



FINAL REPORT 2016

For Public Release

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: **CMSE1501**

Project Title: Determining the shelf life of round modules
and impact on cotton quality

Project Commencement Date: 1/7/2014 **Project Completion Date:** 30/11/2016

CRDC Research Program: 3 Customers

Part 2 – Contact Details

Administrator: Jo Cain

Organisation: CSIRO

Postal Address: **Locked Bag 59, Narrabri NSW 2390**

Ph: 02 6799 1513 **Fax:** 02 6793 1186 **E-mail:** jo.cain@csiro.au

Principal Researcher: Menghe Miao, Principal Research Scientist

Organisation: CSIRO Manufacturing

Postal Address: PO Box 21, Belmont, Vic 3216

Ph: 03-5246 4000 **Fax:** 03-5246 4057 **E-mail:** menghe.miao@csiro.au

Supervisor: Stuart Gordon, Principal Research Scientist

Organisation: CSIRO Manufacturing

Postal Address: PO Box 21, Belmont, Vic 3216

Ph: 03-5246 4000 **Fax:** 03-5246 4057 **E-mail:** stuart.gordon@csiro.au

Signature of Research Provider Representative: _____

Date Submitted: _____

Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

The objective of this project was to determine the shelf-life, i.e., the storage period of the round modules from harvest date through to ginning. The use of the new round module builder harvesters has grown very quickly in Australia, reaching about 90% in 2015. The plastic wrapped round modules are stored out in the open, in a gin yard, subject to solar heat and radiation, wind and rain. Growers have expressed concerns about the consequences of the situation where modules may be kept in the sun and through wet weather conditions for extended periods prior to ginning.

Conventional modules are still the dominant method of seed cotton storage in the USA and were the dominant method in Australia until a few years ago. Almost all existing research and industrial protocols for seed-cotton storage are based on studies of conventional modules. This research has examined changes to fibre and seed quality during storage as a result of changes in moisture, trash, temperature and time of storage [1]. The current recommendation is to harvest and store seed-cotton at moisture levels below 12%. Increased temperature within conventional modules has been used as an indicator of excessive moisture in conventional modules with the subsequent increased risk of fire and reduced fibre quality. Studies in the USA indicate that increases in temperature at harvest and during storage have an effect on the yellowing of seed-cotton. Elevated moisture content also causes yellowing to increase sharply, particularly at levels above 13-14% and especially when the storage period exceeds 45 days.

As the round module is wrapped in multiple layers of plastic (polyethylene) film there are concerns, despite industry protocols, i.e., of keeping seed-cotton at harvest to <12% RH, that both temperature and moisture content might increase unduly during storage resulting in potential impacts on fibre and seed quality. A recent literature survey shows no investigations of the moisture and temperature profiles of round modules during storage nor of the impact of these conditions on fibre quality. Some investigations that broadly inform current industry practice are summarised below.

The guideline for safe storage of cotton bales (lint) is 8% moisture content (cf 12% for seed-cotton). Chun et al [1-3] conducted a microbial census on cotton bales stored for six months from harvest in fall (in the USA). They found that microbial populations did not change significantly within one and two month storage periods during the colder winter months. The greatest microbial changes, associated with moisture content, occurred after six months of storage, during the warmer spring and summer months.

At high moisture, the microbial activities of a wide range of bacteria, will cause changes in the colour and tensile properties of cotton fibre. The level of biodegradation depends on many factors, of which the initial moisture content of the seed-cotton, relative humidity, temperature and the duration of storage are most important [4].

Moisture content of seed cotton can affect the physical properties of the cotton fibre and its processing performance in the gin. Moore and Griffin [5] found that single fibre breaking force increases with increasing moisture content in the range of 3% to 15%, while fibre-seed attachment forces remain constant from 3% to 11% and then decrease as moisture content increased up to 15%. For conventional modules, dry cotton leads to better cleaning efficiency and usually higher colour grades. Higher moisture content can often be associated with improved fibre strength and length [6]. To achieve the best results, seed cotton may be dried

or conditioned according to the moisture content in the cotton module immediately before ginning [7].

