise the treated fibre. Most authors appear to have used a Shirley analyser (e.g. Hurren et. al. 2002, Adamsen et. al. 2002) for the research studies and often reported considerable fibre losses. Kimmel et. al. 2001, used a Spin Lab opener/blender after enzymatic treatment before feeding blends to a coarse-wired Hollingsworth card.

3.6 Chemical separation

In general, the treatments applied to flax in the long-line system have to be assessed from the point of view that they are aimed at maintaining not individualising the long strands of fibres until just before spinning, and then only enough to enable good drafting during wet spinning. The vast majority of fine count yarns produced in Western Europe are wet spun from bleached roving with the flax undergoing alkaline boiling-off followed by peroxide bleaching (Rupp 2000). Hickman 1999 gives some insight into the treatments used to bleach waste cellulose fibres. The general method is to carry out such treatments in two stages in a pressure vessel. The first is a caustic scour with surfactants typically at 120°C, the second stage is a peroxide bleaching typically at 100°C at lower pH and with a stabiliser or scavenger. The latter serves to protect the fibres from catalysed breakdown of the peroxide from heavy metal ions. A continuous treatment is also outlined in which a web of fibres passes through a liquor bath and is then steamed. Schulze 1998 claims a hydrothermal fibre retting process for raw flax combining scouring and bleaching in an ecological framework. The trade name of the process is Flasin and the micronaire of the fibre is claimed to be 6.5 to 8 or an estimated 18 to 21μm. Karus and Leson 1996, state that it involves a detergent processing step which produces a very fine, cotton like flax fibre. Hashem 1999, reports on bleaching of flax with activated peracetic acid at low temperatures after a scouring operation.

3.7. Biological separation

There has been a lot of recent interest in using naturally occurring micro-organisms (Leupin 2000) or their enzymes (Akin et. al. 2002, Müssig et. al. 2000) to give controlled retting in a post-decortication operation on fibre flax and hemp. Leupin 1998, suggested for hemp that this might be carried out on freshly harvested green stems. The resultant fibre is directed at dry processing on the cotton system. The literature does not always report on what fibre diameter has been achieved or the treatment time. However, a minimum treatment time appears to be about six hours and the methods have usually been observed to give less individualisation than chemical treatments or to lead to blend yarns of inferior quality.

3.8. Cotton spinning

In the normal processing route, ginned cotton is opened, blended and cleaned in a blow room, then fed to a cotton card. The card creates a sliver of individualised fibres while removing some of the larger contaminants and entanglements. Multiple slivers are then drafted during several passages on a drawframe to straighten the fibres and make a more uniform sliver of lighter weight. For high quality products and very fine yarns the sliver will also undergo a combing process and additional drawframe passages. The sliver will then be fed to a rotor spinning frame or be made into a twisted roving and fed to a ring spinning frame. The feed system of a rotor spinning frame opens or individualises the fibres of the sliver and feeds them into the circumference of the rotor. A forming strand sweeps up these fibres as they are rotated at high speed about the forming yarn that is drawn out of the middle. The gauge lengths in each stage of cotton processing are no more than 30 to 40mm reflecting the length of the longest fibres. Over-long fibres will be broken or disrupt drafting and are a particular concern in rotor spinning where they produce wrapper fibres and can cause the yarn-forming process to fail. Coarse, short contaminants are also a particular problem for rotor spinning as they can build up in the rotor groove and disrupt yarn formation.

Steffes 2000 reports on the spinning of 50:50 blends of hemp and cotton on rotor spinning machines. The sample of hemp treated by the Flasin method was the stiffest and most brittle and could not be spun satisfactorily.

3.9 Measurement systems

A nominal diameter can be measured by airflow (ISO 2370), strength of individual fibres can be measured using an instrument such as the Fibrodyn but is extremely laborious, and so instead the strength of fibre bundles is measured using a Stelometer (ISO 3060). The reported length, strength and fineness of bast fibres varies enormously in the literature (Ripka and Ferkl 2002, Steffes 2000). Some of the reasons are that the values depend on the degree of individualisation, the inherent strength of the ultimate fibres can be reduced by the individualisation method, the fibres are not round, the properties vary with cultivar and growing conditions and with position on the stalk, and the fibres are not of uniform thickness. Flax fibres, in particular, are tapered towards their ends.

The diameter of the ultimate fibres has been measured by examination of transverse cross-sections under an electron microscope. However, the fibres must be chemically treated to show up the boundaries and a single cross-section measurement will be examining a random position along the length of the component fibres. The Uster high volume instrument (HVI) has been used to examine enzyme treated flax (Ripka and Ferkl 2002) and it was shown that the apparent length and fineness changed with processing but it was noted that no reference standards exist for cottonised flax.

Müssig et. al. 2000, used the Optical Fibre Diameter Analyser (OFDA) to measure the diameter of treated hemp and a sample of chemically treated flax (Flasin), and the Stelometer to measure fibre bundle tenacity. For measurement on the OFDA, 2mm fibre segments are guillotined and then spread on a glass slide using a mechanical spreader. They observed that the flax had the finest diameter (15.3μm) and a strength of almost 20 cN/tex. They also observed that the steam explosion method appeared to retain higher strength in the hemp fibres than the chemical treatments but provided less individualisation.

Sirolan Laserscan is an instrument developed for measuring the diameter of wool fibres but several of these instruments are in commercial use for the measurement of flax. Fibre samples are cut into 2mm long snippets and dropped into a mixing bowl containing a 90:10 mixture of isopropanol/water. The snippets are carried past a laser beam in the liquid flow and their diameter measured. There is a ring of auxiliary detectors to discriminate against two fibres passing the sensor close together that also measure how much the fibre bends (curvature in °/mm). The measurement, as with the OFDA, is one of cross-section and so can be biased if the fibres are non-circular. A distribution of the measured diameters, typically for 2000 snippets, is output along with the mean diameter plus measures of the width of the distribution, CV(D)%, or percentage of coarse fibres (>30.5μm).

4. Results

4.1 Fibre Measurement

All initial wet treatments left the fibre mass somewhat stuck together. No rinse with softener was given. As a result, guillotined sample did not break up well in the Laserscan mixing bowl. Therefore, samples were individualised by hand drafting and fibre snippets prepared using a microtone. The diameter and CV(D) values were then measured using the Laserscan. The measurement was, however, suspect because the coarse edge could be coming from bundles of fibres or single very coarse fibres. Electron micrographs are shown below for a sample of long-line flax (Figure 1) and for linseed (Figures 2 & 3). Samples were held in heat shrunk tubing and cross-sections were cut, then mounted on stubs and imaged in a scanning electron microscope. The first two samples were briefly etched with sodium hydroxide which helped distinguish the lumen and fibre boundaries. Measurement of the fibre diameters revealed that most of the coarse edge must be coming from multiple fibres as the maximum fibre diameter is about 25μm. The large coarse feature in Figure 3 is a piece of hurd and it can be seen that it is made from hollow fibrous elements that make it stiffer and less dense. The bast fibre can be seen peeling away from the hurd. The amount of non-fibrous gum still holding fibres together in the sample of fine long-line flax is still considerable.

The problem of the fibres sticking together on drying was ameliorated by the discovery that some silicone softeners were highly effective at preventing re-glueing of separated fibres. Clumps of fibres were still observed in the Laserscan mixing bowl but separating these clumps using detergent and water followed by air-blasting and drying did not significantly alter the measured diameter distribution. So the Laserscan results have been taken as satisfactory measurements of the degree of fibre individualisation.

