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A REVIEW OF THE EFFECTS OF GINNING PRACTICES ON COTTON FIBRE AND YARN PROPERTIES AND PROCESSING PERFORMANCE

by K W SANDERSON

1. INTRODUCTION

Over the years, since the first formal cotton ginning experiments were conducted by the United States Department of Agriculture in 19261, a large volume of literature, from research papers to popular articles, has been published on the effects of ginning machinery and systems on fibre, yarn and fabric properties, processing efficiency and on bale value and the economics of ginning.

The first breakthrough in ginning technology came much earlier and was, of course, the invention of the mechanical saw gin by Eli Whitney in 17942. Over the years, ginning research has continued intensively, mostly in the United States of America, allowing ginning practices to align with changing requirements and circumstances in both the agricultural and textile sectors of the industry. Significant milestones in the evolution of ginning technology are2-5:

1. The introduction of seed cotton cleaners in the early 1900's to handle increasingly more trashy cotton, brought about by the shortage and cost of labour for hand-picking.
2. The introduction of seed cotton drying facilities in about 1930 to facilitate "smooth" ginning and to improve cleaning and ginning efficiency. Also, seed cotton cleaners were in more general use.
3. The introduction of high capacity gins to cope with shortened harvest periods and rapid mechanical harvesting methods introduced after World War II. There was also the need to improve economics through increased productivity.
4. The introduction of lint cleaners, necessitated initially by the need to remove finer particles from the trashy machine-picked, and some hand-picked, cottons after ginning. They were generally accepted after World War II.

Later, it became necessary to ensure clean, dust-free cottons for modern spinning methods (e.g. rotor machines) and to help meet air pollution restrictions and regulations.

On-going research will ensure that ginning technology continues to be dynamic in meeting the industry's requirements. It was forecast6 that, in some 20 years time, not only would the quality of cotton in the bale have improved but
also that the uniformity of quality within and between bales would be greater than at present and that ginning would be undertaken precisely to specifications set by the purchaser.

In the USA, the three "quality" factors, staple, grade and micronaire are used in the marketplace to determine financial return\(^7\). In addition, ginning out-turn, or the amount of saleable lint produced per unit mass of seed cotton, also affects ginners' returns. Lint grade, determined by colour, trash content and preparation, has always been an important aspect of ginning economics because the pricing structure has rewarded the ginner for producing high-grade lint, with only secondary regard for fibre quality properties such as strength, short fibre content and nepping potential. Maximum bale value, and therefore financial return, has been achieved by balancing lint turnout (ginning out-turn) with lint grade, the former being reduced and the latter increased with additional cleaning processes in the gin. In times when cotton was in good supply and premiums larger\(^8\), the ginner would attempt to improve grade further with yet more cleaning stages. However, this would be accompanied by a loss of fibre quality.

In South Africa, cotton lint is marketed by different criteria to those in the USA, in that price is determined firstly by fibre quality — class — for which minimum fibre length, strength and micronaire levels are specified\(^9\), and then by lint grade, for which there are standards of colour, trash and preparation. This difference affects the commercial importance of, and therefore the outlook towards, lint grade and fibre quality and should be borne in mind during the interpretation of research results.

The conflict between lint grade and fibre quality has been accentuated as ginning technology has advanced with the introduction of drying, expansion of cleaning facilities and higher-capacity machinery\(^5,10\), and this has caused processing difficulties in the mill\(^11\). This conflict, the changes made in crop production practices and the dynamic nature of textile technology have maintained ginning research input at a high level, striving to ensure maximum preservation of inherent fibre quality\(^12\) for the textile industry and, at the same time, meeting the financial requirements of producer and ginner.

This report reviews a cross-section of the large volume of published literature on the effects of ginning, various integral parts of the ginning system and ginning practices on subsequent cotton fibre properties, processing performance and yarn properties. In view of the important inter-relationships between the agricultural and ginning phases of the industry, reference is first made to some agricultural considerations.

2. AGRICULTURAL CONSIDERATIONS

The closely integrated nature of the cotton production and textile industry and the interdependence of each phase of the industry on the others are
well known. Ginning converts cotton from an agricultural crop to an industrial commodity and in order to keep the effects of ginning on fibre quality in perspective, it is necessary to indicate what may have already happened to the fibre in the agricultural phase and why different cottons require different ginning routines.

The largest source of variation of cotton fibre properties is undoubtedly genetic, but, by and large, the cotton belts of the world grow only those cultivars or types which are generally suited to the climatic, biological and agro-economic conditions of each region. Such conditions determine quality over a broad spectrum and in a region such as Southern Africa, a diversity of qualities is found. These are within the species Gossypium hirsutum, commonly referred to as American Upland types, which are of medium length and fineness and which make up the majority of the world's cotton crop. In South Africa alone, there are currently 19 registered commercial cultivars each with its own specific fibre and morphological characteristics.

Variations in cotton fibre properties also occur naturally on the plant, for example, fibre length, fineness and secondary wall thickening (maturity) all vary with position on the seed, between seeds, between bolls and between plants. Grown under similar conditions, however, plants of the same variety will produce fibre of the same average characteristics.

In the field during plant growth, environmental factors can affect fibre properties directly and of these, temperature stress is foremost. Night temperatures below 22°C decrease the rate of fibre elongation and those below 18°C result in shorter fibres. Lower temperatures may also interrupt secondary wall development, resulting in weaker fibres. Water stress slows down growth of the entire plant and consequently the rate of fibre elongation. Shorter fibres result from less available soil moisture and drought conditions although less severe moisture deficits cause premature boll opening and thus reduced secondary wall deposition. Staple length can be reduced by as much as 3 mm by water stress occurring during the 16 days after flowering. Given a variety of cotton planted in a certain type of soil, the variation in fibre properties can be explained to a large extent through the variation in rainfall and temperature.

Growing conditions such as early frost, water stress and disease cause fibre immaturity and the resulting thinner-walled, weaker fibres will be more prone to breakage during mechanical processing, thereby affecting cotton fibre length distribution. In the field, the cotton plant may be attacked by pests and diseases, which, if sufficiently severe, will not only reduce yield but also impair fibre quality. Fibre from a weakened plant may be shorter, more irregular in length and weaker. For example, certain wilt diseases and root rots cause plant moisture deficit which induces premature boll opening with decreased secondary wall deposition. In addition to reducing yield potential by increasing boll shedding, low light intensity, such as produced with an overcast...
sky, can also impair fibre development\textsuperscript{24}.

While good agricultural practises can often minimise the effects of naturally occurring problems, such as low rainfall and pest and disease attack\textsuperscript{15}, fibre properties tend not to be generally affected by cropping systems\textsuperscript{25} except in more specific circumstances\textsuperscript{26-\textsuperscript{34}}.

Exposure of lint in the open boll to prevailing weather conditions during the pre-harvest period may adversely affect fibre properties. Prolonged exposure tends to lower fibre strength\textsuperscript{35} and losses of up to 1\% per week of exposure have been reported\textsuperscript{36-\textsuperscript{40}}. Similar reductions in yarn strength have also been recorded\textsuperscript{37}. Fibre length has also been shown to decrease with increased lint exposure\textsuperscript{37,\textsuperscript{38},\textsuperscript{40},\textsuperscript{41}}. Pre-harvest weathering, however, is typically variable in the severity of its effect on fibre and yarn quality parameters\textsuperscript{41,\textsuperscript{42}}. As an example, rainfall and high humidities occurring during exposure were shown to have a greater effect than the duration of the exposure\textsuperscript{35}.

The effects of the various methods of picking, both hand and mechanical, on fibre quality, are well-known\textsuperscript{22,\textsuperscript{43}-\textsuperscript{48}}. Although mechanical picking is justified economically in many circumstances\textsuperscript{49}, reductions in fibre quality and lint grade are inevitable. Direct quality losses are mainly those of reductions in the uniformity of fibre properties due to the non-selective picking of earlier- and later-matured bolls\textsuperscript{13,\textsuperscript{50}}. Grade is reduced both through colour deterioration during weathering and the greatly increased foreign matter content of the harvested seed cotton\textsuperscript{41}. The latter necessitates additional drying and cleaning processes in the gin which contribute further to reductions in fibre quality\textsuperscript{32,\textsuperscript{33}}.