A recent investigation [8, 9] conducted on round modules harvested at two ranges of moisture content (the lower moisture range 10.4-11.7 %, named as <12%, and higher moisture range 12.6-12.7%, named as >12%) found “...there was a significant difference between the two moisture levels for fibre colour, with seed cotton harvested at >12% resulting in fibre that was yellower, with lower reflectance and a colour grade of 52, compared to a 51 grade for seed cotton harvested at <12% treatment. The seed cotton harvested at >12% had more trash with a leaf grade of 3, compared to a leaf grade of 2 for the seed cotton harvested at the <12% level. There was no significant difference between the two moisture levels in terms of fibre length and strength, but fibre micronaire was higher for the higher moisture content.”

Hamann [10] conducted a laboratory study on the impact of cotton harvesting and storage methods on seed and fibre quality. Samples of seed cotton were sealed in plastic containers for up to three months at varying levels of moisture, density, and trash content. Samples were ginned and the resulting cottonseed and fibre were analysed. The moisture content of the seed cotton used in the experiments were very high, ranging from 12% to 21%. Moisture content was found to be the most prevalent factor, affecting elongation, free fatty acid content, micronaire, length, and colour; both yellowness and reflectance. Increased storage time caused decreases in strength and reflectance, and increases in uniformity, yellowness, and free fatty acid levels.

The moisture levels used in most of these investigations were untypically high in order to demonstrate the effect of moisture on fibre quality. They are not within the recommended range for harvesting cotton and well above the moisture levels commonly seen in Australia. And except for van der Sluijs et al [8 and 9], nor were any of these investigations applied to the new round modules wrapped in plastic.

References

- [1] Anthony WS, Mayfield WD. Cotton ginner's handbook: DIANE Publishing; 1995.
- [2] Chun D, McAlister D, Hughs S, Cobb D. Microbial census and cotton bale moisture during a 6-month storage. Proc Beltwide Cotton Conferences; p. 2425-31.
- [3] Chun D, McAlister D, Cobb D. Microbial activity of stored cotton bales with ambient and moderate moisture levels. J Cotton Sci. 2005; 9:24-9.
- [4] Chun D, Anthony W. Biological degradation of cotton bales due to excess moisture. National Cotton Council Beltwide Cotton Conference.
- [5] Moore VP, Griffin C. The relationship of moisture to cotton quality preservation at gins: US Department of Agriculture, Agricultural Research Service; 1964.
- [6] Byler R. The effect of modest moisture addition to seed cotton before the gin stand on fiber length. J Cotton Sci. 2005; 9:145-54.
- [7] Byler RK. Historical review on the effect of moisture content and the addition of moisture to seed cotton before ginning on fiber length. J Cotton Sci. 2006; 10:300-10.
- [8] van der Sluijs MH, Long RL. The effect of seed cotton moisture during harvesting on—part 1—fiber quality. Textile Research Journal. 2015 Nov 20:0040517515617426.
- [9] van der Sluijs MH, Delhom C. The effect of seed cotton moisture during harvesting on—part 2—yarn and fabric quality. Textile Research Journal. 2016 Jul 13:0040517516659381.
- [10] Hamann MT. Impact of Cotton Harvesting and Storage Methods on Seed and Fiber Quality. MSc Thesis, Texas A&M University, 2011.

Objectives

2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.

The primary objective of the project was to determine the impact of storage period of round modules on cotton fibre quality subject to current recommended industrial conditions. The modules observed were grown commercially using irrigated production and all harvested according to BMP guidelines. The moisture content of the seed-cotton in all modules examined across three different sites in two years was typically below 9%. The trial results represent several thousands of bales tested by commercial cotton testing facilities.

Milestone 1.1. Temperature/moisture mapping and fibre quality assessments in relation to module storage duration. (Performance indicator: Interim report submitted)

Completed.

In addition to the two trial locations (Emerald QLD and Warren NSW) as planned in the proposal, a further trial site was added in the far south of the cotton production area (Hay NSW), taking into account of the recent expansion of the industry into the Murrumbidgee Irrigation Area (MIA).