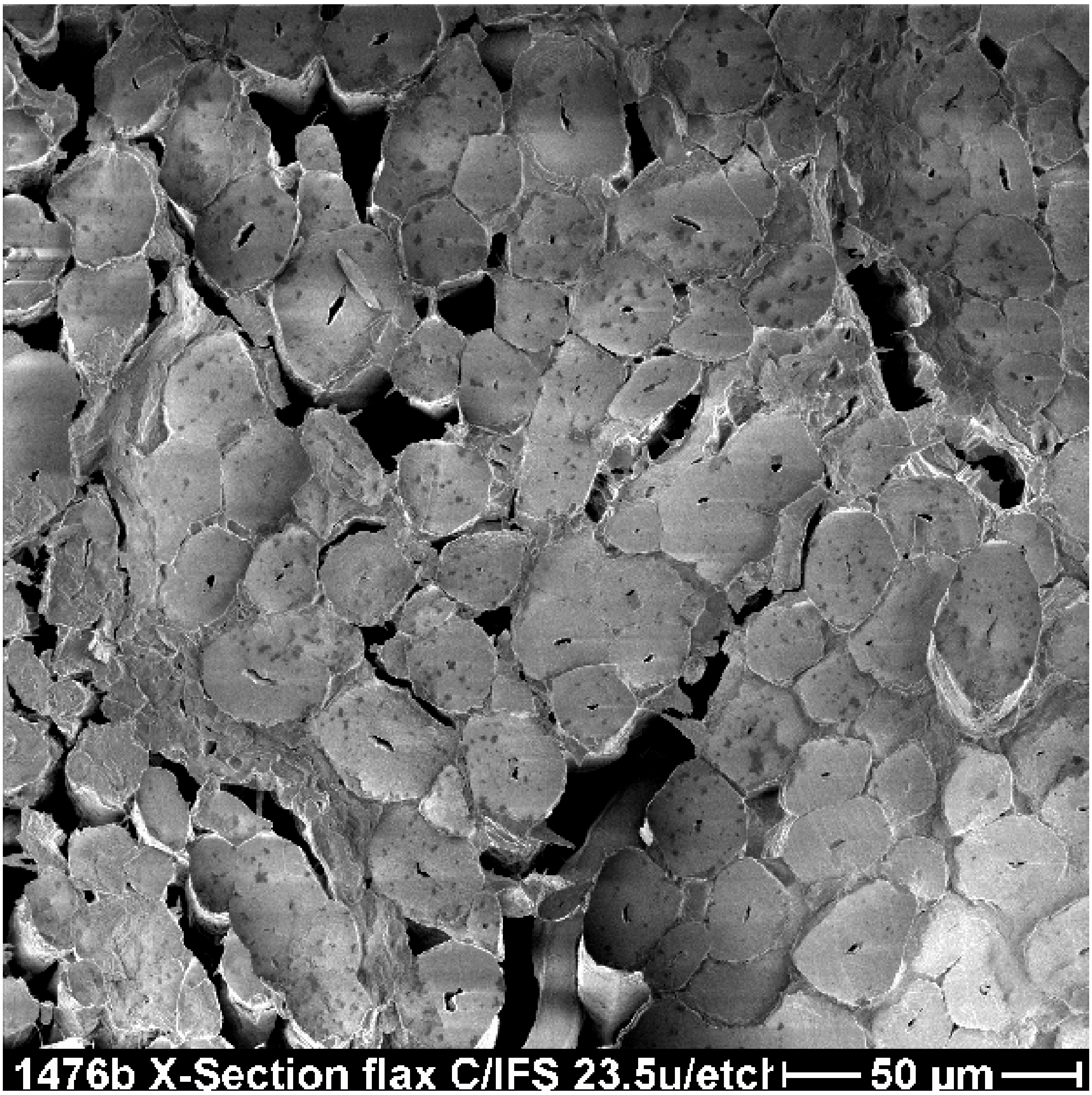


Fig. 1 Electron micrograph of fine long-line flax.

4.2 Mechanical processing

A large bag of field retted Arika linseed stalks, decorticated to a medium level was used for the initial trials. This material still contained 35% to 45% by weight of hurd and non-fibrous material. A Shirley Analsyer (set for wool) was efficient at removing the hurd, but inefficient at transferring good fibre and introduced a large amount of breakage. Only some 10% of input material remained in the "good" fibre output after three successive passes. It was clean and fine but very short.

A hand-operated set of three intersecting crushing rollers was built to aid in the processing of the stalks. It efficiently broke the hurd (of a fresh sample) into smaller pieces which aided subsequent removal. The current version of the rig is shown in Figure 4.

It consists of three pairs of successively finer fluted rollers. The outer sections of the flutes of each roller are not as deep as the section through which fibre is processed and the top roller of each pair is spring loaded. In this way the inflexible parts of the feedstock are bent and broken but there is always a gap between the opposing surfaces of the flutes.

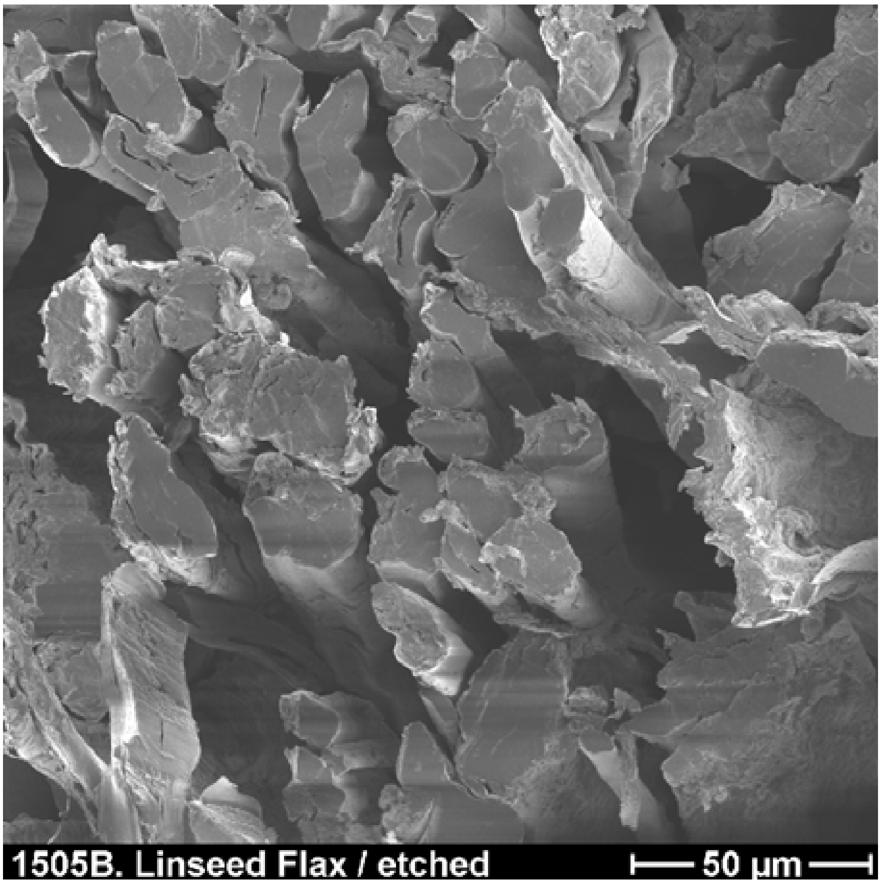


Fig. 2 Electron micrograph of retted and hand-drafted linseed fibre.