Lint grade, as distinct from fibre quality, is based on colour, foreign matter and lint preparation, although the latter is normally of minor concern\textsuperscript{8}. Colour is strongly influenced by pre-harvest weathering in the field\textsuperscript{7} and is usually correlated with the prevailing weather conditions, especially rainfall, rainfall pattern and length of exposure during the open-boll stage\textsuperscript{43,\textsuperscript{53}}. Fluctuations in atmospheric humidity at harvest-time may also cause grade fluctuations but this is dependent upon plant vegetative conditions, the degree of defoliation and weediness\textsuperscript{54}. Defoliation may improve grade, but this is usually accompanied by reduced yields and increased costs\textsuperscript{55}.

In terms of foreign matter content, final lint grade can be significantly affected in the field by land preparation, plant shape, weed control, efficiency of defoliation and picker operation and management\textsuperscript{50}. It has been stated\textsuperscript{8} that a gin simply cannot make good grades from a poorly harvested cotton.

Basinski et al\textsuperscript{41} stated that "the quality of raw cotton, subsequently reflected in yarn quality and processing efficiency, is determined by the interacting effects of the timing of harvests, ginning methods and environmental (mainly weather) factors".

Griffin\textsuperscript{56}, in the Cotton Ginners Handbook (USDA), summarised the
various factors affecting the quality of lint in the bale and, in so doing, placed the agricultural and ginning phases of the cotton production and processing system in perspective in terms of fibre quality:

"Cotton possesses its highest fibre quality and best potential spinning performance when it is on the stalk. Lint quality of the cotton in the bale coming from the gin press depends on many factors, including (1) variety of cotton, (2) soil and weather conditions, (3) cultural and harvesting practices, (4) moisture and trash content, and (5) ginning treatments and processes. Usually, the first four factors exert greater influence on lint quality than extremes in ginning treatment.

Nevertheless, any mechanical handling, up to and including spinning, may modify the natural qualities or characteristics of cotton. Ginning is a series of thermopneumatic and mechanic processes and, at best, can only preserve qualities and characteristics inherent in the cotton when it enters the ginning plant.

3. SEED COTTON DRYING AND MOISTURE CONTROL

The potential benefits of seed cotton drying equipment in gins were recognised by the USDA as early as 1926 and it was, in fact, this which prompted the U.S. Congress to initiate cotton ginning research in the USA.

It has since been stated and often proved that the two most important factors in ginning for quality are fibre moisture content and lint cleaning. Relatively dry cotton in the gin not only facilitates smooth operation of processing machinery, thereby avoiding "rough" preparation, but it also allows plant and other non-fibre material to be separated more easily from the fibre. Drying and the processing of dry cotton, however, can lead to appreciable fibre weakening, breaking and shortening and a balance must be struck between lint cleanliness (grade) and fibre quality. Very often, the desirable balance may fluctuate, depending upon grade price differentials and mill requirements. The general effects of drying on lint grade and yarn strength and appearance are given in Fig. 1.

The direct effect of heat on cotton fibre and the effect of moisture content on cotton fibre properties have been studied for many years. Mann reported in 1927 that dry cotton fibres exhibited different physical properties to wet ones in that they were stiffer, more brittle and weaker. Davidson et al. in 1930 suggested that heating initially removed hygroscopic moisture and then the cellulose was gradually degraded with the removal of the water more closely bound to the cotton fibre. Haas in 1939 found that prolonged heating, even at low temperatures, caused degradation. Wiegerink in 1940 and Walker et al. in 1948 stated that the rate at which heat degraded the cellulose of cotton fibre was
not appreciable below 100°C but increased rapidly thereafter. Hessler et al \textsuperscript{64} reported that immature fibres degraded at all temperatures whereas mature fibres with well-developed secondary wall thickening, resisted decomposition at low temperatures but were degraded at higher temperatures. Grant et al \textsuperscript{65} examined fibres from length arrays and found a preferential breakage of fine and immature fibres during ginning and cleaning.

Farquhar et al \textsuperscript{66} subjected raw cotton in the laboratory to a temperature range of 50° — 220°C over 4 to 24 hours duration and concluded that heat alone accounted for only part of the degradation of cellulose. Orr et al \textsuperscript{67} subjected cotton fibres and yams to various temperatures between 110° and 162°C, various moisture conditions from 3% RH to saturation and various heating periods lasting 2 to 128 hours. There was a simultaneous reduction in strength and elongation to break, indicating that heat degradation weakened fibres by creating, or intensifying, weak points along the fibre. Yarn strength followed the same pattern, although not to the same extent.

An extension\textsuperscript{68} of this earlier research gave no evidence of any radical permanent change in lint properties by gin heating other than a significant change in fibre length distribution towards the shorter fraction and a small decrease in mean fibre length. Laboratory tests, however, showed that fibre strength was lowest immediately after heating when moisture content was very low; it was deduced that the increase in the proportion of short fibres was the
result of excessive fibre breakage during mechanical processing of the too dry cotton.

The belief had long been held amongst mill operators in the USA\textsuperscript{65,69,70} that gins were drying their cottons to excess thereby producing an inferior quality cotton. It was indicated\textsuperscript{71-74} many years ago that heating and drying cotton at temperatures above about 93°C caused changes in cotton fibre which led to inferior products, processing difficulties and increased production costs.

Hart et al\textsuperscript{69} showed that applications of low heat (80°C for 90 s) and high heat (186°C for 90 s) caused a small loss of staple length, a small increase in grade, no change in micronaire value and no reduction in bundle strength, although single fibre breaking strength and elongation decreased. Increased heat also caused progressively poorer dye acceptance. The differences were largest between no heat (ambient temperature) and low heat.

Lietgeb and Wakeham\textsuperscript{70}, using two levels of drying (1 drier at 235°C and 2 driers at 129°C and 99°C), reported small reductions in fibre length and strength with increased heating and drying. There was evidence of significant fibre surface damage and a greater degree of crystallinity with the heated cottons. The excessively dried cottons contained a greater proportion of short fibres, especially after processing, and this was believed to be the main cause of processing difficulties and reduced yarn quality.

Seed cotton moisture content at ginning, as achieved with various temperature combinations of the three driers used (93°C; 66°C or 93°C; 38°C, 66°C or 93°C)\textsuperscript{75}, significantly affected fibre length (Table 1). Both mean fibre length and upper half mean were reduced with decreasing moisture content. Fibre strength also decreased with moisture content but maturity index, fibre fineness and colour were not affected. In a follow-up study\textsuperscript{76}, commercial ginning practices were compared with experimental ginning practices whereby cottons from the former were consistently dried to lower moisture contents than the latter by using higher drying temperatures. Although grade was not consistently affected, both fibre length (mean and upper half mean) and strength tended to be reduced with lower moisture content. It was concluded that, as the ginner could not accurately determine drying requirements by "feel", instrumentation was required in the gin in order to control temperatures and to avoid the tendency to overdry.

It had already been demonstrated\textsuperscript{77} that early-morning machine-picked cotton, with a higher moisture content, produced lower lint grades than drier afternoon-picked cottons, the difference being associated mainly with loss of colour during storage. Lint quality was not affected, provided that excessively moist seed cotton was gin dried without delay. The importance of picking only when the crop was thoroughly dry was stressed.
TABLE 1
SUMMARY OF SIGNIFICANT EFFECTS OF DIFFERENT DRYING TEMPERATURES ON COTTON FIBRE AND YARN PROPERTIES

<table>
<thead>
<tr>
<th>DRYING TREATMENT</th>
<th>93°C Term</th>
<th>93°C Term</th>
<th>93°C Term</th>
<th>93°C Term</th>
<th>93°C Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drier 1</td>
<td>93°C</td>
<td>93°C</td>
<td>93°C</td>
<td>93°C</td>
<td>93°C</td>
</tr>
<tr>
<td>Drier 2</td>
<td>66°C</td>
<td>38°C</td>
<td>66°C</td>
<td>38°C</td>
<td>38°C</td>
</tr>
<tr>
<td>Drier 3</td>
<td>38°C</td>
<td>38°C</td>
<td>38°C</td>
<td>38°C</td>
<td>38°C</td>
</tr>
</tbody>
</table>

| Moisture content (%) | 5.96 | 5.43 | 5.08 | 5.49 | 4.97 |
| (at lint slide)      |      |      |      |      |      |
| Grade index          | 90.67 | 91.55 | 93.55 | 92.88 | 94.88 |
| Upper half mean length (mm) | 27.5 | 27.4 | 27.3 | 27.3 | 27.0 |
| Mean length (mm)     | 23.2 | 22.7 | 22.8 | 22.7 | 22.4 |
| Yarn appearance index| 95.56 | 95.56 | 92.78 | 93.33 | 88.89 |
| Yarn break factor (CSP) | 2754 | 2751 | 2747 | 2725 | 2693 |

(1) Passed through driers twice

Cottons with a range of initial moisture contents (6 to 10%) were subjected to different drying treatments (temperature, duration, number of exposures) which reduced them all to the same moisture content (6%) prior to processing. Differences in grade, staple length and most fibre properties were either small or absent except for spinning end breakage rate which was less for the cotton which required no drying than for the cottons which received drying treatments.