Milestone 1.2. temperature/moisture mapping, fibre quality tests from year 1 and year 2 combined, microbial identification, analysis of results, and recommendations (Performance indicator: final report submitted)

Completed with the submission of this report.

Temperature and moisture mapping trials at the three sites were repeated over two seasons (2014/15 and 2015/16). The level of microbial activity was not measured in these trials due to the fact that the modules at all trial sites were harvested under normal to dry moisture conditions. This meant that microbial activity did not cause any concern for quality of the ginned cotton.

Conclusions and recommendations drawn from the results are presented in this report.

Milestone 1.3. Establishing effect of harvesting time and module storage time on fibre quality by making use of historical industrial data (Performance indicator: Final report includes analysis of commercial harvest data that i) informs calculations of opportune module storage times, ii) the effect of harvesting time and module storage time and conditions on fibre quality and (iii) integrates BOM weather conditions data into the assessment of the effect of storage time on fibre quality)

Completed.

A large database of HVI test data (>220K bales in both 2015 and 2016) matched with picking and ginning dates was analysed. Cotton represented in the databases came from five major cotton growing regions processed in six gins (Moree, Warren, Narrabri, Trangie and Hay). Distributions of cotton characteristics, correlations between module storage duration and interested cotton quality indicators were drawn. Bureau of Meteorology (BOM) weather conditions for each region were examined to identify effects of rain events on fibre quality.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

3.1. Round module storage and ginning trials

Cotton grown in the same field were used in each module storage/ginning trial. Some of the modules were ginned shortly after they arrived in the gin yarn (control or phase 1), with the rest stored in the gin yard and ginned after a period of storage time (identified as phase 2 or phase 3). All phases of ginning for the same trial were carried out in the same gin according to the company's standard operating conditions and procedures.

The fibre quality of each trial was tested at the same testing facility under standard conditions and using standard procedures, i.e., the ITMF HVI Users Guide and the CCAA BMP guidelines.

The locations and coordinates of the three sites are shown in Figure 1.

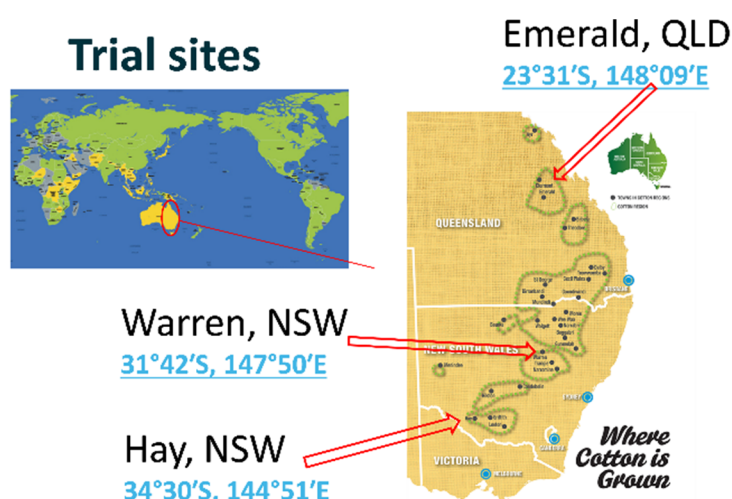


Figure 1. Industrial trial sites.

3.2 Sensor and recording methods for continuous monitoring of round modules

Temperature and humidity in each tagged trial module was monitored using a temperature and humidity sensor connected by cable to a Hobo Pro V2 (U23-002) data logger. The data logger was positioned on the outside of the module with the sensor inserted into the middle of the module (to a depth of 1100 mm) at the desired location using special hand tool manufactured by CSIRO. Values of relative humidity (RH) and temperature inside the module were recorded by the data logger at 15 minute time intervals. At this rate the sensor and data logging system can capture and record one set of data (RH and temperature) every 15 minutes for more than six months without intervention (or every 30 minutes for more than a year). This ability enabled a full history of the conditions that each module was subject to be recorded.

The sensors were fitted into the test modules usually within two weeks after harvest, when they had been relocated to the gin yard. After the sensors were fitted the modules were then stored and examined for the prescribed (phase 2 or 3) periods.