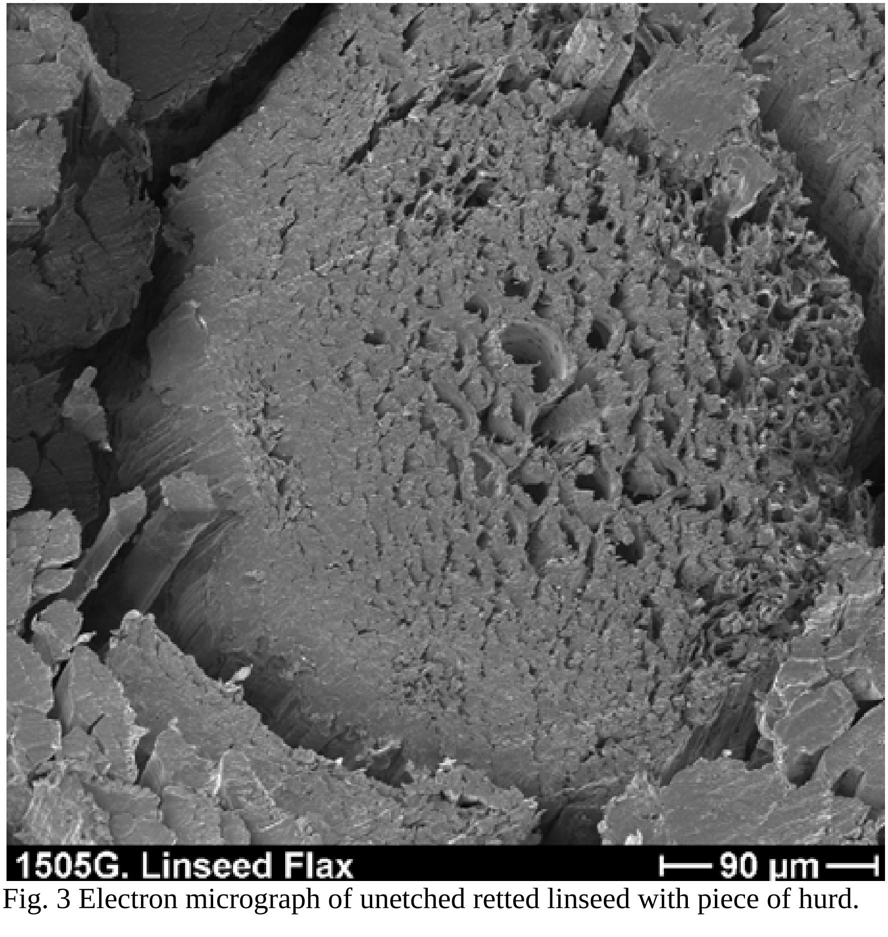


Fig. 3 Electron micrograph of unetched retted linseed with piece of hurd.

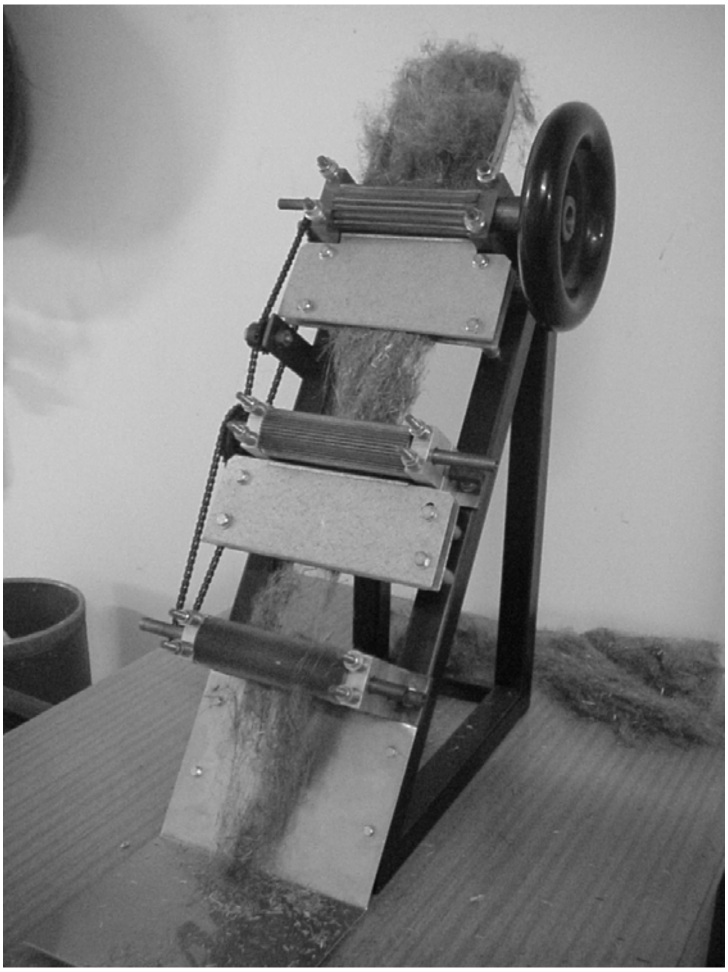


Fig. 4. Hand-driven crushing rig.

Trials with the initial version of this rig showed that a significant amount of hurd, 10% by weight of the input material, dropped out in the process and simple hand drafting removed a further 14% of the original weight. The resultant material was then fed to an intersecting gill used in worsted processing and 5% by weight of the input material fell out but this was judged as insufficient for achieving the desired levels of cleanness. The conclusion was reached that a carding operation was necessary to remove the more than one-third by weight of contaminants and probably needed to be preceded by a fine crushing operation.

The initial version of the crushing rig was horizontal and had the roller pairs close together. In order to allow drafting of the material between rollers, which aligns the hurd perpendicular to the crushing action and helps separation of the fibre from the hurd, the rollers were spaced at a distance longer than most of the fibres. If the spacing is shorter the gripping of fibres by two pairs of rollers prevents a speed differential. It was also observed that the width of each flute should not be so narrow as to trap pieces of hurd aligned along the flute.

Mechanical processing of the stalks (without crushing) was attempted on a miniature woollen card (single swift). The fibre web did not transfer cleanly to the felt doffing cylinder on the first pass but an acceptable batt was prepared on the second pass. The output was judged to be of similar cleanliness to ginned cotton. The yield was only 35% with some 17% unaccounted for (probably embedded in the card and much of it hurd). There was also an additional 12% of soft waste which might be recovered by a re-cycling step. The observation was made that fillet wiring was particularly likely to trap all but the shortest or thinnest pieces of stalk. Processing of a larger sample on the mini-woollen card led to clogging, which means that a better breaking and pre-removal of hurd is required and/or a card without flexible (fillet) wiring. An attempt to card wet was unsuccessful.

The average fibre length of the twice carded and chemically treated fibre was about 8mm with some long fibres and a large amount of short fibre. A non-carded hand-prepared sample was given the same chemical treatment. The treatment was the best that had been found to that stage and consisted of an initial enzyme treatment, followed by caustic with some mechanical agitation and then a bleaching and softener. The second sample had a number of long fibre strands and so a sample was wet combed, to minimise breakage and maximise fibre individualisation, to allow better estimation of the underlying fibre length. The estimated mean fibre length was only a little longer than the first sample but there was a much smaller short fibre content. The implication was that the dry carding, before chemical treatment, gave rise to a considerable amount of breakage and hence short fibre. The underlying fibre length appeared borderline for spinning except in blends with longer fibres. The two samples of processed fibre were shown to a commercial cotton spinning mill. The first was assessed as too short and the second as “nearly spinnable” but with some fibres that were too long. A sample of several hundred gm of flax was prepared using 2 passes through the hand-driven crushing rig followed by hand-drafting to remove more of the hurd. This became the standard material for further chemical tests.

Mechanical action during wet treatment was achieved first by using ball-bearings in shaken flasks and later using tumbling drums. This is discussed further in the section on combined chemical and mechanical separation. A cotton sample card was used to examine the opening and individualisation of treated samples. It was judged that, like the Shirley analyser, the lack of opening stages meant that this card was not very suited to processing fibre that was entangled or not well individualised.

Trials on a small Tatham worsted card, using crushed decorticated fibre, showed it remarkably effective at removing hurd. A schematic of the card is shown in Appendix 1. It is primarily clothed in metallic rather than fillet wire which slows the rate of clogging of the wire with hurd. It was also observed that the hurd was thrown out at the transfer points (labelled). Decorticated and crushed, but not chemically treated, stalks gave a clean fibrous web after two passes on the card. The measured efficiencies (weight in divided by weight out as a percentage) were 88% in crushing, 61% on the first carding and 88% on the second carding. The overall efficiency was therefore 47% with scope to increase this by no more than about 10% by re-cycling the fibre-rich fly lost at such points as between swift and doffer. The residual contamination level was measured by hand extracting all non-fibrous components from the twice carded web. The amount remaining by weight was 2% with a significant component of this being non-hurd fibrous-like stalk segments. The web did not have sufficient strength for easy further processing. It would draft apart under its own weight when lifted out of a can. It is likely that a false-twist take-off for the web would provide some compaction and cohesion but a suitable unit was not available. The rubbing system of a roving frame was tried but was not effective. However, it was demonstrated that good cohesion of the sliver could be obtained by using the crimper box of a Schlumberger PB30 rectilinear worsted comb.