A later study showed that fibre quality characteristics, other than 2.5% span length, were better for those cottons which were harvested dry than for those which were harvested containing excessive moisture. Drying wet cottons with heated air tended to improve fibre properties but reduce ginning out-turn.

As seed cotton moisture content, seed cotton cleaning and lint cleaning are closely inter-related in their joint effect on lint grade, cleaning efficiency, fibre and yarn properties and processing performance, they were often investigated together.

More recently, a four-year study using data obtained from high volume (HVI) testing, confirmed that the moisture content of cotton during gin processing influenced fibre properties more than did gin machinery. In all four years, the drier cottons were both shorter and weaker. Length uniformity decreased with drier cotton in three of the years. Moisture content during ginning strongly influenced lint trash content, with the drier cottons producing the better grades. The general trends are illustrated in Figure 2.
The eventual routine use of driers in the gin to obtain maximum cleaning and grade and the acknowledged harmful effects to fibre quality of ginning too-dry cotton, led to the introduction of restoring moisture to the dry seed cotton after overhead cleaning but before the gin-stand\textsuperscript{3, 85, 86}. Although lint grade decreased slightly, both fibre properties and the resultant yarn properties were protected by the increased level of moisture during ginning. All measures of fibre length (upper quartile mean, upper half mean and mean length) increased, length uniformity improved, short fibre content decreased, fibre and yarn strength increased and spinning efficiency (ends down) improved (Table 2). In another study\textsuperscript{87}, machine-stripped cotton was dried at three levels (ambient, 66°C and 93°C), with and without moisture restoration. Drying treatments, especially at 93°C, reduced classer’s staple length and fibre length and increased variability and short fibre content. Moisture restoration at the feeder replaced most of the moisture lost during drying and helped to preserve fibre properties during ginning and lint cleaning, especially with the 66°C drying treatment. Irrespective of moisture restoration, all drying treatments significantly reduced non-lint content. Yarn quality showed similar trends to fibre quality.

Fig. 2 – The effect of moisture content during ginning on selected HVI fibre properties\textsuperscript{84}.
<table>
<thead>
<tr>
<th></th>
<th>1961</th>
<th>1962</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dried, no moisture</td>
<td>Dried, moisture</td>
</tr>
<tr>
<td></td>
<td>restored</td>
<td>restored by spray</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at wagon</td>
<td>6.0</td>
<td>6.2</td>
</tr>
<tr>
<td>at gin-stand</td>
<td>5.3</td>
<td>7.7</td>
</tr>
<tr>
<td>at 1st lint cleaner</td>
<td>3.2</td>
<td>7.9</td>
</tr>
<tr>
<td>Trash content (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at wagon</td>
<td>28.6</td>
<td>29.8</td>
</tr>
<tr>
<td>at gin-stand</td>
<td>6.0</td>
<td>7.8</td>
</tr>
<tr>
<td>at lint slide</td>
<td>2.35</td>
<td>3.30</td>
</tr>
<tr>
<td>Seed cotton cleaning efficiency (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>80</td>
</tr>
<tr>
<td>Lint cleaning efficiency (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>66</td>
</tr>
<tr>
<td>Grade</td>
<td>SLM</td>
<td>SLM</td>
</tr>
<tr>
<td>Staple length (32nd in.)</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Fibrograph length:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper half mean (mm)</td>
<td>21.8</td>
<td>23.1</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>16.5</td>
<td>17.8</td>
</tr>
<tr>
<td>Uniformity ratio (%)</td>
<td>75</td>
<td>77</td>
</tr>
<tr>
<td>Suter-Webb array length:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper quartile mean (mm)</td>
<td>24.9</td>
<td>26.2</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>19.6</td>
<td>21.1</td>
</tr>
<tr>
<td>CV (%)</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>Fibres shorter than 12.5 mm (%)</td>
<td>19.5</td>
<td>13.6</td>
</tr>
<tr>
<td>Strength (cn/tex, o gauge, Prassley)</td>
<td>32.7</td>
<td>32.7</td>
</tr>
<tr>
<td>Processing and Yarn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blowroom and card waste (%)</td>
<td>5.86</td>
<td>5.87</td>
</tr>
<tr>
<td>Nefts (card web)/1000 cm²</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>Ends down/1000 spindle hr</td>
<td>93</td>
<td>106</td>
</tr>
<tr>
<td>Yarn break factor</td>
<td>1499</td>
<td>1620</td>
</tr>
<tr>
<td>Yarn appearance index</td>
<td>97.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Yarn strength (cn)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No. neps/1000 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thick places/1000 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thin places/1000 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Irregularity, CV (%)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
While moisture restoration gave protection against certain losses in fibre properties attributable to severe drying, it was considered that controlled drying to correct moisture levels was preferable to overdrying followed by restoration of moisture before the gin-stand. The main function of moisture restoration at the gin should thus be to raise the moisture level of those cottons which are delivered too dry.

Research has thus established that the optimum moisture range is a compromise between smooth ginning/effective cleaning and quality preservation. It has been reported that the optimum fibre moisture range is 6-8%. Operating difficulties, rough preparation and lower grades can be expected above 8%; while low moistures, 5% or less, and high drying temperatures, 120°C or more, may significantly reduce fibre quality, particularly fibre length, spinning performance and yarn quality.

Because yarn properties are a function of the fibre properties, heating and moisture content affect yarn quality in a similar way to fibre quality. These effects are usually in the later stages of processing where damage to the cotton tends to make itself more noticeable. Three major spinning quality parameters are yarn strength, appearance and end breakage rate; these are all dependent on fibre length, length uniformity and short fibre content. It is considered that the presence of a larger number of short fibres is a major cause of reduced yarn quality and increased processing difficulties. Studies have shown conclusively that yarn break factor and yarn strength decrease with the increased severity of drying and reduced moisture content of the cotton at the time of ginning. Yarn appearance and uniformity were reduced with increased heating and lower moisture content. Increased card web neps and yarn neppiness were caused by increased gin drying. In general, therefore, yarn quality is best with minimum drying and cleaning but, in practice, this must be balanced against removal of trash to a desirable level.

Lower moisture levels at ginning tended to result in weaker grey (greige) fabric, although wet treatments (e.g. bleaching, resin treatment) which reduce strength in any event, tended to reduce such differences.

Spinning end breakage rates were significantly increased with increased heating and reduced moisture content, differences tending to be less obvious with fewer cleaning stages. Loom stoppages also increased with the severity of heating.

Foreign matter content was reduced with lower moisture levels and therefore lint grade improved significantly. It has also been reported that grade index was not consistently affected by heat and that grade was not a good indicator of spinning performance potential. Because higher temperature and lower moisture content enhanced waste extraction in the gin, less mill waste was subsequently extracted. Fine dust levels in ginned lint decreased as composite grade increased and moisture content during processing decreased.
4. SEED COTTON CLEANING

The greater use of seed cotton, or overhead, cleaning equipment has gradually developed over the years in order to accommodate the increasingly more trashy cottons produced by rougher harvesting methods. The manipulation of seed cotton moisture content, through drying, has greatly enhanced the efficiency of seed cotton cleaning.

The machinery is divided by task into cleaners and extractors, although some machines may be dual-purpose. Cleaners open the seed cotton and remove fine trash, leaves and dirt and are generally referred to as cylinder, or inclined, cleaners and more specifically as air-line, hot-air or gravity-fed cleaners. Extractors remove the large trash particles (hulls, stems) and are named accordingly (e.g. bur machine, stick and leaf machine, extractor-feeder). A well-equipped gin should contain not only the machinery necessary to handle the most trashy cottons likely to be delivered but also the flexibility to be able to use the minimum of equipment necessary to produce the desirable grade.