Figure 2. Temperature and moisture sensor with data logger for continuous monitoring of round modules.

3.3. Converting temperature and relative humidity into moisture content

As the sensors measure the instantaneous temperature and relative humidity of the air gap in the sensor housing situated inside the round modules, the measured data needed to be related to the moisture content of the fibre. To do this loose seed cotton of known moisture content was sealed in a plastic bag with the data logging sensor inserted at the centre of the bag. More than 5 kg of loose seed-cotton was hand pressed into a plastic bag to achieve a density of 300 kg/m^3 , which is approximately the same as the density of seed cotton in a typical round module. The moisture content of the loose seed cotton was adjusted to the desired level by spraying distilled water. The sealed bag was then conditioned in a climate chamber set to a desired temperature between 10°C and 50°C . The chamber temperature was adjusted to 50°C and kept at that temperature for 48 h, during which the RH reading from the sensor stabilized. The chamber temperature was then lowered by 5°C to 45°C and kept for 24 hours, and so on until the chamber temperature reached 10°C . The moisture content in the seed cotton was measured before sealing the bag and after the temperature experiment completed to ensure there was not loss or gain of moisture during the experiment.

The isothermal relationship between the stabilised relative humidity and temperature for four levels of moisture content obtained in this way were all linear, as shown in Figure 3. The results show that the relative humidity increased slightly with the increase of temperature in the air gap in the cotton bag. At low moisture content (6.3%), the relative humidity was 51.5% when the temperature in the bag was 10°C . The relative humidity increased by 8.2% to 59.7% when the temperature in the bag was raised to 50°C . When the moisture content was 9% or higher, the increase of relative humidity due to temperature change from 10°C to 50°C was considerably smaller, at 4.5%.

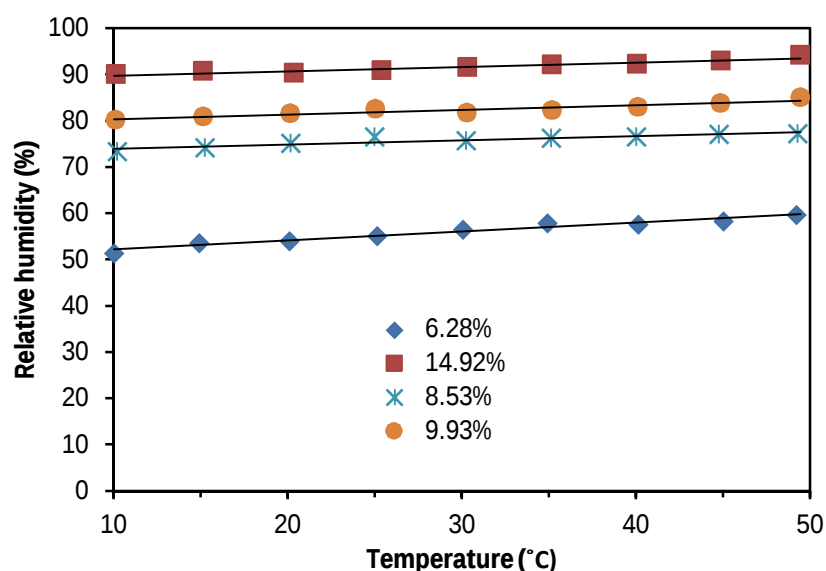


Figure 3. Isothermal relationships between temperature and relative humidity of seed cotton at different moisture contents.

3.4. Laboratory experiments

A series of laboratory experiments were conducted to closer examine the effects of microbial activity and to extend the moisture treatment range of seed-cotton. To do this small (3 kg) samples of seed cotton were conditioned in a climate chamber at desired temperature and relative humidity conditions for a predetermined period of time. The seed cotton was then ginned on a miniature gin at CSIRO and the fibre quality measured by HVI.

In a further laboratory experiment, cotton lint was carded at CSIRO's cotton processing mill. The carded web was treated in UV accelerated weathering tester and in the climate chamber. Single fibre tensile test and colourimetry were carried out to determine changes of cotton fibre quality.