Prior to the experiments to improve cohesion, single carded web was gilled three times into a sliver of 6.3 ktex. The process was labour intensive because of the difficulty of handling and feeding the weak slivers. The sliver was then fed to a Schlafhorst Autocoro fitted with 46mm T-246 rotors, spinning at 70,000 rpm and with an opening roller speed of 7000 rpm. The opening roller provided considerable opening of the fibres and appeared to throw out most of the remaining hurd, however, a yarn could not be spun. The reason appeared to be a combination of excessive fibre length and excessive stiffness.

All the above processing trials were performed on samples from the original bag of medium processed Arika. Samples of several other varieties were prepared for measurement of diameter and length. These included a more recently processed bale of Arika, some Argyle with very little retting and some markedly over-retted Balinka. Similar quantities of each were given two passes through the crushing rig and hand drafted to further remove hurd. The resultant output of cleaner fibre was

75%, 56% and 35% by weight of the input material. The hardly retted Argyle had a low yield because the original decortication process had left more hurd and because the hurd and bast fibre were still strongly attached so that good fibre was removed with the hurd. The Balinka had a very low yield because it had had very little processing and was so heavily retted that much short fibre fell out.

4.3 Chemical processing

A wide range of preliminary trials were made in search of good conditions for fibre individualisation. These trials were carried out on field retted and decorticated stalks supplied by TFCA. The variety was Arika and the fibre was crushed and hand drafted to remove the larger pieces of stalk and hurd. The chemical treatments were made in either a closed Ahiba sample dyeing unit at temperatures up to 95°C or in flasks above a hot water bath at temperatures to 50°C. Treatments were assessed visually and tactilely and subsequently by Laserscan diameter measurement. Most treatments allowed the ultimate fibres to be teased out by hand while the fibre was wet but in all cases the fibres re-attached firmly on drying. Such re-glueing was judged to be certain to lead to unacceptable breakage and insufficient individualisation in further processing. Rinses with various softeners and other surface active agents were tried but, although they softened the dried fibre mass, they did not appear to allow additional fibre separation. Most treatments left the hurd sufficiently stiff to be easily removed by a further mechanical step. All the initial treatments left long (over 60mm) fibre strands which would not have allowed processing on the cotton system.

It was found that mechanical agitation was needed and could be achieved using ball-bearings in the bottom of the flasks as they were oscillated. However, the treatment was very dependent on the liquor level. Low liquor levels meant that the fibre samples rolled into a ball and were no longer acted upon, and high levels meant that the sample floated above the balls.

The best treatment, referred to as the standard treatment in Table 1, was 70g/l NaOH with 20g/l SDS at 50°C for 20 hours in a flask with ball bearings, followed by a neutral rinse, then a rinse with 1% silicone softener. This was significantly better than the same treatment without balls, which had a coarser diameter, wider distribution and larger coarse fibre content. Both were much better than treatment in hot water alone. The curvature values have been shown in the tables although at this stage it is not understood why they appear to vary.

Table 1. Laserscan results for some initial treatments.

Trial	D µm	CV(D)%	>30.5µm	Curv.	Treatment
32	16.0	54.1	5.5	95	standard
46	17.1	63.2	8.9	105	standard but no balls
45	22.5	71.1	23.2	92	standard but no chemicals or balls

New samples of fibre were subject to further treatments. The results, Table 2, cannot be directly compared with the results in Table 1 because they did not come from exactly the same lot of fibre. What can be observed is that an acetic acid rinse appears to improve separation, that rinsing in a jet of tap water provides improved individualisation, and that a different softener did not make much of a difference to the measured value. The silicone softener gave a softer handle for dried material but it seems that the individualisation in liquid is similar.

Table 2. Laserscan results for variants to standard treatment.

Trial	D µm	CV(D)%	>30.5µm	Curv.	Treatment
53	16.7	60.5	8.8	97	standard + silicone softener

54	16.4	49.4	5.9	97	53 + acid rinse before softener
55	15.7	51.6	4.3	100	54 + hot tap rinse
56	15.6	51.9	5.0	96	54 + cold tap rinse
59	16.4	59.1	7.3	86	54 + Alkamine CA instead of silicone

The measured diameter distribution for trial 56 is shown in Figure 5. The distribution peaks at 12μm and has a long tail of coarse fibres, which are believed to be predominantly unindividualised multiple fibres. The extent of the tail is a good measure of the degree of individualisation.

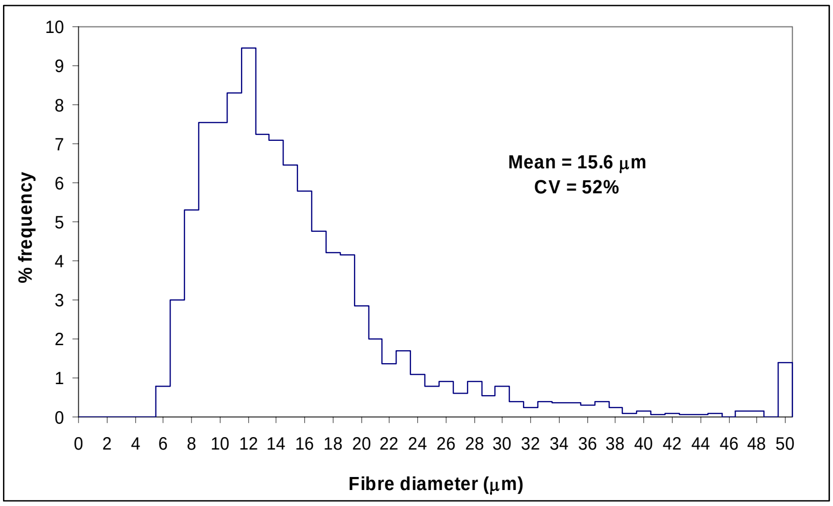


Fig. 5. Laserscan diameter distribution for treated linseed.

Some of the same material was also given a shorter treatment at higher temperature in the Ahiba. The lack of mechanical agitation left many long strands of fibre, so the treated fibre after rinsing was then further treated with ball bearings in the flasks without chemicals as per the standard treatment, followed by a rinse in the softener. The results are shown in Table 3 and indicate that the Ahiba treatment had loosened the fibres enough to give improved individualisation with the mechanical action. Hand drafting of the sample prior to testing only marginally improved the diameter measurement, but jetting with a high pressure hot water jet produced further individualisation.

Unfortunately, a practical method of high-pressure jetting in which the fibre could be restrained and not lost through a mesh or in the water flow was not found.

Table 3. Laserscan results for Ahiba

Trial	D μm	CV(D)%	>30.5μm	Curv.	Treatment
64	16.1	59.5	7.0	91	Ahiba (95 deg. C, 1 hr) then balls
64	16.0	53.8	5.9	93	extensively hand drafted
64	15.6	54.5	5.4	97	jetted + extensively hand drafted

Three commercial enzymes, Ultrazyme, Pectinex and Energex, were tested at pH values from 4.5 to 5.5 for time intervals up to 8 hours at 50°C, either before or after the standard NaOH treatment. Treatment with the enzyme prior to NaOH appeared to offer a marginal improvement in colour and separation, with the Ultrazyme treated samples feeling slightly softer. However, the improvement was considered to be too small to be of interest.

4.4 Combined chemical and mechanical separation

In order to achieve higher levels of mechanical agitation a set of Werner Mathis tumbling drums were obtained. The unit is shown in Figure 6. Each of the four cylindrical drums has three ridges, one with a pair of rods, to lift the material out of the liquor as the drums are rotated. The drums can be heated via a hot air system and the speed of rotation and on/off cycles can be arbitrarily adjusted.

The initial treatment tried was the standard recipe with 20g/l of SDS. At the speed used this gave rise to excessive foaming and subsequently the level of surfactant was reduced to 2g/l. Ball bearings were added but the mechanical action was excessive to the extent of pulverising the fibres. The initial treatment for only 2 hours at 50°C followed by some additional shaking without chemicals was quite effective, as shown in Table 4, and could be further improved by jetting.