Lint grades normally tend to improve and yarn strength and appearance deteriorate with an increase in the number of seed cotton cleaning cylinders; these trends are illustrated in Fig. 3. It has also been reported however, that seed cotton cleaning for stripper harvested cotton, which included up to five cleaners (28 cylinders) and three extractors, had little effect on fibre and yarn properties. As would be expected, the more elaborate the seed cotton cleaning system, the greater was the amount of trash extracted. Although a significant amount of trash was removed, seed cotton cleaners did not have a large effect on lint grade in comparison with the effect of lint cleaners.

The use of additional overhead cleaners in conjunction with reduced moisture content has been found to reduce fibre length. Although additional overhead cleaning increased short fibre content, this only became evident during later processing stages in the mill. Fibre strength was adversely affected only when overhead cleaning was associated with very low moisture levels. Grade was improved but elaborate cleaning gave similar grades to moderate cleaning when moisture content was low and two lint cleaners were used after ginning. While seed cotton cleaning improved trash grades, as measured by HVI, lower moisture content had the greater effect. These tests also showed no effect of seed cotton cleaning on fibre length.

A further study investigated the effects of processing rate through various seed cotton cleaners. Processing rates between 1 700 and 7 400 kg per hour per metre width of machine (kg/h/m) had only minor effects on the overall performance of a complete cleaning system and there was no effect on final lint quality (Table 3). At 10 000 kg/h/m, performance dropped, foreign matter content at the gin-stand increased significantly and lint grade was reduced significantly. There were no significant effects on staple length, upper half mean
Fig. 3:

(A) Effect of seed-cotton cleaners on lint grade and yarn strength$^{56}$. 

(B) Effects of seed-cotton cleaners on lint grade and yarn appearance for hand-picked and machine picked cotton$^{56}$. 

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TABLE 3
EFFECT OF PROCESSING RATE ON THE EFFICIENCY OF SEED COTTON CLEANING AND ON FIBRE PROPERTIES\textsuperscript{101}. 

<table>
<thead>
<tr>
<th>Processing rate (kg/h/m)</th>
<th>1700</th>
<th>2800</th>
<th>4300</th>
<th>5800</th>
<th>7400</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning efficiency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burs</td>
<td>97.6</td>
<td>96.6</td>
<td>97.0</td>
<td>95.8</td>
<td>95.8</td>
<td>94.2</td>
</tr>
<tr>
<td>Stick</td>
<td>94.7</td>
<td>95.1</td>
<td>94.1</td>
<td>91.6</td>
<td>92.6</td>
<td>88.1</td>
</tr>
<tr>
<td>Fine trash</td>
<td>85.4</td>
<td>85.9</td>
<td>87.9</td>
<td>86.2</td>
<td>83.0</td>
<td>83.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>94.9</td>
<td>94.4</td>
<td>94.6</td>
<td>93.2</td>
<td>92.9</td>
<td>90.8</td>
</tr>
<tr>
<td>Foreign matter (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed cotton at ginstand</td>
<td>3.3</td>
<td>3.7</td>
<td>3.5</td>
<td>4.6</td>
<td>4.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Lint</td>
<td>4.6</td>
<td>4.9</td>
<td>4.7</td>
<td>4.8</td>
<td>4.8</td>
<td>5.1</td>
</tr>
<tr>
<td>Upper half mean length (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length uniformity (%)</td>
<td>23.4</td>
<td>23.1</td>
<td>23.4</td>
<td>23.1</td>
<td>23.4</td>
<td>23.4</td>
</tr>
<tr>
<td>Fibre strength (cN/tex)</td>
<td>78</td>
<td>78</td>
<td>78</td>
<td>79</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Grade index</td>
<td>22</td>
<td>23</td>
<td>23</td>
<td>24</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Staple length (32nd in.)</td>
<td>89</td>
<td>86</td>
<td>86</td>
<td>88</td>
<td>89</td>
<td>83</td>
</tr>
<tr>
<td>Micronaire</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

length, length uniformity, fibre strength and micronaire. Lint cleaning tended to minimise any differences in non-lint content.

It has been found that nepes in the card web increased significantly with additional seed cotton cleaners but end breakage rates during spinning were not apparently related to the level of cleaning\textsuperscript{96}. While in one study\textsuperscript{102} the use of elaborate overhead cleaning equipment reduced spinning performance in comparison with moderate cleaning, another study\textsuperscript{103} showed that the quality of both ring and open-end spun yarns were little affected by the level of overhead cleaning. A further report\textsuperscript{94} indicated that seed cotton cleaning had no effect on spinning performance, warp and filling yarn properties, weaving performance and fabric strength.

There is little reported evidence of fibre damage and loss of yarn quality due to the action of extractors. Mahkamov and Towery\textsuperscript{104}, however, reported that the forces acting on the fibre due to the action of overhead cleaners were insignificant with the exception of the bur machine. In a range of seed cotton
cleaning sequences, the performances of a stick machine and a bur machine were directly compared and later, these were compared with a combination bur and stick machine. Although the stick machine removed more coarse and fine trash and was more efficient than the bur machine (Fig 4), no differences were detected in 2.5% span length, 50% span length, staple length or grade of the resultant lint. (Table 4). The combination bur and stick machine removed more trash than either the stick or the bur machine.

A commercial stick remover was shown to facilitate seed cotton cleaning and to contribute towards improved grades without having any adverse effect on fibre properties and spinning performance. Follow-up investigations showed that, in combination with two lint cleaners, no combination of stick cleaner and cylinder cleaner produced significantly better fibre or yarn characteristics.

While efficiencies have already been improved, experiments have indicated that the performance of stick machines could be further improved with other design changes, such as increasing tooth density and changing grid-bar design to improve the loading characteristics of the saw cylinder.

### TABLE 4

**EFFECT OF SEED COTTON CLEANING ARRANGEMENTS BEFORE AND AFTER CLEANING ON COTTON FIBRE PROPERTIES**

<table>
<thead>
<tr>
<th></th>
<th>16 CYLINDERS + 2 STICK MACHINES</th>
<th>16 CYLINDERS + 2 BUR MACHINES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cotton A</td>
<td>Cotton B</td>
</tr>
<tr>
<td>Before lint cleaning:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign matter (%)</td>
<td>12.3</td>
<td>6.0</td>
</tr>
<tr>
<td>2.5% span length (mm)</td>
<td>29.2</td>
<td>26.7</td>
</tr>
<tr>
<td>50% span length (mm)</td>
<td>13.0</td>
<td>11.9</td>
</tr>
<tr>
<td>After two lint cleaners:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign matter (%)</td>
<td>5.0</td>
<td>2.5</td>
</tr>
<tr>
<td>2.5% span length (mm)</td>
<td>28.2</td>
<td>25.7</td>
</tr>
<tr>
<td>50% span length (mm)</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Grade index</td>
<td>79.0</td>
<td>89.0</td>
</tr>
<tr>
<td>Classer's staple (32nd.in.)</td>
<td>34.0</td>
<td>31.7</td>
</tr>
</tbody>
</table>

### 5. GINNING

Lord explained that cotton fibres break during ginning if the forces applied to overcome their basal attachment to the seed exceeded the fibre breaking load. He described the pattern of breakage mathematically and found that predictions of mean fibre length and length distribution agreed well with
Fig. 4 – The effect of foreign matter content of seed-cotton upon the cleaning efficiency of a stick machine and a bur machine. 

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direct measurement. Comparisons between mechanically ginned cotton and hand-ginned samples showed that there was a reduction of some 1.6 mm to 3.2 mm in mean fibre length caused by passage through the gin. Counts showed that some 16% of fibres were broken during their removal from the seed and that an even higher proportion of the remaining basal parts broke again. In the case of immature cotton, with less well-developed secondary wall thickening, and genetically weaker fibre, ginning breakage increased and generated a greater proportion of short fibres. Lord suggested that increased short fibre content after gin heating and drying may not only be caused by weakening of the fibre but possibly also by strengthening of its attachment to the seed, thereby leading to increased breakage during ginning. Fibre-to-seed attachment strength continues to receive attention. Other plant, fibre and seed characteristics have also been shown to be associated with ginning performance.