3.5. Analysis of industrial database

The project team was given access to a very large sample of HVI results from the 2015 and 2016 seasons. The HVI data were matched to the harvest and ginning dates. The database included 222,793 bales from the 2015 season and 222,337 bales from the 2016 season. Distributions of cotton characteristics, correlations were drawn between module storage duration (number of days between picking and ginning) and interested cotton quality indicators.

Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

4.1 Weather conditions in trial sites - Bureau of Meteorology

Emerald is located in central Queensland, where the weather conditions during the ginning season (March to May) over the two years fluctuated between the low 20s and the low 40s in temperature (°C) and between less than 20% and more than 90% in relative humidity.

Warren is located in mid-north NSW, about half way between Emerald and Hay. The temperature pattern in Warren is similar to that in Hay albeit with warmer days and less rain expected in early winter.

Hay is close to the southern border region of NSW. The weather can be cool to mild during picking (April – June) and ginning season (April – September). Winter rain from the south is common.

Figures 4(a, b and c) show BOM data from the two seasons observed during the project in each location.

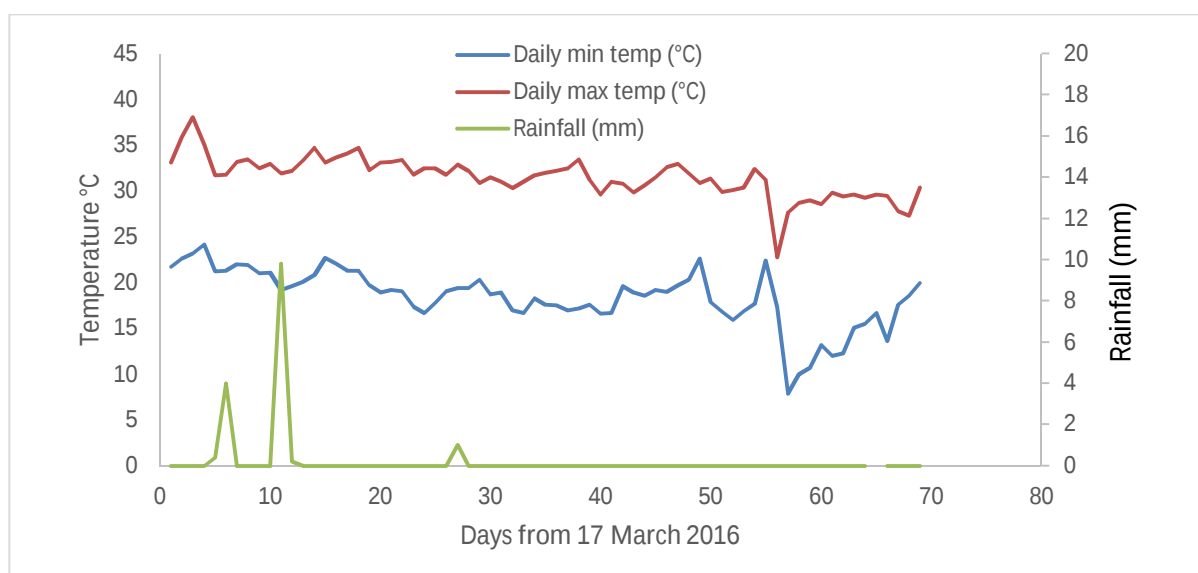


Figure 4a BOM weather report 17 March – 23 May 2016 Emerald, QLD.

