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The Effect of Various Processing Stages During Ginning on Fiber Quality

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ABSTRACT

This study was conducted to determine the effectiveness, in terms of cleaning efficiency and fiber quality, of the seed cotton cleaning stages installed in cotton gins that process predominately spindle-harvested, irrigated Upland cotton and to determine the effect of the various processing stages during ginning on gin turn out and fiber quality. The study showed that the average amount of trash content present in seed cotton was typically < 10%. The seed cotton cleaning process was able to remove 20 to 40% with the remainder of the trash removed by subsequent lint cleaning stages. The study also showed that the gin stand has no influence on fiber quality provided that the gin stand was not overloaded, maintained to manufacturers recommendations, and moisture levels maintained within the recommended levels. Flow-through air lint cleaners had no significant effect on fiber quality with minimal reduction in trash. The controlled-batt saw lint cleaners had positive and significant effects on color and trash; negative effects on length, length uniformity, short fiber and nep content, elongation; and no effect on strength, micronaire, fineness, maturity, number and size of SCN and fiber nep size. The batt-less saw lint cleaners had similar effects on fiber quality, although not as severe. The controlled-batt saw lint cleaners were more aggressive than the batt-less saw lint cleaners and removed more trash and hence achieved a better color grade, with this improvement resulting in notable reductions in lint turn out, fiber length, and increased short fiber and nep content.

The purpose of ginning is to separate cotton fiber from seed and produce cotton lint that is a saleable and processable commodity. The layout, size, type, and technology of the gin can take on a number of forms, which depend mainly on the type of cotton grown, production and harvesting conditions, economic factors, as well customer requirements (Estur and Gergely, 2010). In essence, modern ginning is a combination of thermal, pneumatic, and mechanical processes (Anthony and Bragg, 1987). Historically, the process of separating the lint from the seed was done either by hand or with an early version of a roller gin, which was laborious and slow and has been replaced by saw ginning. The invention and commercialization of the saw gin resulted in an immediate and dramatic increase in cotton production worldwide (Dever, 1986, Mayfield and Anthony, 1994).

Irrespective of which method is used to gin cotton, the ginner has two objectives: (1) to produce lint of enough quality and quantity to enhance and maximize the return to the grower, and (2) to produce a fiber with minimum damage to satisfy the demand from the spinner and the consumer (Anon, 2001, Anthony, 1994a). Ginning is, therefore, an essential link between the cotton grower and cotton spinning mill, with the the quality of ginned cotton directly related to the quality of seed cotton prior to ginning; the gin is only able to maintain the quality of cotton taken from the field, never improve it. Cotton gins are typically equipped with processing systems that include: (1) module feeder, (2) dryers, (3) seed cotton cleaners, (4) gin stands, (5) lint cleaners, (6) battery condenser, (7) bale packaging, and (8) trash handling systems.

The introduction of mechanical harvesting and the resultant practice of once-over harvesting with the aid of chemical boll openers and defoliants, has led to trashier, more variable, and sometimes higher moisture content cotton being delivered to the gins. This has led to the need for more extensive drying and cleaning systems. Seed cotton cleaners were introduced in the early 1900s and function to open or break large wads of seed cotton and remove foreign material, such as leaves, trash, carpels, burrs, stems and other plant material, as well as dust. Extractors and stick machines are used to remove sticks, burrs, and other large pieces of foreign matter from seed cotton (Baker, Anthony, et al., 1994, Sanderson,

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1985b). Driers were introduced during the 1930s and are now standard equipment in all gins, with several different systems used to dry seed cotton. Irrespective of which system is used, the time of exposure to heat should not be excessive, and the temperature in the drying system should be kept below 177 °C (351 °F) to prevent fiber damage (Anon, 2001, Anthony, 1994b, Anthony and Griffin, 2001, Boykin, 2005, Gordon, van der Sluijs, et al., 2010, Hughs, 1985, Hughs, Mangialardi, et al., 1994, Mayfield, Baker, et al., 1983, Rutherford, McKenzie, et al., 1991, Sanderson, 1985b).

An overview of 39 studies conducted by the USDA during the 1960s and 1980s indicated that, in general, an increase in seed cotton cleaning did not adversely affect fiber or yarn quality, but did improve color and leaf grade, with any changes in the amount of cleaning only having a minor effect on spinning performance and yarn quality (Baker and Bragg, 1988, Baker, Columbus, et al., 1977, Cocke, Mangialardi, et al., 1985, Columbus, 1993, Wanjura, Faulkner, et al., 2012). This was confirmed by a three-year study conducted in South Africa during 1980 through 1982 that showed that the number of seed cotton cleaning units reduced trash but did not appear to affect fiber properties to any significant extent (Sanderson, 1985a).

The actual ginning process, that is, the separation of lint from seed, occurs at the gin stand, and hence, the gin stand is the heart of the ginning process. The capacity of the gin and the quality and processing performance of the lint in the spinning process are dependent on the condition and adjustment of the gin stand. Hence, gin stands must be operated as per manufacturer's recommendations. Gin stands that are overloaded can influence the damage suffered by the cotton seed and the quality of the cotton lint (Anon, 2001, Anthony, 1985, Anthony, 1985, Bagshaw, 2012, Columbus, Van Doorn, et al., 1994, Griffin, 1979, Griffin and McCaskill, 1969, Mangialardi, Bargeron, et al., 1988, Moore and Shaw, 1967, Pressley and Thomas, 1951, Sanderson, 1985b).