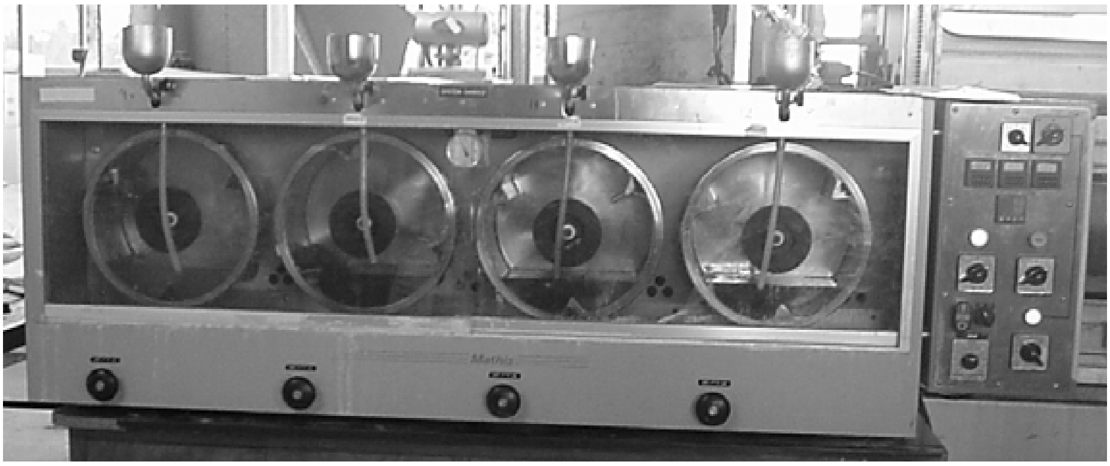


Fig. 6. Werner Mathis tumbling drums

Table 4. Laserscan results for initial treatment in tumbling drums.

Trial	D µm	CV(D)%	>30.5µm	Curv.	Treatment
66	17.0	54.0	7.2	90	tumbled (no balls) 2 hrs, then balls
66	16.7	55.7	7.2	91	extensively hand drafted
66	16.2	52.5	5.8	90	jetted + extensively hand drafted

Tumbling for 5 hours at 50°C and moderate speed (settings 3 and 1) with 70g/l NaOH and 2g/l SDS, followed by a rinse, 2% acetic acid tumbled for 5 mins and then softener for 10 mins became the new standard treatment and a mean fibre diameter of 16.0µm, CV(D)=61.3% was achieved. A pre-rinse for two hours in detergent gave no clear advantage and using CTAB instead of SDS gave inferior results. The silicone softener CF1122 was clearly superior to SA4118 and CFE1340. An attempt was made to scale up to larger (40 litre) drums and a 20 hour treatment was tried at four different speeds. The fibres were well individualised but became matted.

A sample of crushed and hand drafted but not carded Arika was given the new standard treatment and then carded on a cotton sample card. The waste blown out from the main cylinder had a measured fibre diameter of 13.9µm and CV(D)=47.5%, the output fibre measured 16.3µm and CV(D)=54.0%. This indicated that the more highly individualised and therefore shorter fibre was going to be difficult to keep on a cotton card. Much of the hurd appeared in the output but the sample card has stationary flats and only one fibre transfer point so could not be expected to provide good contaminant removal.

Bleaching with hydrogen peroxide at three levels (20, 30 & 40 g/l of 50% H_2O_2) together with 70g/l NaOH and SDS was tested in flasks (shaken) for 5 hrs at 50°C and in the Ahiba for 5 hrs at 50°C, 3 hrs at 70°C, and 1 hr at 90°C. The shaken treatment gave good whiteness and fibre separation, the Ahiba treatment still left longer strands of multiple fibres. A significant drop in strength was observed as the treatment level increased.

4.5 Fineness, length & strength

In order to obtain a measure of the finest achievable fibre diameter the standard treatment in combination with 40g/l of 50% H_2O_2 was used at a higher tumbling speed (settings 3 and 3). The treatment greatly weakened the fibres but still allowed a diameter measurement. The results are shown in Table. 5. The samples tested were the original sample of Arika after crushing and two carding passages on the Tatham card. Three new decorticated samples of linseed: Balinka, a taller variety but the sample had been highly retted, a new sample of Arika that had been baled, Argyle but the sample had been hardly retted, and another sample of Arika with coarse stems that had not been decorticated. A sample of decorticated Linola (a modified variety of linseed for the production of edible oils) was also included. All five new samples were crushed in the hand-driven rig and then hand-drafted to reduce the amount of hurd. In addition, a sample of fine long-line flax from a set of International Fineness Standards (IFS) and a commercially obtained sample of long-line hemp from China were also tested. The final two results shown are for the twice-carded Arika with a shortened treatment described below.

Table 5. Laserscan measured fibre diameter for over-treated samples.

Sample	Diameter μm	CV(D)%	Curv. °/mm
Arika – 2x carded	15.3	39.6	107
Balinka – high ret	17.5	43.7	90
Arika – baled	15.4	42.7	102
Argyle – low ret	16.3	45.4	91
Arika – coarse stems	14.5	44.6	94
Hemp – long-line	21.2	50.0	102
Flax – long-line (IFS:21.7)	14.3	35.7	80
Linola	15.0	45.2	96
Arika – sliver, baked after 100% pick-up	17.0	60.6	82
Arika – sliver, baked after 200% pick-up	15.9	52.2	88

The first surprising discovery was that there are varieties of flax available which are similar in fineness to linseed. This long-line flax sample also had the lowest CV(D) which indicates that the long-line processing route has helped break down the coarsest bundles. The lower CV(D) of this and the twice carded Arika may also reflect freedom from some of the finer hurd which could get counted as coarse fibres. The Linola appears similar to the Arika. The Argyle may have appeared coarser because the low retting meant it was less individualised by the chemical treatment. The Balinka appears to be a coarser variety but not as coarse as the hemp. It should be noted that the flax sampled tested here was from the finest of the IFS samples and other flax samples may be coarser.

The mean length of the ultimate fibres of the long-line flax was visually assessed by wet drafting the treated sample. The length appeared to be only about 15mm. The fibre ends were examined under a microscope for both samples and almost all the flax fibres had tapered ends whereas a significant percentage of the linseed fibres appeared to have been broken.

Samples of twice carded Arika had been successfully processed into a sliver (see earlier). It was then desirable to establish if this sliver could be treated without disruption. To be practical in a commercial environment the treatment also needed to be rapid. The method tested was to pad the sliver with 70g/l NaOH, 20 g/l of 50% H_2O_2 and 2g/l SDS at various pick-ups using a pad mangle and then to oven dry the material. The drying concentrates the liquor taken up and leads to more rapid chemical action.

The sliver was then rinsed by hand in water, acetic acid and softener before being allowed to dry under ambient conditions. The integrity of the sliver was maintained but the whiteness and fibre individualisation (see Table 5), which varied with the level of pick-up, were not quite as good as the tumbling treatments. The small sections of sliver were judged to be feasible for processing on a cotton draw frame except that the level of fibre damage was too high. A 250g quantity of uncarded

Arika was also treated. The conditioned weight after treatment but before softener was added was 178g, a yield of 71%. The method looked promising except for the fibre damage and that the remaining hurd may have been excessively softened leading to a lower removal efficiency.

In order to obtain measurements of the best achievable fibre strength and length, additional trials were undertaken without the hydrogen peroxide. Samples of fibre were padded with 70g/l NaOH and 2g/l SDS at 200% pick-up then oven-dried at 80°C. The material was then rinsed and tumbled at higher speed (settings 3 and 3) at 50°C for one hour in water with softener before drying under ambient conditions. Samples tested were twice carded Arika (SA1), long-line flax [IFS: 28.7] (SA2) and long-line hemp. Fibre individualisation was moderate and the long-line flax and hemp could be hand-drafted into material with mean fibre lengths of about 50 and 70mm respectively. The treated Arika sample was then given a single pass through the Shirley analyser which threw out 60% , apparently because the material was still clumpy. The fibre diameter before treatment and of both components after this operation were measured (Table 6).