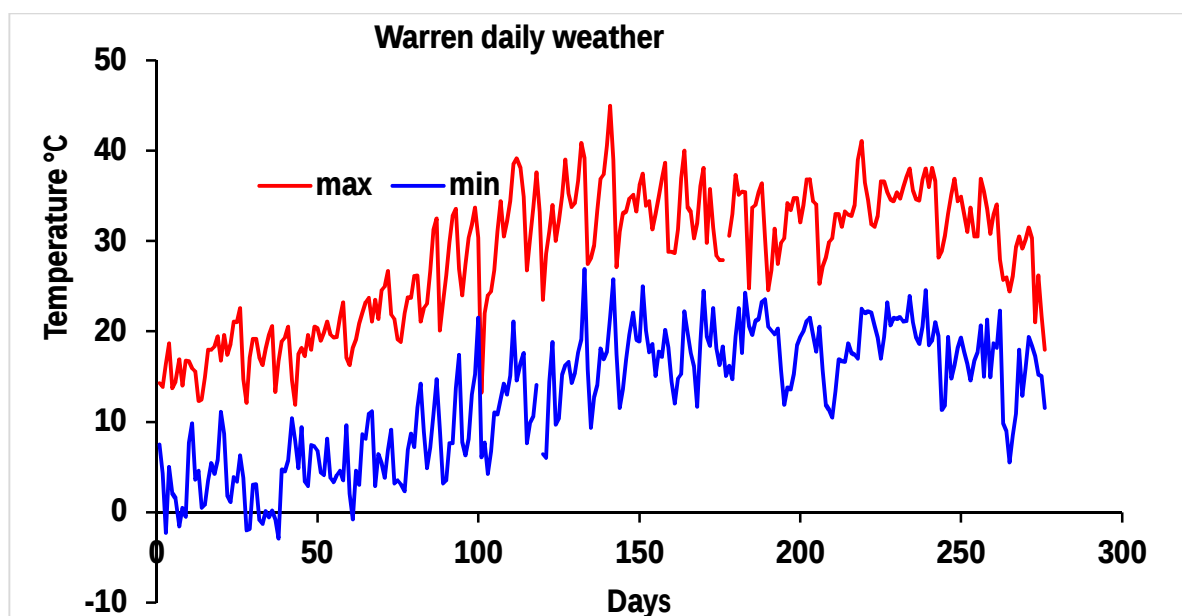


Figure 4b. BOM temperature in Warren from 6 July 2014 to 7 April 2015.

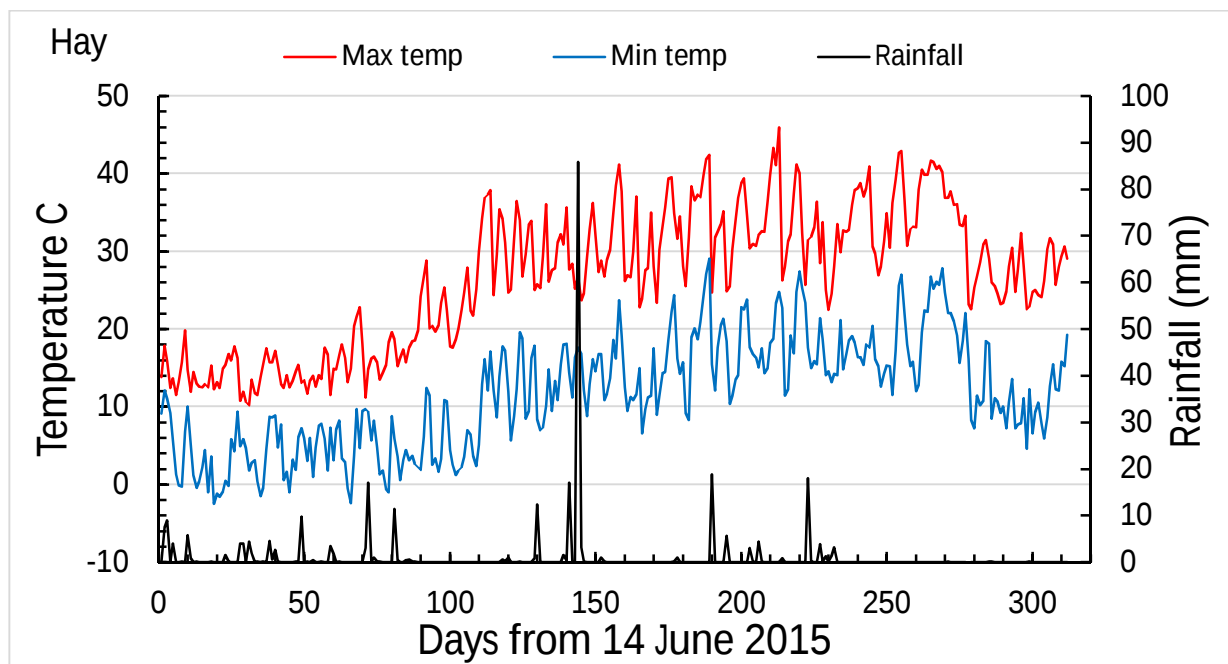


Figure 4c. BOM weather report of temperature and daily rainfall in Hay from 14 June 2015 to 15 April 2016.