For optimum ginning performance, the coarse trash content of seed cotton presented to the gin-stand should be less than 2% and should have a fibre moisture content of less than 8%. In one series of experiments, the higher trash contents produced with simple seed cotton cleaning arrangements appeared to affect the rate of ginning. In one specific case, an increase in bur content from 0.5% to 1.1%, caused a reduction in the ginning rate from 4.0 bales/h to 3.75 bales/h. In another case, in which sticks dominated burs, ginning rates varied from 2.95 to 4.12 bales/h, caused by a variation in total trash content from 21.6% to 6.2%.

In addition to a reduction in ginning capacity, lint grade through preparation, fibre quality and spinning performance can be severely affected at the gin-stand if it is not well-maintained and correctly adjusted and it is important that manufacturers’ recommendations and technical specifications are followed. While worn ribs, damaged saws and faulty dosing may reduce ginning rates and cause rough preparation, the skill of the gin-stand operator is critical. Operational settings, such as feed rate and seed finger adjustment, affect ginning rate, seed roll density, ginning out-turn and fibre quality. It has been shown that as feed rate increases, so seed roll density increases causing a reduction in fibre length and an increase in short fibre content (Figs. 5 and 6).

The need to achieve economic processing rates has led to design changes and increased machine throughput in precleaning and ginning. At these higher production rates (5-8 bales per hour per stand), it becomes less possible to preserve fibre quality; possible consequences may be increased nep formation, more seed coat particles (motes), a greater proportion of short fibres and increased dust levels.

In a four-year study, Griffin showed that when a modern, high capacity gin was operated within manufacturers’ recommendations, short fibre content of the resultant lint was no larger than that from the typical low capacity
1. Feeder sample  
2. Gin stand sample  
3. First lint cleaner sample  
4. Second lint cleaner sample.  
  Shaded portions represent before (upper) and after (lower) Shirley analyser.

**Fig. 5 – Effect of seed roll density on staple length of cotton**

![Graph showing the effect of seed roll density on staple length of cotton.](image)

1. Feeder sample  
2. Gin stand sample  
3. First lint cleaner sample  
4. Second lint cleaner sample.  
  Shaded portions represent before (lower) and after (upper) Shirley analyser.

**Fig. 6 – Effect of seed roll density on short fibre content of cotton**
(1.5 bales/h) gin of 25 years previously. The worst ginning technique, in terms of excessive short fibre content, was ginning cotton with a low moisture content at greater than recommended rates and using two stages of saw-cylinder lint cleaning. In fact, high fibre breakage was due not to machine design faults but to the manner in which the entire ginning process was conducted. Further, fibre moisture content was the most important single ginning factor affecting the length characteristics of cotton, its subsequent manufacturing performance and yarn quality.

The majority of the world's cottons are saw-ginned while roller ginning is usually, but not always, associated with the processing of extra-long staple cottons. In comparison with saw ginning, roller ginning is slower, more labour-intensive, has higher energy requirements but is less capital intensive. However, it gives a larger ginning out-turn although with more trash, and produces a higher quality lint in terms of longer fibres, fewer short fibres and better uniformity.

In Russia, it has also been reported that saw ginning produced more fibre faults than roller ginning, mainly accounted for by the larger number of "bunches" and "knots". Nep counts were smaller with roller ginning in the card web, in the yarn, and in the fabric.

Processing efficiency, including end breakage rates, of roller ginned cotton was better than that of saw ginned cotton. In general, roller ginning produced yarns and fabrics of better quality. Carded yarns spun from roller ginned cotton were significantly stronger but not combed yarns; combed yarns from roller ginned cotton had a better appearance. Sewing threads showed no significant differences. The action of carding has also been shown almost to eliminate the quality advantages of roller ginning. Another report indicated that saw and roller ginned lints produced yarns of similar lea strength although saw ginned lint gave slightly higher single thread strength. Fabrics from roller ginned cotton had a higher elongation and breaking strength but combed cottons were similar in tearing strength.

By and large, comparisons between saw and roller ginning have been made with long staple cottons. With a medium staple cotton, it has been reported that method of ginning had no significant effect on fibre and yarn parameters.

6. LINT CLEANERS

Lint cleaners were developed specifically to remove the foreign matter left in the lint by the seed cotton cleaners and extractors. The use of such cleaners achieved significant grade improvements, particularly with the dirtier machine-picked cottons. Such extraneous matter, now small in size, may consist of leaf particles, stems, bark, grass, seeds, motes, spindle-twist, sand and dust. Virtually
all ginneries in the USA have lint cleaning facilities with most possessing two or more cleaning stages\textsuperscript{125,126}.

There are basically two types of lint cleaner, the flow-through, or air-jet, cleaner and the controlled-batt saw cylinder lint cleaner. The former is less effective in removing trash and improving grade although it does no damage to fibre properties\textsuperscript{127} while the latter is more common and is the type reviewed hereafter.

Of the various gin operations and management decisions affecting bale value and lint quality, fibre moisture content and lint cleaning, separately and in combination, are the two most important factors in terms of quality\textsuperscript{8}. This is clearly illustrated in Figures 7 to 9. Similar to the gin-stand itself, the lint cleaner is a precision machine operating within close tolerances which should be within manufacturers specifications\textsuperscript{88}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fibermoisture.png}
\caption{The effects of fibre moisture during lint cleaning on grade\textsuperscript{8}.}
\end{figure}
Fig. 8 – The effects on fibre moisture during lint cleaning on staple length.

Fig. 9 – The effects of number of lint cleaning stages on nepS.

Various studies\textsuperscript{128,129} showed that non-lint content decreased and cumulative cleaning efficiency increased as the number of lint cleaners used increased (Figs 10 and 11). The efficiency of individual cleaners, however, decreased with each additional stage; the reduction in non-lint content also decreased from stage to stage.

Later studies\textsuperscript{126}, using commercial gins, indicated that cleaning efficiencies of about 35% and 50% could be expected from one and two stages of
Fig. 10 – Cumulative cleaning efficiency of number of stages of saw-cylinder lint cleaning.\[ \log Y = 1.592 + 0.508 \log X \]
\[ r = 0.998 \]

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Fig. 11 – Total waste extracted by saw-cylinder lint cleaners and the nonlint content of this material.¹²⁸
lint cleaning respectively and that the second cleaner would be less efficient than the first, removing about 25% less foreign matter than the first. In addition, the level of cleaning efficiency would, in any event, be related, albeit rather loosely, to the initial foreign matter content of the lint entering the cleaner (Fig. 12).

Fig. 12:  
(a) Effect of nonlint content of cotton before lint cleaning on cleaning efficiency of first lint cleaner $^{126}$.

(b) Cumulative cleaning efficiency of two lint cleaners in tandem vs nonlint content of cotton before lint cleaning $^{126}$.
It had previously been shown\textsuperscript{130} that lint cleaning shifted trash particle size distribution towards the smaller fragments because the larger fragments were more easily removed (Figs. 13 and 14). In addition, in a fragment size distribution, the larger fragments accounted for the larger proportion of total fragment mass. It was surmised\textsuperscript{126} therefore that the first lint cleaner would be more efficient than the second because lint entering the first contained a

Fig. 13 – Accumulated percent of total fragments by mass and number, starting with largest group. Data shown for none and four lint-cleaning stages\textsuperscript{130}.

<table>
<thead>
<tr>
<th>WASTE</th>
<th>FRAGMENT SIZE MM</th>
<th>Funiculi mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11.5</td>
<td>&gt; 5</td>
</tr>
</tbody>
</table>

Fig. 14 – Seed-coat fragments and funiculi removed by four stages of lint cleaning \textsuperscript{130}.
greater proportion of the more easily removed larger trash particles than that entering the second. Similarly, a third lint cleaner would exhibit a lower efficiency than the second cleaner because it would be fed with lint containing smaller, more persistent trash particles. Furthermore, cleaning efficiency would be higher with high trash cottons which would contain even greater numbers of large, heavy, more easily dislodged particles.

Many experiments on the effects of lint cleaners on bale value, grade, wastes, processing performance and fibre, yarn and fabric properties have been conducted over the years. Most incorporated some details of the inter-relationship between lint cleaning and seed cotton drying and cleaning. A summary of the results of a selection of these serve to illustrate the main effects.