Some damage to the fiber and seed occurs during the ginning process at the gin stand, where the actual separation of the fibers from the seed occurs (Hughs, Holt, et al., 2017, Mangialardi, Bargeron, et al., 1988, Pressley and Thomas, 1951). Studies have shown that the condition, position, and setting of the saws, as well as the pitch and shape of the saw teeth, are important in maintaining the production capacity of the gin, the quality of the lint produced by the gin, as well as the ginning turn out (Bennett and Gerdes, 1939, Columbus, Van Doorn, et al., 1994, Doraiswamy, Chellamani, et al., 1993). Dull and broken gin saws, as well as bent saw teeth, increase neps (Anthony, 1985, Anthony, 1985, Columbus, Van Doorn, et al., 1994, Leonard, 1969, Mangialardi, 1985).

Lint cleaning was introduced during the 1940s and was developed specifically to remove foreign matter left in the lint after the seed cotton cleaning and ginning stages. Lint cleaners remove leaf particles, grass, motes, stems, bark, seeds, fine trash, sand, and dust and can improve the grade of cotton by removing foreign matter as well as by blending light, spotted cotton (Dever, 1986, Mangialardi, 1981, Mayfield, Baker, et al., 1983, St Clair and Roberts, 1958). Most modern gins have two or more stages of lint cleaning, with two being the most common. The use of more than two saw lint cleaners is generally discouraged due to increasing amounts of short fibers and neps (Hughs, Armijo, et al., 2013, Whitelock, Armijo, et al., 2011). The amount and type of lint cleaning required is dependent on the existing market price differentials between grades, the operating performance of the equipment in the gin, and the trash content and color of the seed cotton itself (Backe, 1988, Baker, 1976, Baker and Bragg, 1988, Berkley, 1957, Doraiswamy, Chellamani, et al., 1993, Mangialardi, 1972, Mangialardi, 1981, Mangialardi, 1995, Mayfield, 1988, Mayfield, 1988, Mayfield, 1989, Mayfield, Baker, et al., 1983, Novick, Jones, et al., 1988).

There are essentially three types of machines used for lint cleaning: the flow-through air lint cleaner, controlled-batt saw lint cleaner, and the batt-less saw lint cleaner (e.g., Sentinel™ and Regal™). Flow-through air lint cleaners, commonly referred to as air-type lint cleaners have no saw, brushes, or moving parts, with cotton transported by air through a duct with an sudden change in direction, which results in the ejection of trash due to centrifugal forces (Doraiswamy, Chellamani, et al., 1993, Mangialardi, 1996a, Mangialardi and Anthony, 1998, Mangialardi, Baker, et al., 1994). These lint cleaners are generally installed immediately behind the gin stand preceding the saw-type lint cleaner, although sometimes they are installed after the first saw-type lint cleaner (Doraiswamy, Chellamani, et al., 1993, Mangialardi, 1990, Mangialardi and Anthony, 1998, Mangialardi, Baker, et al., 1994, Rutherford, McKenzie, et al., 1991). These lint cleaners are less effective in removing trash and improving the grade of the cotton than the saw-type lint cleaner, but they remove less fiber from the bale and do not adversely affect the quality of the fiber as much (Anon, 2001, Berkley, 1957, Le, 2008, Mangialardi, 1990, Mangialardi and Anthony, 1998, Sanderson, 1985b, St Clair and Roberts, 1958).

Controlled-batt saw lint cleaners form lint into a batt that is fed through compression rollers onto a saw cylinder with grid bars and then removed by a doffing brush. Controlled-batt saw lint cleaners are the most common lint cleaner in the ginning industry and are based on cleaning principles that were developed in the 1940s. They generally improve the grade of the lint and reduce card room dust levels as well as residue build up in rotors during rotor spinning, and are recognized as the standard type of cleaner in the ginning industry (Aldrich, 1976, Mangialardi, 1996b). The improper use of controlled-batt saw lint cleaners can reduce ginning turn out and bale value, because fiber length and length uniformity are reduced. These lint cleaners can also adversely affect nep and short fiber levels, as well as yarn appearance, irregularity, and imperfections. They also reduce the size of any remaining trash particles, making them difficult and costly to remove in the spinning mill.

According to an extensive study conducted in the U.S. during 2005 and 2006, controlled-batt saw lint cleaners resulted in a significant increase in cotton grade, with the first and second lint cleaners significantly increasing the grade. This improvement in grade was associated with a decrease in nonlint content and reduction in manufacturing waste in the spinning mill. The number of controlled-batt saw lint cleaners also affected the fiber length, with each lint cleaner significantly reducing fiber length by 0.38 mm; this decrease in fiber length was also associated with a decrease in length uniformity by 0.7% and increase in short fiber content. Neps increased by up to 45 neps/gram with each saw lint cleaner (Hardin, Barnes, et al., 2018, Whitelock, Armijo, et al., 2011). Similar results were achieved by a follow-up laboratory study (Hughs, Armijo, et al., 2013).

Batt-less saw lint cleaners were introduced in 1999 by the Lummus Corporation (Sentinel™) and feed fibers directly to the saw without forming a batt. Trials showed that there was an improvement in fiber properties such as length as tested by HVI and AFIS, with the nep and short fiber content dramatically reduced when using the Sentinel™ lint cleaner as opposed to the traditional controlled-batt saw lint cleaner (Rutherford, 2008, Rutherford, Van Doorn, et al., 2002, Rutherford, Van Doorn, et al., 1999). The improved fiber quality and throughput capacity have led to the acceptance of the Sentinel™ lint cleaner by the ginning industry.