The sodium hydroxide treatment is expected to break down the lignins but not to significantly damage the cellulose of the fibres. However, a further bleaching and cleaning step is required if the fibre is to be suitable for a higher value application. In order to minimise fibre damage a milder peroxide treatment was carried out at a lower pH and moderate temperature in a second treatment, and using a fibre protective agent (sodium silicate). Thus, further samples of fibre were padded with 70g/l NaOH and 2g/l SDS at 200% pick-up then oven-dried at 80°C. The material was then rinsed and tumbled at 50°C for one hour in water with 2g/l NaOH, 5g/l H_2O_2 and 1% sodium silicate, then rinsed in acetic acid before drying under ambient conditions. All lots re-glued on drying and would have been difficult to open without significant breakage. The lots were rinsed for 1 minute in water and softener before being allowed to dry under ambient conditions. The resultant material was easily opened by hand. Length profiles were obtained using a cotton comb sorter for all three samples. The material tested was twice carded Arika (SB1), hand-crushed and drafted Arika from the baled lot (SB2), and heavily retted Balinka (SB3).

Table 6. Diameter measurements of twice carded Arika made on the Laserscan.

Sample	D μm	CV(D)%	Curv. °/mm
SA1	16.9	61.5	94
SA1 – hand drafted	16.6	58.4	91
SA1 – Shirley analysed	15.4	51.9	100
SA1 – waste Shirley analysed	16.1	52.8	103
SB1	15.9	52.2	92
SB1 – using OFDA spreader	15.9	47.2	104

The bleaching operation further improved fibre individualisation although not as much as the violent opening of the Shirley analyser. More than half the input fibre was rejected (waste) by the Shirley analyser but the reduced fibre diameter was not because the rejected fibre was coarser than the input material. Surprisingly, the mechanical action of the OFDA spreader, that spreads guillotined fibre snippets on a glass slide for measurement, did not give a reduction in mean fibre diameter measured on the Laserscan. The lots SB1, 2 & 3 were all very white and satisfactory bleaching could probably be obtained with a shorter time or lower concentrations. The remaining hurd showed up clearly because it turned yellow in the bleaching. Some of the pieces of hurd were quite long and thin but an appropriately designed carding arrangement (with transfer points where the hurd does not fall back into the fibre mass) should be highly effective at removing the remaining hurd. The difficulty would be in retaining the short fibre.

The three samples (SB1, SB2 and SB3) were measured for length by hand preparation of fibre beards using a cotton comb sorter. Photographs of the fibre arrays are shown in Figures 7,8 & 9. The length characteristics of these staple fibre diagrams are given in Table 7. Some of the longest fibres are still not fully individualised but none were too long for the cotton system. The disappointing result was that the taller variety, Balinka, did not give a longer mean length. Although this might be due to the heavy retting. The carding operation seems to have reduced the number of long fibres but not had a big effect on the mean length.

Table 7. Length properties of treated linseed.

Sample	Effective length mm	% less than 10mm	Mean length mm
SB1 – Arika 2 x carded	13.5	62	9
SB2 – Arika baled	19	65	10
SB3 – Balinka	14.5	73	9

The bundle tenacity of various samples was made using the Sirolan Tensor. A gauge length of 0.5mm was chosen because of the very short fibre lengths of some samples. Most bundle strength measurements in the literature use the standard gauge length of 3.2mm. This difference should not greatly affect the measured tenacities except for very short fibres. The fibre arrays were prepared by clamping samples in one jaw and combing the array, then clamping in the other draw and combing out any ungripped fibres. For the treated Arika sample this meant that a significant number of fibres shorter than the full jaw could be present. The results are shown in Table 8. The strength of the fibres from the combined treatment was also determined by comb sorting groups of fibres longer than about 15mm and measuring these on the Tensor. The samples were smaller than normally used and only one or two measurements per sample were made, so the results have to be treated with some caution.

Table 8. Fibre bundle tenacity measure at 0.5mm gauge on Tensor.

Sample	Bundle Tenacity cN/tex
Flax – long-line [IFS:28.7]*	35.7
Flax – long-line, mild treatment (SA2)	16.6
Argyle – low ret, crushed and hand drafted	16.2
Arika – baled, crushed and hand drafted	18.3
Balinka – high ret, crushed and hand drafted	14.4
Arika – 2x carded	16.3
Arika – 2x carded, mild treatment (SA1)	8.1
Arika – 2x carded, full treatment (SB1)	9.9
Arika – baled, full treatment (SB2)	16.6
Balinka – high ret, full treatment (SB3)	15.2

* some slippage of fibres through the jaws occurred

Others (Czekalski 2000) have also observed a drop in tenacity (from 35.7 down to 12 to 20 cN/tex) as the average linear density of fibres (bundles) is reduced. The hypothesised explanation for the apparent drop in strength is the increased fibre individualisation. Tenacity is a measure of the peak force to break and when multiple fibres are glued strongly together they uniformly share the load and must all break together. When fibres are individualised they can be broken sequentially and the peak load is correspondingly reduced. This is particularly likely to occur with brittle fibres, that is fibres with low elongation at break. If there are slightly different lengths of fibres being gripped between the jaws then some fibres can be fully loaded before others have started to bear the load.

The lower tenacity of the twice carded and treated Arika is not understood but may be because the preliminary carding has weakened the longer fibres or allowed a more complete individualisation by the chemical treatment, or the fibres were less straight (more curved or angled). The similar results for both the baled Arika and the Balinka before and after the full chemical treatment strongly suggest that the chemical treatment has not significantly damaged the fibres.