In 1961, six commercial gins in three states of the USA were used to measure the effects of multiple (up to 3) lint cleaning on bale value, fibre properties and spinning performance (Table 5). Each additional lint cleaning

### Table 5

**THE EFFECT OF NUMBER OF LINT CLEANERS ON GRADE, FIBRE PROPERTIES AND PROCESSING PERFORMANCE**

<table>
<thead>
<tr>
<th>NO. OF LINT CLEANERS</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average grade index</td>
<td>93</td>
<td>99</td>
<td>101</td>
<td>102</td>
</tr>
<tr>
<td>Staple length (32nd in.)</td>
<td>33.50</td>
<td>33.59</td>
<td>33.59</td>
<td>33.57</td>
</tr>
<tr>
<td>Fibre length (array):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper quartile (mm)</td>
<td>29.7</td>
<td>29.7</td>
<td>29.5</td>
<td>29.2</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>24.9</td>
<td>24.6</td>
<td>24.1</td>
<td>23.6</td>
</tr>
<tr>
<td>CV (%)</td>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>% fibres less than 12.5 mm</td>
<td>35.2</td>
<td>36.5</td>
<td>37.9</td>
<td>39.3</td>
</tr>
<tr>
<td>Fibre length (Fibrograph):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper half mean (mm)</td>
<td>26.4</td>
<td>26.4</td>
<td>26.4</td>
<td>25.9</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>21.6</td>
<td>21.3</td>
<td>21.3</td>
<td>20.8</td>
</tr>
<tr>
<td>Uniformity ratio (%)</td>
<td>81</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Micronaire</td>
<td>4.0</td>
<td>4.0</td>
<td>3.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Fibre strength (cN/tex; 3.2 mm; Pressley)</td>
<td>22.6</td>
<td>22.3</td>
<td>22.8</td>
<td>22.5</td>
</tr>
<tr>
<td>No. of nep/s/1000cm² card web</td>
<td>34</td>
<td>42</td>
<td>48</td>
<td>56</td>
</tr>
<tr>
<td>Ends down index</td>
<td>100</td>
<td>99</td>
<td>130</td>
<td>200</td>
</tr>
<tr>
<td>Yarn appearance index</td>
<td>90</td>
<td>89</td>
<td>85</td>
<td>82</td>
</tr>
<tr>
<td>Yarn strength index (15 tex)</td>
<td>100</td>
<td>100</td>
<td>99</td>
<td>97</td>
</tr>
</tbody>
</table>
stage reduced non-lint content and improved grades, particularly after one stage, until almost all bales had been upgraded after three stages. Reductions in non-lint content became progressively smaller. There was a small but significant increase in classer's staple length after one lint cleaning but no effects thereafter; this observation was more likely due to improved lint appearance than to any increase in staple length.

All measurements of length, both by array (upper quartile length and mean length) and by fibrograph (upper half mean length and mean length) showed small reductions, progressive with each additional lint cleaner. Coefficient of length variability, percentage of fibres less than 12.5 mm and neps in the card web were all adversely and progressively affected by an increasing number of lint cleaners. Uniformity ratio, micronaire and fibre strength showed no change.

Although the effect was not significant, end breakage rates during spinning were substantially higher with two and particularly three lint cleaners and an increase could normally be expected. Additional lint cleaners tended to affect yarn appearance and yarn strength (15 tex) adversely although neither trend was significant and the latter was inconsistent.

The authors concluded that the ginner could "operate more economically and render better service by using only the best combination of lint cleaning and seed cotton cleaning for the cotton being ginned at any specific time. The spinning tests of this study indicate that unwise and excessive lint cleaning of a particular grade of cotton can increase costs of processing in textile mills and can reduce the quality of manufactured products". Shortly thereafter, in 1962, the National Cotton Council of the USA adopted the recommendation\textsuperscript{141} that "in view of the vital importance of maintaining maximum cotton quality in today's highly competitive textile markets, both here and abroad, no more stages of lint cleaning than are essential to produce maximum bale value should be used".

Research continued on various aspects of lint cleaning\textsuperscript{136} - \textsuperscript{139} and in 1967/68, a study\textsuperscript{128} was undertaken to provide data on the operation of controlled-batt saw-cylinder lint cleaners, the predominant type, to facilitate the prediction of the effect of lint cleaning on bale value, lint quality and waste composition. Increasing the number of lint cleaners increased grade index and decreased non-lint content progressively; differences in both cases were highly significant after one cleaner, becoming progressively smaller and not significant with the third cleaner (Table 6). Cumulative cleaning efficiency increased significantly at each stage although individual efficiency declined (Fig 10).

Staple length decreased significantly with each additional cleaner, the
TABLE 6
THE EFFECT OF NUMBER OF LINT CLEANERS ON GRADE, FIBRE QUALITY AND PROCESSING PERFORMANCE\(^{128}\).

<table>
<thead>
<tr>
<th>NO. OF LINT CLEANERS</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade index</td>
<td>87.9</td>
<td>92.1</td>
<td>95.0</td>
<td>96.0</td>
</tr>
<tr>
<td>Grade</td>
<td>LM+</td>
<td>SLM</td>
<td>SLM</td>
<td>SLM+</td>
</tr>
<tr>
<td>Non-lint content (%)</td>
<td>6.20</td>
<td>3.76</td>
<td>2.64</td>
<td>1.99</td>
</tr>
<tr>
<td>Cumulative cleaning efficiency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staple length (32nd in.)</td>
<td>34.93</td>
<td>34.70</td>
<td>34.47</td>
<td>34.38</td>
</tr>
<tr>
<td>Fibre length (Fibrograph):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5% span (mm)</td>
<td>28.4</td>
<td>28.3</td>
<td>28.0</td>
<td>27.9</td>
</tr>
<tr>
<td>50% span (mm)</td>
<td>12.9</td>
<td>12.6</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Uniformity ratio (%)</td>
<td>45.2</td>
<td>44.7</td>
<td>44.0</td>
<td>44.2</td>
</tr>
<tr>
<td>Fibre length (array):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper quartile (mm)</td>
<td>31.4</td>
<td>31.1</td>
<td>30.9</td>
<td>30.8</td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>25.9</td>
<td>25.3</td>
<td>25.0</td>
<td>24.9</td>
</tr>
<tr>
<td>CV (%)</td>
<td>29.5</td>
<td>31.0</td>
<td>31.4</td>
<td>31.6</td>
</tr>
<tr>
<td>% fibres less than 12.5 mm</td>
<td>8.6</td>
<td>9.8</td>
<td>10.0</td>
<td>10.4</td>
</tr>
<tr>
<td>Blowroom and card waste (%)</td>
<td>9.8</td>
<td>7.2</td>
<td>6.0</td>
<td>5.8</td>
</tr>
<tr>
<td>No. of nep/1000cm(^2) card web</td>
<td>23.3</td>
<td>34.4</td>
<td>44.6</td>
<td>46.8</td>
</tr>
<tr>
<td>Yarn skein strength (kg):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 tex</td>
<td>17.7</td>
<td>17.4</td>
<td>16.8</td>
<td>16.8</td>
</tr>
<tr>
<td>27 tex</td>
<td>49.4</td>
<td>48.3</td>
<td>47.8</td>
<td>47.7</td>
</tr>
<tr>
<td>Average yarn break factor (CSP)</td>
<td>2182</td>
<td>2131</td>
<td>2085</td>
<td>2080</td>
</tr>
<tr>
<td>Average yarn appearance index</td>
<td>88.0</td>
<td>85.4</td>
<td>82.0</td>
<td>78.0</td>
</tr>
</tbody>
</table>

difference between no cleaning and one cleaner being non-significant and highly significant between none and two and three cleaners. All measured fibre length parameters were reduced significantly with an increase in the amount of lint cleaning; differences were not always significant after one cleaner but all were after two cleaners. Uniformity ratio (Fibrograph) decreased and coefficient of length variation (array) increased significantly with an increase in lint cleaners. Short fibre content increased significantly with the number of lint cleaners, the increase being highly significant after one cleaner (Fig 15).

As expected, blowroom and card wastes decreased with each stage of lint cleaning; the decreases were progressively smaller but nevertheless significant, except with three lint cleaners. The amount of waste was greater from the cotton which had the higher initial trash content. The number of nepes in the card web increased progressively with lint cleaning; the number after one lint cleaner was not significantly higher than that for no lint cleaner but the overall increase was
highly significant thereafter (Fig 16). Yarn skein strengths decreased slightly with each additional lint cleaner and the decrease in average break factor was significant after one cleaner and highly significant after two (Fig 17). Yarn appearance showed a small but consistent decline with each additional cleaner, the effect being highly significant after two stages (Fig 17).