Australia produces predominately irrigated, spindle-harvested Upland cotton (*Gossypium hirsutum* L.), which is ginned with modern super-high-capacity saw gins that are capable of producing more than 1,000 bales per day and more than 100,000 bales per season (van der Sluijs and Holt, 2017). Most gins in Australia are equipped with only two stages of seed cotton cleaning and drying, with two stages of lint cleaning to process irrigated, spindle-harvested cotton.

This study was initiated for two reasons: (1) to determine the cleaning efficiency and effect on fiber quality of seed cotton cleaning stages currently installed in Australian gins in removing trash content. Concerns have been raised whether gins will be able to cope with the almost three-fold increase in trash (Wanjura et al., 2017) delivered to the gin as the industry moves to increased rain-fed (dryland) cotton production and the adoption of the John Deere CS690 round-module stripper. And (2) to determine the influence of the various cotton gin processing systems, particularly lint cleaning, in a high production system on fiber quality. All gins in Australia have two stages of saw lint cleaning in tandem, which are generally used all the time. The reason being that the Australian base grade is Middling (31) with 3-leaf and as cotton is sold predominately on the forward market there is an expectation of Strict Middling (21) with 2-leaf. This grading is somewhat higher than the U.S. base grade that is Strict Low Middling (41) with 4-leaf. The number of lint cleaners exceeds the number of lint cleaners recommended and preferred by the textile industry (Anthony, 2005, Hardin, Barnes, et al., 2018, Mangialardi, 1993) and is in response to the survey on research requirements and needs of the Australian industry, which raised concerns about lint cleaning in terms of quality (van der Sluijs and Holt, 2017).

MATERIALS AND METHODS

The study was conducted during the 2014 and 2015 season, with seed cotton harvested from one field in Moree in the Gwydir Valley in the cotton growing area of New South Wales (NSW). Cotton was produced during the 2014 growing season (planted in 2014; defoliated, harvested, and ginned in 2015), with an estimated average fiber yield of 3254 kg/ha (Table 1).

Table 1. Field size, planting, harvest, and gin date

Field size (ha)	Planting date	1st Harvest Aid date	2nd Harvest Aid date	3rd Harvest Aid date	Harvest date	Gin date
170.5	25 Oct	27 Mar	10 Apr	20 Apr	5 May	10 & 11 June

Table 2. Number and weight of modules, number of bales, and lint turn out

Gin	Number of modules	Total weight of modules (kg)	Number of 227 kg bales	Lint Turn Out %
A	18	41,540	78	42.4
B	18	40,840	76	41.7

The cotton variety was Sicot 74BRF (Stiller, 2010), which was, at that time, the most popular Upland variety grown in Australia. The field was subjected to standard management practices for irrigated cotton in Australia. The field was first subjected to harvest aids by air, with a mixture of leaf defoliant (0.2 L/ha thidiazuron), boll opener (1L/ha ethephon), and defoliant spray oil (l L/ha). It was sprayed by air for a second time with a mixture of leaf defoliant (0.2 L/ha thidiazuron) and defoliant spray oil (l L/ha). It was sprayed by air a third time with a mixture of leaf defoliant (0.2 L/ha thidiazuron), boll opener (2 L/ha ethephon), and defoliant spray oil (l L/ha). The field was harvested using a grower-owned and operated JD 7760 round-module spindle harvester, equipped with PRO-16 row units, which was maintained and operated via normal industry practice and manufacturers recommendations. The ambient air conditions of the field (temperature and relative humidity) were monitored to ensure that moisture content was ≤ 12%. This ensured no excessive drying was needed during the ginning process, as previous studies showed that high seed cotton moisture can affect the processing performance of the gin as well the quality of the fiber and seed (van der Sluijs and Delhom, 2016, van der Sluijs and Long, 2015).

Thirty-six modules, produced sequentially, were chosen for this study, with the first set of 18 modules ginned at Brighann Ginning and the second set of 18 modules ginned at North West Ginning, both situated in Moree, NSW. All modules were ginned under standard commercial conditions with standard processing stages required for spindle-harvested Upland cotton to achieve the Australian base grade. Both gins are modern super-high-capacity gins equipped with 4 x 170 saw gin stands that can produce a total of 60 bales per hour (Buser, 1999, Columbus, Van Doorn, et al., 1994, Hughs, Holt, et al., 2017). Both gins are well maintained, operated according to manufacturer's recommendations and moisture levels monitored and maintained to achieve the required reduction in trash without damaging fiber quality. Both gins are predominately equipped with machines from Lummus Corporation (Savannah, GA). These gins are referred to as Gin A and Gin B. Table 2 summarizes the details of modules and ginned bales of fiber produced by the two gins.

The layout of the two gins are slightly different. Gin A has a stationary head module feeder, 1st stage burner and tower dryer, hot air cleaner, stick machine and TrashMaster™, 2nd stage dryer (Universal Collider, Samuel Jackson, Lubbock, TX), hot air cleaner, pre-700 feeder, conditioning hopper, 700 feeder, gin stand (170 Imperial III), air-type lint cleaner (Super-Jet®), batt-less lint cleaner (2 x Sentinel™), battery conditioner/steam roller, press and bale handling. Samples were collected as per Table 3.

Table 3. Sample collection points and designation for Gin A

Gin Process	Designation
Module	AA
After Module Feeder	AB
After Tower Dryer	AC
After Hot air dryer	AD
After Stick Machine	AE
After Trash Master	AF
After Collider Dryer	AG
After Hot Air Cleaner	AH
After 700 Pre-feeder	AI
After 700 feeder	AJ
Gin Stand	AK
Super Jet	AL
1st L/C	AM
2nd L/C	AN

Gin B has a moving head module feeder, hot box burner, rock trap, control bin, 1st stage burner and tower dryers, hot air cleaner, stick machine (TrashMaster™), 2nd stage burner and tower dryer, hot air cleaner, conveyor distributer, conditioner, moisture conditioner hoppers, Model 700 feeder, gin stand (170 Imperial III), air-type lint cleaner (Super-Jet®), controlled-batt saw lint cleaner (2 x Model 108), battery conditioner/steam roller, press and bale handling. Samples were collected as per Table 4.