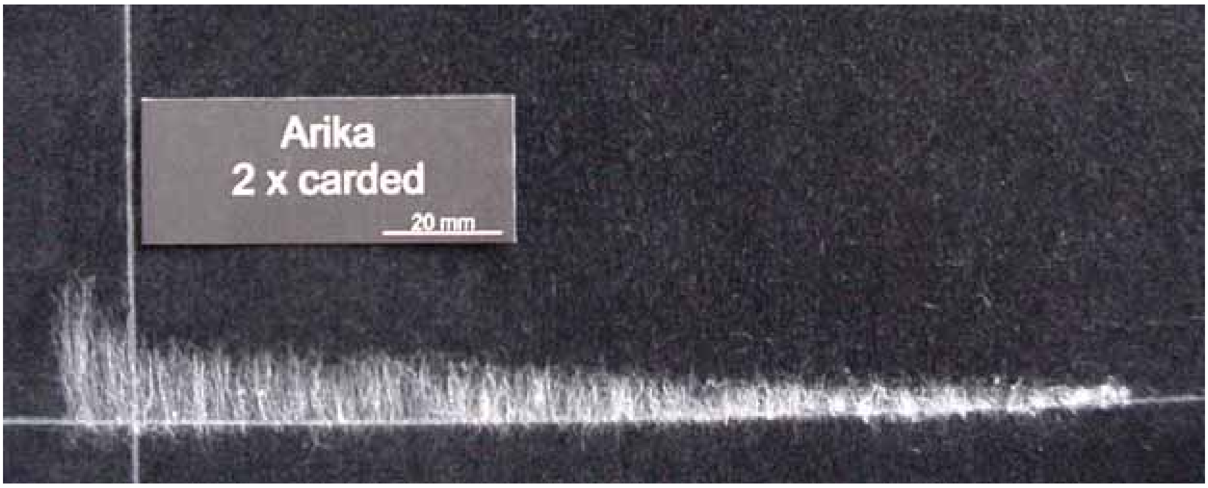


Fig. 7. Fibre array for twice carded Arika

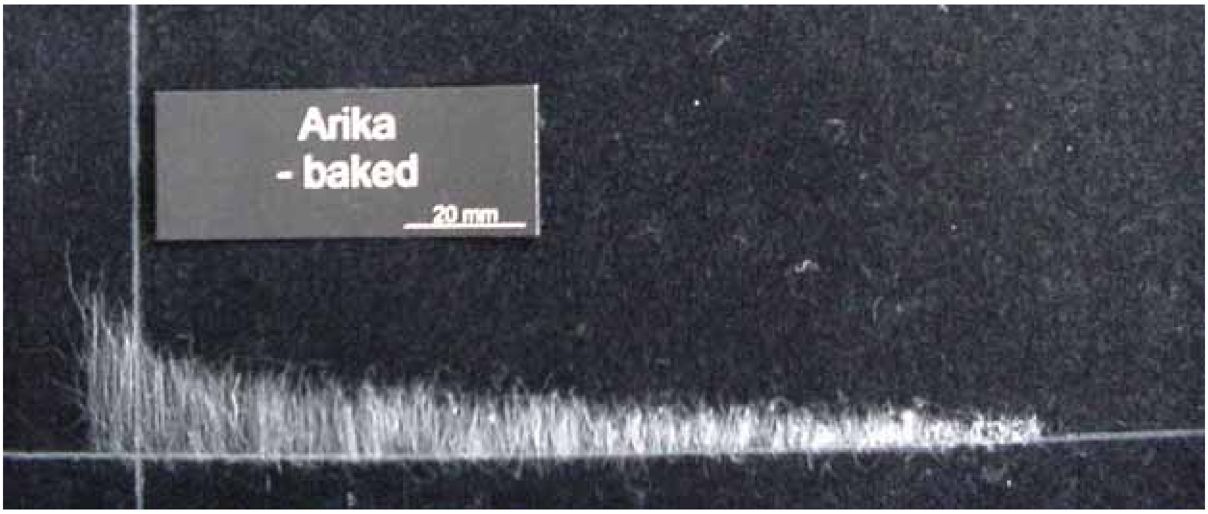


Fig. 8. Fibre array for baled Arika (all samples had baking treatment).

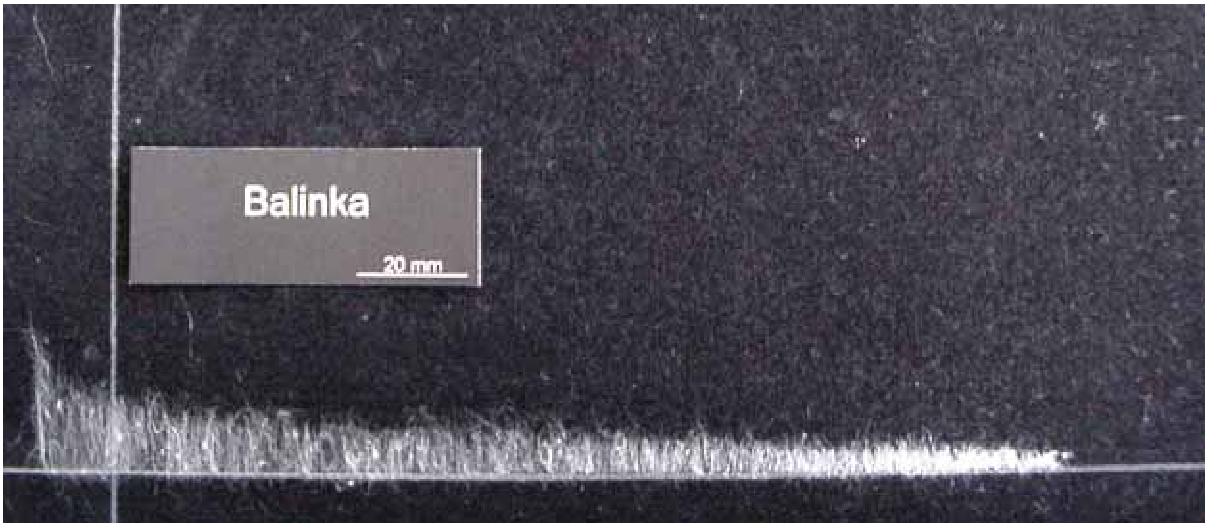


Fig. 9. Fibre array for taller variety Balinka.

5. Discussion

In order for linseed stalks to be used in a high-value product via cotton spinning machinery the two key requirements are removal of contaminants and preparation into a fibre of suitable length and fineness. The experimental studies have shown that a worsted card clothed with metallic wire can give good removal of hurd from moderately retted and decorticated linseed stalks. The level of fibre breakage appears acceptable. It would be expected that the card wire will gradually clog with hurd but this can be minimised if the hurd is broken into as short lengths as possible prior to carding. Gradual opening with multiple transfer points is needed for high yields and effective removal of contaminants and also to minimise breakage which will give rise to excessive short fibre when chemical fibre separation occurs.

Existing routes for utilising long-line flax on the cotton system all appear to involve cutting the fibres to an appropriate maximum length. This is not feasible unless the fibres are aligned approximately perpendicular to the cutter and so cannot be easily applied to the linseed until after a sliver is formed. The strategy adopted was to seek to minimise the possibility of long fibres by breaking the bast down into its ultimate fibres using chemical treatments. The combined bleaching (H_2O_2) and de-gumming (NaOH) treatment, without a stabiliser and at high concentrations, but at moderate temperature (50^0C) with tumbling for 5 hours, gave very good individualisation but excessive damage. In the search for a more rapid treatment, baking, at 80 ^{0}C and 100% to 200% pick-up of a scouring (70g/l NaOH plus surfactant) liquor followed by rinsing was found to be reasonably effective at fibre individualisation, but better if followed by a bleaching step and tumbling wet, and application of a softener was still essential.

Bleaching (H_2O_2) at high pH caused marked fibre damage but it appeared that very little fibre damage occurred if the bleaching was at 50°C for one hour in water with 2g/l NaOH, 5g/l H_2O_2 and 1% sodium silicate. The literature states (Hickman 1999) that organic or non-silicate stabilizers are preferred as calcium ions from the fibre or the water supplies cause precipitation of silicates and these deposits can be filtered onto the fibre mass. Similar treatments without mechanical agitation (the tumbling) leave many long (multiple) fibres. This was initially seen as a disadvantage because there was less fibre individualisation. However, maintaining a longer fibre length might allow processing on cotton carding and drawing machinery and the cotton ring spinning system and, if having any fibres longer than about 50 mm could be avoided, it might allow spinning on the rotor system. However, the fibres could be expected to further individualise and the yarns disintegrate during washing of the resultant fabrics. This can only be avoided if the short fibres can be bound with twist, by the longer fibres, into the yarn. It is therefore concluded that linseed fibre, of the varieties examined, is only suitable for use in yarns if blended with a longer component such as good length cotton or synthetic fibre.

Cotton opening, cleaning and carding machinery is generally designed to remove short, thick contaminants and is known to be poor at removing lighter components such as seed coat fragments or more fibrous contaminants. It therefore appears essential that the bulk of contaminant removal must occur before input to the cotton system. Long-line flax is relatively free of contaminants but decorticated linseed stalks have high contaminant levels and these need to be greatly reduced before input to the cotton system. Fibre individualisation and uniformity will also aid in the speed and evenness of the needed chemical treatment. A hurd breaking step and specialised carding is therefore recommended as the first stage after decortication.

There appear to be two options after a specialised cleaning/opening carding. The first is to prepare the fibre as loose stock for input and blending in a cotton blow-room prior to cotton carding. The second is to form a sliver during the cleaning/opening carding, treat the sliver, and then blend on the cotton drawframe. The second method avoids the need for special opening equipment for the loose stock after chemical treatment and the potential loss of fibre in cotton carding. The trials carried out indicated that chemical treatment and rinsing of a sliver could be carried out without excessive disruption of the sliver. A disadvantage of the second method is that any remaining contaminants must be effectively removed in the opening of rotor spinning or thrown out during ring spinning.

The chemical treatments for both options could be carried out in batch form using pressure vessels such as those used for yarn dyeing. It may be possible to achieve adequate treatment in a single stage operation but a two stage operation with scouring followed by bleaching seems preferable. It has been shown that a pad and bake step followed by a rinse can be used on a sliver or loose stock but it has not been established whether a satisfactory bleaching can be carried out in a baking operation without excessive fibre damage. For all treatments investigated a softener was essential to prevent re-glueing of fibres during drying. The sliver pad/bake system is attractive in terms of a continuous system that could be implemented on a modest scale. The baking step is also attractive from an occupational health and safety viewpoint as it avoids the need for open liquor baths at high temperature and pH.