It was thus shown that more lint cleaners not only produced progressively higher grades, shorter fibre length and lower bale weight but also, in the mill, more neps and decreased yarn strength and appearance. It was concluded that, for the styles of cotton and production and harvest practices under consideration, maximum bale value with preservation of fibre quality would be most often achieved with one lint cleaner for the cleaner early-season cottons and two lint cleaners for the more trashy late-season cottons. Three lint cleaners should be reserved for below grade cottons.

*Fig. 15 – Fibre-length distribution of ginned lint as affected by amount of lint cleaning*
Fig. 16 – Neps per 100 square inches of card web, as affected by number of lint-cleaning stages.

Further studies were undertaken from 1969 to 1972 with stripper-picked cottons grown on the Texas High Plains, with the objective of formulating ginning recommendations, including seed cotton and lint cleaning, for typical stripper-picked cottons. The results, including the inter-relationship between overhead cleaners and lint cleaners are summarised below:

1. Grade increased progressively, the largest increase being after one lint cleaner with smaller or no increases after two and three cleaners. One and two lint cleaners reduced non-lint content significantly but three had little or no further effect.

2. The more seed cotton cleaners used, the fewer lint cleaners were required to achieve minimum trash content and maximum grade. Sole reliance on lint cleaners with no seed cotton cleaners to remove trash resulted in higher trash, lower grade and lower bale value. One additional lint cleaner was required to compensate for bypassing two or more seed cotton cleaners.
Fig. 17 – Effect of lint-cleaning stages on the average break factor (CSP) and average appearance index for the two standard yarn numbers (22s and 50s) spun.

1. Classer's staple length tended to be longer after one lint cleaner but this was thought to be due to the smoother appearance of the lint after cleaning.

2. Successive lint cleaning stages generally tended to reduce fibre length (2,5% span, upper quartile and mean) but the reductions were either small or absent with two and three stages. Length uniformity was sometimes reduced with two and three stages.

3. Short fibre content tended to increase in line with reduced fibre length.

4. Neps in the card web tended to increase with more lint cleaners.

5. Blowroom and card wastes were progressively decreased with more lint cleaners but the reduction after three was not significant.

6. Yarn strength and break factor tended to decrease with more lint cleaners but differences were often small and not significant, reductions due to lint cleaning often being dependent on the level of the preceding seed cotton cleaning treatments.

7. On average, yarn appearance was best after one or two lint cleaners and significantly lower after three. Similarly, yarn imperfections were highest...
with no lint cleaning and after three cleaners and lowest after one or two cleaners.

Overall, two stages of lint cleaning were best for bale value and fibre quality for this particular style of cotton and the differences in lint and yarn quality were generally not significant. Three lint cleaners generally produced inferior fibre and yarn qualities. The final effect of lint cleaning was confounded with initial trash content, moisture content and level of seed cotton cleaning.

Experiments were conducted from 1976 to 1978 to update lint cleaning recommendations for typical spindle-picked cottons using a range of commercial models of lint cleaner. Using up to two stages of lint cleaner, additional lint cleaning reduced trash content and ginning out-turn, improved classer’s grade and reduced 2.5% span length and uniformity ratio slightly. It was recommended that, in the circumstance of stable grade price differentials, one stage of lint cleaning should be used with clean spindle-picked cotton and two stages with more trashy cotton — assuming standard seed-cotton cleaning routines. Should differentials change, then maximum bale value would be attained only if the ginner evaluated his cottons accurately and selected that amount of lint cleaning which would balance loss or gain of mass against grade change. In certain extreme circumstances, no lint cleaning or three stages of lint cleaners may sometimes be required.

Although micronaire-fineness is influenced primarily by cultivar and growing conditions, it was found to decrease slightly but statistically significantly with increased lint cleaning. This was probably due to the reduction in foreign matter content causing reduced Micronaire airflow.

The effects of lint cleaning on the improvement of cotton colour and on removing grass from spindle-picked cottons have also been investigated. The classer’s colour element of grade was improved significantly and consistently by increasing the number of lint cleaning stages. While the largest improvement was obtained with one lint cleaner, there were further smaller improvements with each additional stage. Lint cleaning removed grass, stems and bark in a similar pattern, although some remained in the lint even after three stages. One or two stages were recommended for normal circumstances, depending on the frequency of occurrence of light spot and grass, stems and bark, but the importance of adopting production practices that prevent the harvesting of such trash was stressed.

A more recent study with Mid-South (USA) cotton explored the effects of excessive lint cleaning, up to six stages, on fibre and yarn quality and processing performance. Similar to previous results, non-lint and manufacturing wastes were reduced, fibre length was reduced, grade, short fibre content, neps and spinning end breakage were increased and yarn strength and appearance were reduced with an increasing level of lint cleaning. These
responses continued through to the six stages of cleaning. It was concluded that, while bale value and fibre quality were reduced with more than normal (two stages) lint cleaning, the resultant lint was cleaner and still had spinnable characteristics, albeit at a lower level, especially with ring spinning.

Another investigation\textsuperscript{147} showed that a higher level of yarn quality was achieved with the cotton that received less than normal lint cleaning at the gin. The results indicated that the carding process was capable of removing effectively the additional trash that would have normally been removed either at the gin or in the opening line.

With the recent focus on the reduction of respirable dust in mills, the influence of lint cleaner sequences at the gin on subsequent dust levels and on micro-dust build-up in the rotors of open-end spinning machines has also been investigated.

Saw-ginned cotton was shown\textsuperscript{148} to produce less dust in the cardroom than roller-ginned cotton and two saw lint cleaners produced cotton with less dust than one lint cleaner.

It was later shown\textsuperscript{146} that the level of air-borne dust in the cardroom and the level of card-fly were progressively reduced with increased lint cleaning through to six stages (Table 7).

**TABLE 7**

**THE EFFECTS OF TWO, FOUR AND SIX STAGES OF LINT CLEANING ON CARDROOM DUST LEVEL AND FLY INDEX\textsuperscript{146}**

<table>
<thead>
<tr>
<th>NO. OF LINT CLEANERS</th>
<th>2</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust level (mg/m\textsuperscript{3})</td>
<td>1.75</td>
<td>1.46</td>
<td>1.32</td>
</tr>
<tr>
<td>Fly index (μg/h)</td>
<td>12.7</td>
<td>11.6</td>
<td>11.0</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Vertical Elutriator

In another study\textsuperscript{140}, it was found that, although card-room dust levels were reduced progressively with super-normal lint cleaning (Table 8), the levels attained were insufficient, even in combination with mill cleaning, to meet maximum dust level limits. The build-up of micro-dust residues in spinning rotors did not correlate with amount of lint cleaning.

Card room dust levels were found\textsuperscript{149} to be 0.4-0.6 mg/m\textsuperscript{3} higher when cotton was lint cleaned with reduced air-wash and with one grid-bar removed from the cleaner. This effect was in line with differences in foreign matter content, lint grade and manufacturing waste levels. Although foreign matter content of the lint was decreased with increased drying (0.83%) and with more lint cleaning (0.34%), measured card room dust levels varied little. It was
TABLE 8
THE EFFECTS OF MULTIPLE LINT CLEANING SEQUENCES ON CARDROOM DUST LEVEL AND ROTOR RESIDUE\textsuperscript{140}.

<table>
<thead>
<tr>
<th>Lint cleaning sequence\textsuperscript{1}</th>
<th>Airborne dust\textsuperscript{2} (mg/m\textsuperscript{3})</th>
<th>Rotor residue (mg/kg/rotor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoLC</td>
<td>3.19</td>
<td>0.075</td>
</tr>
<tr>
<td>2SCLC</td>
<td>2.67</td>
<td>0.073</td>
</tr>
<tr>
<td>1AJLC + 2SCLC</td>
<td>2.54</td>
<td>0.082</td>
</tr>
<tr>
<td>3AJLC + 2SCLC</td>
<td>2.66</td>
<td>0.078</td>
</tr>
<tr>
<td>4SCLC</td>
<td>2.35</td>
<td>0.075</td>
</tr>
</tbody>
</table>

\textsuperscript{1}NoLC = No lint cleaner  \hspace{1cm} \textsuperscript{2}Vertical Elutriator
SCLC = Saw cylinder lint cleaner
AJLC = Air jet lint cleaner

It was surmised that increased drying and cleaning did, in fact, reduce the amount of dust in the cotton but that measured respirable dust values may have included a measure of airborne cotton fibre particles.