Table 4. Sample collection points and designation for Gin B

Gin Process	Designation
Module	BA
Feeder Belt	BB
Before Hot Air Cleaners	BC
Before TrashMaster	BD
After TrashMaster	BE
Before 2nd Stage H/Air Cleaners	BF
After 2nd Stage H/Air Cleaners	BG
After Conditioner	BH
Before Gin Stand	BI
Gin Stand	BJ
Super Jet	BK
1st L/C	BL
2nd L/C	BM

One sample of 400 to 500 g was collected three times (i.e., 3 replicates) during processing of the trial modules, with the first set of samples collected after processing 6 RM, another set collected after processing 12 RM, and the last set after processing 15 RM. Samples were collected after every machine in the processing stage: prior to and after the module feeder, from all the machines during first stage and second stage cleaning and drying, prior and after the gin stand, and prior and after the flow-through air and lint cleaners.

As the seed cotton samples collected during the seed cotton cleaning and drying stages still contained seed, 300 g of each sample were sent to Cotton Seed Distributors (CSD) in Dalby, Queensland, for ginning on their custom-made Continental 20 saw gin, with a pre-cleaner to remove trash and sticks with no lint cleaning. Twenty grams of the resultant fiber from each stage was then processed twice through the Tianjin Jiacheng Mechatronic Equipment Co., Ltd, DSOP-02 digital-sample opening machine at Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Geelong, Victoria. This process was necessary to gently remove trash and dust still present in the fiber to enable fiber quality determination (Fig. 1).

Figure 1. Gin and Opener used to gin and clean seed cotton samples.

Classing samples from opposite sides of each bale were collected at the gin after bale formation. These bale samples as well as the samples collected from the gin stand and lint cleaners were subjected to objective measurement, as per ASTM D5867 (ASTM, 2012), using an Uster® Technologies HVI™ 1000 (Knoxville, TN) at Auscott classing (Sydney, NSW). Two subsamples of each sample were tested for color in terms of yellowness (+b), reflectance (Rd), upper-half mean length (UHML) (mm), bundle strength (g/tex), and micronaire. The above-mentioned quality attributes (excluding HVI color) are used by merchants in Australia to value and trade cotton bales. Visual classing of the lint was assessed for color (color grade), visible trash (leaf grade), and preparation (degree of smoothness or roughness of the cotton sample), according to the 2015 grades as established by USDA AMS, as per ASTM D1684 (ASTM, 2012). Three subsamples of each sample were tested for maturity ratio and fiber fineness by Cottonscope instrument (BSC Electronics, WA, Australia). In addition, these samples, as well as the samples collected during the seed cotton cleaning stages, were also subjected to testing via Uster® Technologies Advanced Fiber Information System instrument (AFIS PRO, Knoxville, TN). Three subsamples of 5,000 fibers each were tested to determine total fiber, seed coat neps (SCN), trash (> 500 µm), dust (< 500 µm), and percent visible foreign matter (VFM%) as per ASTM D5866 (ASTM, 2012).

The samples were tested randomly to minimize any bias and the instrument was thoroughly cleaned between samples to prevent any cross contamination of the results, specifically in terms of trash and dust. The percentage of the weight of usable fiber per the weight of unginned seed cotton (lint turn out) was calculated by the commercial ginning operators at a commercial scale using module and ginned bale weights.

To test for statistical differences between treatment means, ANOVA was conducted on the experimental data using Genstat 16.0 (Lawes Agricultural Trust, IACR Rothamsted, UK). The standard deviation (sd) was also calculated to provide a measure of the amount of variation. Where significant statistical differences at the $\alpha = 0.05$ and lower level were identified, Fisher's least significant differences (LSD) were calculated from which the means differences were derived. For ease of interpretation, nonsignificant results were designated as ns. Means with the same letter were not significantly different.

RESULTS AND DISCUSSION

Seed Cotton Cleaning. Seed cotton consists of fiber, seed, and trash. To quantify the amount of trash removed during the seed cotton cleaning process it is necessary to determine the proportions of the three components. Previous studies conducted in Australia in 2016 and 2017 (van der Sluijs, 2018, van der Sluijs, Nahi, et al., 2018), concluded that the average percentage of seed present in seed cotton, irrespective of variety was 47.2%. With this assumption and the measured weight of seed cotton and lint, the amount and percentage of trash was calculated. As can be seen in Tables 5 and 6 the average trash content present in the seed cotton averaged from 7.3 to 8.2% (AA and BA), which was similar to trials conducted at two other gins (van der Sluijs, 2017) and is considered typical for spindle-harvested, irrigated cotton (Anthony, 2005, van der Sluijs, 2018, van der Sluijs, Nahi, et al., 2018, Wanjura, Baker, et al., 2017). The effect of the various seed cotton cleaning stages installed in Gin A and Gin B as the seed cotton is processed are shown in Appendix 1.