The sliver system requires that the output of the card be able to be turned into a continuous sliver of adequate strength. A practical system in a mill would require the development of a suitable unit at the end of the card. It is likely that this could be achieved by a false-twist device feeding a crimper-box arrangement. Such a sliver could be given one or two gilling operations to better align the fibres and make for a constant weight sliver for the later drawframe passages. In fact, gilling is likely to be essential for producing a sliver of adequate quality. Alignment of the fibres and removal of hooked fibres would also make a “stretch-breaking” operation during wet processing feasible. The ultimate fibres draft easily when wet, after the scouring treatment, and a suitable drafting zone should ensure that there are no fibres longer than allowed by the zone, and so avoid any over-long fibres during dry spinning, without a cutting operation.

There may be longer fine varieties of linseed but the mean fibre length of well-individualised samples of the seed varieties of flax examined were found to be of the order of 8 to 10mm. This means that they are comparable in length to cotton linters (waste). The price of cotton is normally between AUS$2 and $2.50/kg and cotton linters about $1/kg. The price of the flax fibre after decortication to the levels examined is estimated by TFCA to be upward of $1/kg. However, the trials undertaken suggest that only 50% by weight will be available as good fibre after mechanical processing and only 70% to 80% of this will be left after chemical treatment. The treatment involves at least one drying step plus labour and capital so it appears that processed fibre has to cost upward of $3/kg and probably significantly more, unless much cleaner fibre can be produced at modest cost.

The decorticated linseed fibre after two worsted carding passages had a mean fibre length of about 50mm. This means that it could be processed on worsted or semi-worsted machinery used in wool processing. Such machinery, modified slightly for flax, is already available commercially for processing either cut long-line fibre or waste tow from the long-line system However, the flax is normally longer and cleaner and the machinery might need some modification to give sufficient sliver cohesion. Existing manufacturers who use this machinery could be contacted but all are overseas and utilise a lower value or waste stream from a heavily subsidised raw material, so the linseed is likely to be too expensive.

It is difficult to make a high value product from the linseed stalks because softness and fine yarns require very good individualisation. Good individualisation necessarily means shorter fibres and thus lower yarn strength and higher fibre losses. The lower strength means that the fibres are less suitable for high strength, wear-resistant products such as canvas and upholstery. The trapping of the short fibres also requires high twist which will make any fabrics stiffer and more expensive to produce.

The more promising products for an upgraded fibre appear to in some cosmetic or medical products if highly cleaned and bleached, or as re-inforcing in a composite such as an alternative to cotton tyre cord. Kuchova et. al. 2002 claimed improved properties of modified cottonised flax over blends of rayon and polyester in non-woven medical applications. Hickman 1999 outlined a processing route for bleached cellulose. The major issue in using linseed stalks in cosmetic and medical products would be the need for near complete removal or chemical breakdown of the hurd. It has been observed that the strength of hemp composites improved with fibre individualisation (Müssig 2002).

Hence, the aim of this project to convert waste stalks from linseed production into a high value fibre suitable for processing on the cotton system, and to demonstrate that there was potential demand for fabrics made from the fibre, did not succeed. All samples of linseed were found to give fibre inherently too short for easy use on the cotton system. The principles of potential processing routes were established, the best reported division of bast fibre into its ultimate components was achieved, and a novel method of rapid treatment was demonstrated. It appeared that fully processed fibre could be used in blends but the cost and likely attributes were not considered very promising. All the seed cultivars appeared similar in length properties though with some variation in fineness. The main impact of the production conditions was the degree of retting which had a large detrimental impact on yield and contaminant level if either insufficient or excessive.

6. Implications

The research has shown that retted and decorticated linseed stalks can be processed into a fibre of surprising fineness and with little loss in strength per fibre. However, high quality and price from spinning of fine yarns requires good individualisation which, for the linseed examined, necessarily meant short fibres. High price applications also require fibre free from contaminants. It appears that this can be achieved with appropriate machinery but is a disadvantage relative to conventional long-line flax. It is judged that the fibre is potentially more suited for non-woven applications or for use as re-inforcing in composites where its fineness is a potential advantage.

The new processing route is potentially more applicable to the tall varieties of flax and hemp. It appeared to work on samples of long-line flax and hemp, although the hemp was either coarser or less easily divided. One fine sample of flax examined appeared to have ultimate fibres as fine as the best linseed varieties and was individualised more finely than any bast fibre reported in the literature. There is a commercial process (Flasin) available in Europe for producing cotton-like fibre from flax but few details have been obtained.

The growing of flax and hemp is heavily subsidised in Europe and scutched fibre could probably be imported into Australia more cheaply than it could be produced locally. Therefore, development of a processing route for such fibre will not readily benefit Australian growers, but a niche processor might gain some advantage.

7. Recommendations

Further work on processing linseed for input to the cotton system should await the demonstration of varieties with longer fine fibre or the specification of a blend product where the fibre had particular advantages, for example absorbency, and where the short fibres could be adequately secured.

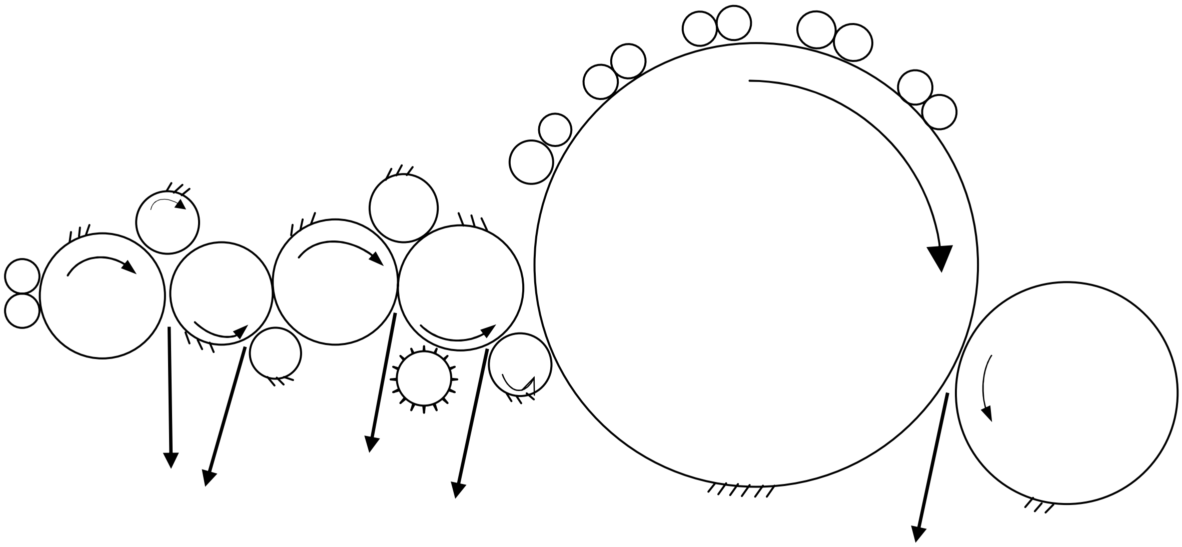
Sample quantities of individualised and/or bleached fibre should be made available to TFCA for discussions with customers who might use the fibre in composites or medical products.

8. Appendix 1.

Tatham Card

Card Property/Setting	Diameter mm	Speed m/min
Lickerin	230	8.7
Lickerin Worker 1	165	8.5
Transfer 1	200	18.2
Lickerin Worker 2	175	7.9
Transfer 2	315	36.6
Lickerin Worker 3	175	10.4
Morel	305	71.7
Morel Burr Beater	175	9.9
Transfer 3	175	10.4
Swift	1290	154
Swift Worker 1	80	6.6
Swift Worker 2	80	6.6
Swift Worker 3	80	6.6
Swift Worker 4	80	6.6
Strippers	80 – 110	39.7 – 57.4
Doffer	650	5-10

Schematic showing direction of wire teeth and direction of rotation of cylinders plus the main transfer points where hurd is ejected.



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