A further report\textsuperscript{150} stated that cardroom dust levels decreased with increased gin cleaning, although the reduction (16\%) was significant only with an elaborate cleaning arrangement incorporating three lint cleaners. In comparison, there was a 50\% reduction when an additional card sequence was used.

Commercial saw-cylinder lint cleaners vary widely in design detail and operational recommendations and, for them to clean efficiently with minimal fibre damage, they need to be adjusted and operated correctly\textsuperscript{125}. For example, one study\textsuperscript{151} showed that cleaning efficiency, and therefore grade, was directly related to saw cylinder speed and to combing ratio, which was increased by increasing saw-cylinder speed or by decreasing feed-roller speed (Fig 18). Increased saw speeds and combing ratios, however, reduced staple length (Fig 19), increased short fibre content and length variation (Figs 20 and 21) and increased nep formation (Fig 22). For maximum cleaning efficiency and minimum fibre damage, saw cylinder speeds of 800-1100 rev/min combined with combing ratios of 12.5 - 37.5 were recommended.

Related experiments\textsuperscript{152} investigated the effects of a range of lint cleaner feed rates over the range, 200 to 1000 kg per hour per metre length of saw cylinder, and of a range of batt masses over the range, 145 to 590 g/m\textsuperscript{2} (10.3 to 41.8 combing ratio, respectively). High feed rates resulted in decreased cleaning efficiency and possibly reduced bale value. Decreasing the feed rate gave highly
significant increases in cleaning efficiency (Fig 23), higher grades and some bale value increases; it caused no detrimental effects to fibre length, strength or nep formation. High batt masses, above 430 g/m², (30,9 combing ratio) resulted in reduced cleaning efficiency and excessive fibre breakage. As cleaning efficiency did not improve below 200 g/m² (15,4 combing ratio), this batt mass was recommended for efficient lint cleaning operations and maximum returns, with a practical upper limit of 290 g/m² (20,6 combing ratio).

It was also reported at about the same time that increased lint cleaner feed rates over the range 400 to 760 kg per hour per metre length of saw cylinder, had no significant effects on lint cleaner efficiency, fibre length measurements or
Fig. 19 – Effect of lint cleaner saw-cylinder speed and feed-roller speed on staple length of cotton. 

Fig. 20:
(a) Effect of lint cleaner saw-cylinder speed on fibre-length distribution.
(b) Effect of lint cleaner feed-roller speed on fibre-length distribution.
Fig. 21 - Effect of saw-cylinder speed and feed-roller speed on coefficient of length variation\textsuperscript{151}.

Fig. 22 - Nep count as a function of saw-cylinder speed and feed-roller speed lint cleaner\textsuperscript{151}.

Fig. 23 - Effect of lint cleaner feed rate on cleaning efficiency\textsuperscript{152}.

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bale value. Increased saw cylinder speed over the range 775 to 1010 rev/min significantly increased lint cleaner efficiency but decreased classer’s staple length; none of the fibre length measurements, however, were affected and there was no shift in fibre length distribution towards the shorter fibres. Variations in feed roll speed had little or no effect on lint cleaner efficiency and fibre length values.

Later investigations also showed that the efficiency of lint cleaners improved with decreases in batt density and with increases in saw-cylinder speed. Increased saw-cylinder speeds, however, decreased classer’s staple length, increased short fibre content and extracted greater amounts of lint from the bale.

In other experiments, batt mass, combing ratio, saw speed, feed bar-to-saw clearance, and grid bar-to-saw clearance and feed roll-to-feed bar tension were measured for their effect on cleaning efficiency, lint wastage and fibre quality. Batt mass, combing ratio and saw speed were found to be the major variables affecting cleaning efficiency and lint wastage although the other variables produced some smaller effects. Within the ranges of variables tested, there was little effect on fibre quality.

Lint cleaner adjustments and modifications have also been shown to affect rotor microdust residues and cardroom dust levels. A combination of increased saw-speed and increased combing ratio reduced rotor deposits, with combing ratio possibly having the major effect. An increase in combing ratio from 25 to 50 reduced cardroom dust level by 11% but had no effect on rotor deposits; the fitting of special air-suction nozzles on to lint cleaners reduced neither cardroom dust levels nor rotor deposits.

In a comparison of the influence of individual gin machines on grade, staple length, ginning out-turn and financial return, it was found that initial cotton condition, gin machinery and fibre moisture content each had a significant effect. The average order of importance of each machine in increasing financial return was:

1. Two lint cleaners
2. One lint cleaner
3. Impact cleaner
4. Cylinder cleaner
5. Stick machine
6. Feeder/gin stand.

7. BALING

Neither the act of baling cotton, nor its longer term storage in bales under pressure are known to affect cotton fibre and yarn quality or processing performance in any direct way. The primary forces involved in packaging cotton are compressive force and resilient force, and these are known to be

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substantial\textsuperscript{158}. Test results showed that the compression of lint was unaffected by cultivar\textsuperscript{159} and that resilient forces were affected less by cultivar than by other factors\textsuperscript{160}. Bale packaging systems could thus be designed with little emphasis on cultivar.

Lack of standardisation in bale dimensions and bale density and poor packaging standards have, however, given cause for concern in terms of storage, transportation, mill efficiency and quality control for some considerable time\textsuperscript{161}. Standardisation of bale dimensions and density would facilitate handling, stacking, storage and transportation although domestic and international preferences often differ and freight rates and load restrictions often dictate final size and mass.

In the mill, it is preferable that bales have similar opening characteristics so that even feeding and controlled blending in the opening line are ensured. These characteristics are governed by consistency of bale mass, length, width and expanded thickness after removal of the bands, the latter being dependent upon bale density. The introduction of automatic opening and feeding installations and higher speed processing has emphasised the need for a greater degree of uniformity in this respect.

Effective bale packaging, or wrapping, affords protection to the lint during storage and transit between gin and mill. In the USA packaging standards have recently been approved and these specify what is acceptable as a "merchandisable" bale\textsuperscript{162,163}. In certain instances it is mandatory for bales to be fully covered, other than two sample holes per side.

Packaging materials themselves have led to serious contamination problems and both natural and synthetic fibres or film are known to have found their way through to the yarn and fabric, with serious consequences\textsuperscript{164}. Judicious choice of wrapping material is therefore essential. It has been suggested\textsuperscript{165} that the traditional method of bale sampling through the side wrapper not only defaces the bale and partly destroys the protective packaging but also introduces contaminants (pieces of wrapper material) into the body of the lint in the bale.

Analysis of bale data\textsuperscript{161} collected from more than 30 countries in 1967 and 1977 showed that, over the ten year period, there had been a considerable voluntary improvement in bale standardisation (Fig 24). It was suggested that a continuing trend of decreasing variability in bale mass and density linked with improved automatic bale opening and feed control should improve mill efficiency and quality control.
Fig. 24:

(a) Bale mass distribution for 38 countries reported in 1967 survey.\textsuperscript{161}

(b) Bale mass distribution for 30 countries, reported in 1977 survey.\textsuperscript{161}

(c) Bale density distribution for 38 countries reported in 1967.\textsuperscript{161}

(d) Bale density distribution for 30 countries reported in 1977.\textsuperscript{161}
8. SUMMARY

Cotton ginning is the mid-point in a closely-linked chain of events which allows an agricultural product, seed cotton, to be transformed into a valuable industrial commodity, cotton lint.

The genetic potential of a cotton plant is modified by its growing environment and, in the open boll on the plant, fibre quality is at its maximum. Each stage of handling and processing thereafter materially influences the quality and value of the product.

The method and efficiency of harvesting determine, to a large extent, ginning procedures, although in setting up a ginning operation, it is essential to know not only the description of the incoming seed cotton but also the requirements of the purchaser and the grade/quality price structure.

The quality of a gin's output will often be limited by the quality of its input and, while drying and cleaning routines will improve grade substantially, fibre quality can be preserved but not enhanced. Beyond a certain point, further improvement in grade would be at the expense of quality.

Because they have the largest impact on lint grade and fibre quality, the two most important operations in the ginning system are fibre moisture adjustment and lint cleaning.

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