Gin A. The incoming moisture of the modules as measured by the Vomax 851B cotton moisture meter averaged < 11%, thus the burner settings for processing the seed cotton during the first stage drying was set at 100 to 65 °C (212-149 °F), with the burners set at 75 to 58 °C (167-136 °F) during second stage drying, with moisture levels at the gin stand maintained between 5 and 8%. There was an overall reduction in trash content of 22.7%, with a large reduction in trash of 17.9% occurring at the stick machine (AE), with further minimal amounts of trash removed after the first-stage hot air cleaner and the 700 feeders. Interestingly, there was a slight increase in the amount of trash after the module feeder and tower dryer and a large increase of 13.8% after the second-stage hot air cleaner (AH) (Table 5 and Appendix 1). The increase in trash after the second-stage hot air cleaner was also noted in the AFIS PRO results and was attributed to an increase in dust content (16 particles/g) as well as a slight reduction in trash size (9 µm) (Table 7).

Table 5. Average amount of % lint, seed, and trash present at the various stages

Gin Process	% Lint	% Seed	% Trash
AA	45.5	47.2	7.3
AB	45.2	47.2	7.6
AC	45.1	47.2	7.7
AD	45.7	47.2	7.1
AE	46.9	47.2	5.9
AF	46.7	47.2	6.1
AG	46.9	47.2	5.9
AH	46.3	47.2	6.5
AI	47.2	47.2	5.6
AJ	47.2	47.2	5.6

Table 6. Average amount of % lint, seed, and trash present at the various stages

Gin Process	% Lint	% Seed	% Trash
BA	44.6	47.2	8.2
BB	45.5	47.2	7.3
BC	45.1	47.2	7.7
BD	45.4	47.2	7.4
BE	45.8	47.2	7.0
BF	45.9	47.2	6.9
BG	45.3	47.2	7.5
BH	46.6	47.2	6.2
BI	47.3	47.2	5.5

Table 7. AFIS PRO determined trash for seed cotton for Gin A

Gin Process	Total trash /gram	sd	Total trash size µm	sd	Trash /gram	sd	Dust /gram	sd	VFM %	sd
AA	254d	81	368	40	56c	20	197	63	0.90	0.36
AB	191c	72	361	26	43b	15	148	58	0.62	0.23
AC	183b	76	366	54	39a	19	144	54	0.69	0.42
AD	197b	90	375	62	42b	18	155	77	0.72	0.33
AE	175b	73	372	43	40a	12	135	63	0.63	0.62
AF	139a	52	369	46	30a	9	109	47	0.46	0.16
AG	162b	89	363	57	34a	14	128	30	0.60	0.29
AH	178b	76	354	44	35a	13	144	66	0.57	0.75
AI	121a	56	399	61	29a	13	93	46	0.55	0.22
AJ	171b	58	345	34	33a	14	139	47	0.50	0.21
p value	<0.001		ns		<0.001		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different.

Gin B. The incoming moisture of the modules as measured by the Vomax 851B cotton moisture meter averaged < 10%, thus the hot box burner was set at 60 °C (140 °F) with the burners set at 55 to 45 °C (131-113 °F) during second-stage drying, with moisture levels at the gin stand maintained between 5 and 8%. There was an overall reduction in the trash content of 32.8%. There was a large reduction of 11.8% after the module feeder (BA), followed by the stick machine (BE) with a reduction of 5.8%, with minimal trash removed by the conditioners and the 700 feeders (BH and BI). The amount of trash increased 5.6% after the feeder belt (BC), which can be attributed to dust generated in that area. As was the case in Gin A there was an increase of 8.4% in the amount of trash after the second-stage hot air cleaner (BG) (Table 6). These changes were also noted in the AFIS PRO results, with a significant increase in the trash (56 particles/g) and dust counts (248 particles/g) after the feeder belt (BC), and a substantial increase in dust content (84 particles/g) as well as a slight reduction in trash size (23 µm) after the second-stage hot air cleaner (BG) (Table 12).

Lint Turn Out. Average lint turn out for Gin A was 42.4% and 41.7% for Gin B (Table 2), with the difference of 0.7% significant for a grower in terms of economic return. This difference was not entirely unexpected as the controlled-batt saw type lint cleaner is more aggressive than the batt-less saw lint cleaner and, thus, removed more trash and usable lint. Previous studies (Anthony, 2005, Baker and Brashears, 1999, Mangialardi, 1993, Mangialardi, 1996b, Mangialardi and Anthony, 2003) showed that two controlled-batt saw-type lint cleaners can reduce bale weights by up to 60 lb (27 kg) and reduce gin turn out by up to 2%. The difference in trash content between Gin A and Gin B is shown in the HVI and AFIS PRO trash results as shown in Tables 10 and 15.

Fiber Quality. *Gin A.* As can be seen in Tables 7 and 8, there were significant differences between the average trash and nep results, as measured by AFIS PRO, gathered from the various seed cotton cleaning equipment prior to the gin stand, designated AA to AJ. Seed cotton cleaning had positive and significant effects on total trash and trash counts; negative results on total nep and fibrous neps; and no effect on number and size of SCN, fiber nep size, fineness and maturity. As observed in the seed cotton cleaning section, there was a significant decrease in the amount of trash, in terms of total trash content and trash count as the seed cotton was processed through the various cleaning equipment. Although there was an insignificant overall reduction in trash size, there was an increase of 12.7% after the 700 feeders (AI). Although there was no effect on SCN, there was however, a significant increase of 41% (201 to 284 neps/g) in the number of fibrous neps after the module feeder (AB), with this amount of fibrous neps maintained throughout the rest of the seed cotton cleaning process. This increase in fibrous neps can be due to several reasons: irregular feed to beaters; bent teeth; working surfaces are not clean, smooth, free from nicks, rough spots and rust; and that the piping is free of nicks, joints, and dents; and is not too long (van der Sluijs and Hunter, 2016). There was also a slight but insignificant increase in nep and SCN size, which increased by 11 µm (651 to 662 µm) and by 47 µm (890 to 937 µm) respectively. There was also a small but insignificant increase in fiber fineness, which increased by 9 mtex (182 to 191 mtex) and could be attributed to the removal of immature fibers.

As can be seen in Tables 9, 10, and 11, there were significant differences between the average lint results gathered after the ginning process. The air flow lint cleaner (AL) had virtually no effect on the fiber properties, with slight and insignificant improvements in AFIS PRO and HVI trash levels. Batt-less saw lint cleaners had positive and significant effects on color and trash; negative effects on fiber length, nep content, and fiber fineness; and no effect on strength, short fiber content, length uniformity, micronaire, elongation, maturity ratio, number and size of SCN, and fiber nep size. The batt-less saw lint cleaners improved the color results in terms of +b and Rd values, resulting in the HVI color grade improving from 41-1 (Strict Low Middling) after the gin stand (AK) and air type lint cleaner (AL), to 31-1 (Middling), after the first and second batt-less saw lint cleaner (AM and AN). This color grade was maintained to the bales of lint produced with the average color grade 31-1 and the visual color grade of 31 with leaf grade of 3, which is the Australian base grade for Upland cotton. The improvement in fiber color coincided with reduced trash and dust counts as measured by AFIS PRO and significant reduced trash count, percentage area, and trash grade as measured by HVI, especially after the second batt-less saw lint cleaner. The mean trash size increased from 332 µm before lint cleaning to 352 µm after two batt-less saw lint cleaners (Table 10). It is currently unclear what the reasons are for this slight but significant increase in mean trash size.

There was a slight deterioration in the fiber length after the first batt-less saw lint cleaner (AM), with a larger and significant decrease after the second batt-less saw lint cleaner (AN) of 0.54 mm, which is equal to one 32nd shorter (39 to 38). The total and fibrous neps both increased by 17% after the first batt-less saw lint cleaner (AM) and a further increase of 10% after the second batt-less saw lint cleaner (AN) (Table 11). In terms of fineness and maturity as determined by the Cottonscope instrument, there was also a small but statistically significant decrease in fiber fineness, with fiber fineness on average 3 and 7 mtex finer, respectively, after the first and second batt-less saw lint cleaners (AM and AN). After the second batt-less saw lint cleaner (AN) the fiber is transported via the lint flue to the battery condenser and lint slide before being pressed into a high-density bale.

Table 8. AFIS PRO and Cottonscope determined fiber properties for seed cotton for Gin A

Gin Process	AFIS PRO										Cottonscope			
	Total neps/gram	sd	Fiber neps/gram	sd	SCN /gram	sd	Nep size µm	sd	SCN size µm	sd	Fn mtex	sd	MR	sd
AA	214a	26	201a	26	13	3	651	19	890	146	182	6	0.98	0.00
AB	296b	47	284b	49	12	4	655	21	924	152	187	11	0.97	0.02
AC	314b	57	301b	56	13	5	653	11	885	116	191	9	0.98	0.01
AD	304b	49	292b	48	12	5	661	17	800	261	195	6	0.98	0.01
AE	296b	50	285b	49	10	4	663	11	1030	191	190	9	0.97	0.01
AF	318b	38	307b	40	11	5	651	12	914	153	191	14	0.95	0.01
AG	298b	55	287b	54	11	4	655	17	878	113	197	7	0.97	0.02
AH	321b	84	308b	82	13	4	658	18	868	161	190	9	0.97	0.01
AI	323b	31	312b	30	11	6	656	16	1000	160	201	5	0.99	0.01
AJ	311b	32	298b	31	13	6	662	12	937	177	191	11	0.97	0.02
P value	<0.001		<0.001		ns		ns		ns		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different.

Table 9. HVI determined fiber properties for cotton lint for Gin A

Gin Process	+b	sd	Rd	sd	UHML mm	sd	UI %	sd	SFI %	sd	Str g/tex	sd	El %	sd	Mic	sd
AK	7.0a	0.2	76.4a	0.8	31.18b	0.3	82	0.9	8.3	0.5	31.2	0.9	5.4	0.1	4.02	0.08
AL	7.1a	0.3	77.0a	1.1	31.46c	0.5	82	1	7.7	0.7	31.4	0.5	5.3	0.1	4.01	0.11
AM	7.5b	0.2	79.6b	0.7	31.12b	0.5	82	0.7	8.3	0.7	31.0	0.5	5.3	0.1	4.03	0.08
AN	7.4b	0.3	80.4b	0.5	30.58a	0.4	82	0.5	8.8	0.4	30.1	0.7	5.3	0.1	4.08	0.19
P value	<0.001		<0.001		<0.001		ns		ns		ns		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 10. HVI and AFIS PRO determined trash for cotton lint for Gin A

Gin Process	HVI						AFIS PRO											
	Trash count	sd	% Area	sd	Leaf grade	sd	Total trash/gram	sd	Total trash size µm	sd	Trash /gram	sd	Dust /gram	sd	VFM %	sd
AK	31c	5	0.47c	0.20	3.0c	0.4	280	32	332a	10	49	5	231	30	0.85	0.15
AL	27c	6	0.41c	0.19	2.9c	0.5	256	49	335a	18	44	9	212	42	0.76	0.14
AM	21b	4	0.26b	0.10	2.6b	0.5	249	63	350b	12	46	11	203	52	0.91	0.31
AN	16a	4	0.18a	0.04	2.1a	0.3	213	34	352b	13	40	8	173	27	0.77	0.17
P value	<0.001		<0.001		<0.001		ns		<0.001		ns		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 11. AFIS PRO and Cottonscope determined fiber properties for cotton lint for Gin A

Gin Process	AFIS PRO										Cottonscope			
	Total neps/ gram	sd	Fiber neps/gram	sd	SCN /gram	sd	Nep size µm	sd	SCN size µm	sd	Fn mtex	sd	MR	sd
AK	248a	23	230a	23	18	5	685	9	944	72	195b	5	0.96	0.01
AL	252a	26	235a	25	17	2	678	8	937	61	194b	4	0.96	0.02
AM	295b	36	275b	36	20	4	685	11	948	38	191a	4	0.96	0.02
AN	324c	29	304c	28	20	5	687	12	927	71	188a	4	0.96	0.01
p value	<0.001		<0.001		ns		ns		ns		<0.001		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Gin B. As can be seen in Tables 12 and 13, there were no significant differences between the average trash and nep results obtained from the seed cotton cleaning equipment prior to the gin stand, designated BA to BI. There were, however, significant differences in terms of trash, although these differences do not result in an overall reduction in the trash and dust count. For example, there was a large increase in trash values as measured by AFIS PRO after the feeder belt (BC) and after the second stage hot air cleaner (BG), which was mainly due to increased dust and trash counts (Table 12).

As can be seen in Tables 14, 15, and 16, there were significant differences between the average lint results gathered after the ginning process. The air flow lint cleaner (BK) had little effect on the fiber properties, with slight increase in trash levels mainly due to increased dust count as measured by AFIS PRO. The controlled-batt saw lint cleaners had positive and significant effects on color and trash; negative effects on length, length uniformity, short fiber index, elongation, total and fibrous nep content; and no effect on strength, micronaire, fineness, maturity, number and size of SCN, and fiber nep size. The controlled-batt saw lint cleaners improved color results in terms of +b and Rd values, resulting in the HVI color grade improving from 31-2 (Middling) after the gin stand (BJ) and air type lint cleaner (BK), to 21-2 (Strict Middling) after the first and second controlled-batt saw lint cleaner (BL and BM). This color grade was maintained to the bales of lint produced with the average HVI color grade of 21-1 and visual color grade 21 with leaf grade of 3; which is better than the Australian base grade for Upland cotton and resulted in a small premium. The improvement in fiber color coincided with significantly reduced trash and dust counts, as well as VFM% as measured by AFIS PRO and significantly reduced trash count, % area, and trash grade as measured by HVI, especially after the second controlled-batt saw lint cleaner (Table 15).

There was a slight deterioration in the fiber length after the first controlled-batt saw lint cleaner with a larger and significant decrease after the second controlled-batt saw lint cleaner (BM) of 0.68 mm, which is one 32nd shorter (39 to 38). There was also a deterioration in length uniformity from 83 to 81 and an increase in short fiber index of just over 1% after the first and second controlled-batt saw lint cleaners. There was also a significant difference in the elongation value after the second controlled-batt saw lint cleaner, possibly due to issues with the HVI elongation measurement, that is; high replicate variation, fiber slippage, and crimp and also that this is a noncalibrated measurement (Table 14). The amount of total and fibrous neps both increased by 17% after the first controlled-batt saw lint cleaner (BL) and a further increase of 10% after the second controlled-batt saw lint cleaner (BM) (Table 16). After the second controlled-batt saw lint cleaner (BM) the fiber is transported via the lint flue to the battery condenser and lint slide before being pressed into a high-density bale.

Table 12. AFIS PRO determined trash for seed cotton for Gin B

Gin Process	Total trash/ gram	sd	Trash size µm	sd	Trash /gram	sd	Dust /gram	sd	VFM %	sd
BA	261a	49	351	13	51a	10	209a	39	0.86	0.23
BB	275a	99	363	15	58b	23	217a	76	0.99	0.49
BC	579b	223	356	19	114d	23	465b	184	2.16	0.81
BD	364a	202	379	23	79c	55	285a	165	1.50	0.73
BE	393a	142	360	34	74b	43	318a	123	1.53	0.44
BF	260a	134	377	29	52a	23	208a	112	1.11	0.56
BG	361a	78	354	13	68b	12	292a	64	1.36	0.30
BH	312a	106	377	47	63b	10	250a	92	1.25	0.39
BI	217a	64	382	16	45a	29	171a	52	1.01	0.33
p value	<0.001		ns		<0.001		<0.001		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 13. AFIS PRO and Cottonscope determined fiber properties for seed cotton for Gin B

Gin Process	AFIS PRO										Cottonscope			
	Total neps/ gram	sd	Fiber neps/ gram	sd	SCN /gram	sd	Nep size µm	sd	SCN size µm	sd	Fn mtex	sd	MR	sd
BA	278	43	269	44	9a	1	655	4	977	85	186	7	0.94	0.02
BB	272	24	258	26	15a	3	665	9	991	20	192	7	0.96	0.01
BC	283	22	257	22	26b	7	675	12	914	83	184	8	0.94	0.01
BD	305	40	291	39	15a	6	667	13	923	61	190	10	0.95	0.01
BE	307	47	287	45	21b	5	670	8	942	43	183	13	0.95	0.02
BF	297	35	282	39	16a	6	667	14	944	95	193	7	0.96	0.01
BG	334	37	314	37	20b	5	671	7	925	111	190	10	0.95	0.01
BH	318	23	298	28	19b	6	677	15	920	75	187	8	0.96	0.01
BI	313	29	293	30	21b	6	678	8	967	38	189	7	0.96	0.01
p value	ns		ns		ns		ns		ns		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 14. HVI determined fiber properties for cotton lint for Gin B

Gin Process	+b	sd	Rd	sd	UHML mm	sd	UI %	sd	SFI %	sd	Str g/tex	sd	El %	sd	Mic	sd
BJ	7.5a	0.3	78.0a	1.0	30.88d	0.57	83c	1	8.2a	1.2	30.1	0.7	6.0a	0.3	4.23	0.08
BK	7.5a	0.3	78.3a	0.5	30.67b	0.80	83c	1	8.4b	0.9	30.2	1.0	6.1b	0.3	4.22	0.07
BL	7.6a	0.3	78.4a	0.6	30.73c	0.4	82b	1	8.8c	1.0	30.2	0.7	6.1b	0.3	4.23	0.09
BM	7.9b	0.3	80.3b	0.8	30.05a	0.25	81a	1	9.9d	0.6	29.8	0.7	6.6c	0.3	4.19	0.07
p value	<0.001		<0.001		<0.001		<0.001		<0.001		ns		<0.001		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 15. HVI and AFIS PRO determined trash for cotton lint for Gin B

Gin Process	HVI						AFIS PRO											
	Trash count	sd	% Area	sd	Leaf grade	sd	Total trash/ gram	sd	Total trash size µm	sd	Trash/ gram	sd	Dust/ gram	sd	VFM %	sd
BJ	34b	17	0.43b	0.23	1	1	209b	21	359	21	40b	6	169b	17	0.80b	0.14
BK	34b	13	0.47c	0.25	1	0	250c	37	358	18	49c	10	201c	28	1.00c	0.23
BL	33b	8	0.41b	0.16	1	0	253c	37	354	18	49c	9	204c	31	0.94b	0.16
BM	26a	4	0.19a	0.08	1	0	137a	27	368	27	29a	6	109a	22	0.51a	0.11
P value	<0.001		<0.001		ns		<0.001		ns		<0.001		<0.001		<0.001	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

Table 16. AFIS PRO and Cottonscope determined fiber properties for cotton lint for Gin B

Gin Process	AFIS PRO										Cottonscope			
	Total nep/ gram	sd	Fiber neps/ gram	sd	SCN/ gram	sd	Nep size µm	sd	SCN size µm	sd	Fn mtex	sd	MR	sd
BJ	212a	17	197a	16	15	3	670	10	883	61	191	4	0.96	0.01
BK	222a	14	206a	14	15	2	674	10	911	51	190	4	0.96	0.01
BL	229b	17	214b	18	16	4	673	12	874	70	191	5	0.96	0.10
BM	334c	26	317c	27	16	3	677	6	929	54	189	3	0.96	0.04
p value	<0.001		<0.001		ns		ns		ns		ns		ns	

nonsignificant results are designated as ns, with means, with the same letter were not significantly different

CONCLUSION

This study was conducted to determine: (1) the cleaning efficiency and effect on fiber quality of seed cotton cleaning stages installed in Australian cotton gins that currently process predominately irrigated, spindle-harvested Upland cotton, and (2) the influence of the various cotton gin processing systems on fiber quality and gin turn out. Results from this study, and other similar studies show that the amount of trash delivered to Australian gins was typically < 10%, with gins able to reduce the amount of trash by 20 to 40% during the seed cotton cleaning process with the remaining trash removed by subsequent lint cleaning stages. Currently this reduction in trash and the performance of the cotton gins, in general, is enough to obtain the fiber quality required for Australian cotton to be competitive on the international cotton market. However, as the industry moves to increased rain-fed cotton production and the associated large increase in trash due to increased harvesting by strippers, the current seed cotton cleaning stages installed will not be able achieve the leaf grades required by the forward market. Gins will need to adapt by upgrading, replacing, or even installing additional equipment in their seed cotton cleaning lines as well as adding automated process controls to cope with increased trash and reduce the number of lint cleaners used to achieve the required grades.

In terms of fiber quality, results from the study show that the gin stand has no influence on fiber quality if they are not overloaded, are maintained to manufacturers recommendations, and that moisture levels are maintained between 5 and 8%. Flow-through air lint cleaners had no effect on fiber quality, with only minimal reduction in trash. The controlled-batt saw lint cleaners and batt-less saw lint cleaners (Sentinel™) generally had positive and significant effects on color and trash; negative effects on fiber length, nep content, and fiber fineness; and no effect on strength, short fiber content, length uniformity, micronaire, elongation, number and size of SCN, and fiber nep size. The controlled-batt saw lint cleaners were more aggressive than the batt-less saw lint cleaners and removed more trash, and hence, achieved a better color grade, with this improvement resulting in an approximate 1% reduction in gin turn out. The fiber length was 0.5 mm shorter (approximately one 32nd), with 1.1% more short fibers and slightly more fibrous neps.

Gin process control systems that provide on-line measurement of moisture and fiber parameters (currently only leaf grade) are currently being installed in a large number of gins to assist ginners in minimizing fiber damage and maximizing turn out to realize the best return for the grower (Hardin, Barnes, et al., 2018, van der Sluijs and Hunter, 2016).

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DISCLAIMER

Mention of product or trade names does not constitute an endorsement by Textile Technical Services over other comparable products. Products or trade names are listed for reference only.

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Appendix 1 – Seed cotton processing through the cotton Gin (Gin A)

AA

AB

AB

AD

AE

AF

AG

AH

AI

AJ

Appendix 1 – Seed cotton processing through the cotton Gin (Gin B)

BA

BB

BC

BD

BE

BF

BG

BH

BI

BJ