4.2. Temperature and humidity distributions inside round modules

Temperature in the centre of the module (core temperature) as high as 48.6°C was recorded in early March, in Emerald where the daily average ambient temperature was 31.2°C. Module core temperature and relative humidity (RH) were stable within one day and unaffected by the daily fluctuation of ambient temperature and relative humidity. Some modules had much higher initial core temperature and RH than others, reflecting the temperature and humidity at the time of harvesting. Modules with higher initial temperature had lower RH. This pattern corresponds to the relationship between ambient temperature and RH in a typical non-rainy day.

Module core temperature decreased as the climate became cooler but was always significantly higher than the daily average ambient temperature. The initial difference in temperature between modules disappeared over about a one-month time period, as shown in Figure 5.

There was little gain, or loss, of moisture from the round modules during storage. The difference in relative humidity between the modules did not change during storage. The difference in the initial RH for the modules may be attributed to the different harvesting times for the individual modules. The overall decreasing trend of relative humidity over the storage period is a result of decrease in temperature (refer to the humidity isothermal curves in Figure 3), rather than a loss of moisture from the module during storage. Figure 5 also shows that the core relative humidity in the modules was generally lower than the daily average ambient relative humidity.

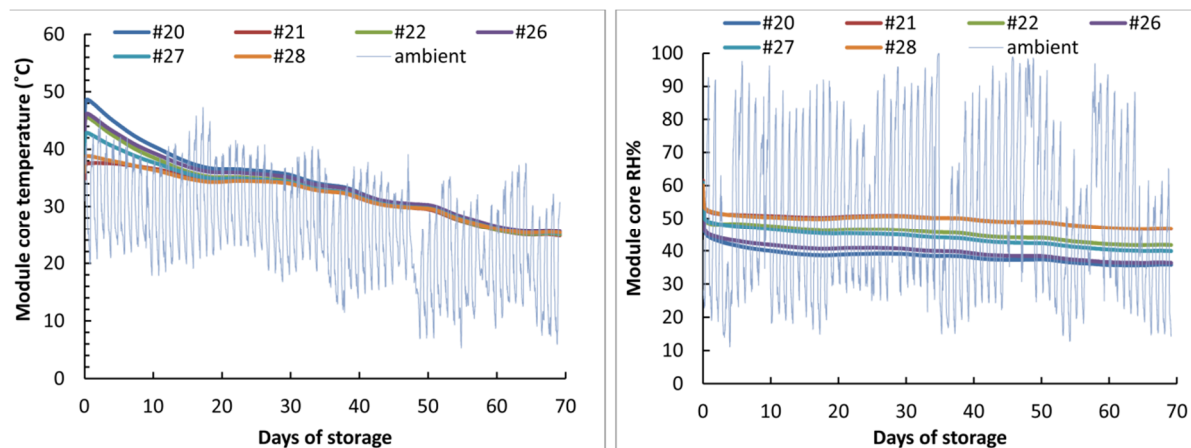


Figure 5. Temperature and relative humidity in the centre of round modules. Emerald, QLD, From 3 March to 11 May 2015.

Within each module, the temperature and RH at the top region, where cotton is exposed to maximum solar heat, fluctuates significantly while conditions in the lower parts of the module are very stable within a day. Cotton at the top of the module starts to dry out after about 80 days of storage at a higher rate than the rest part of the module, resulting in an uneven distribution of relative humidity in the module. The bottom region of a module is cooler than the rest of the module and ends up wetter than the rest of the module after a long storage period.

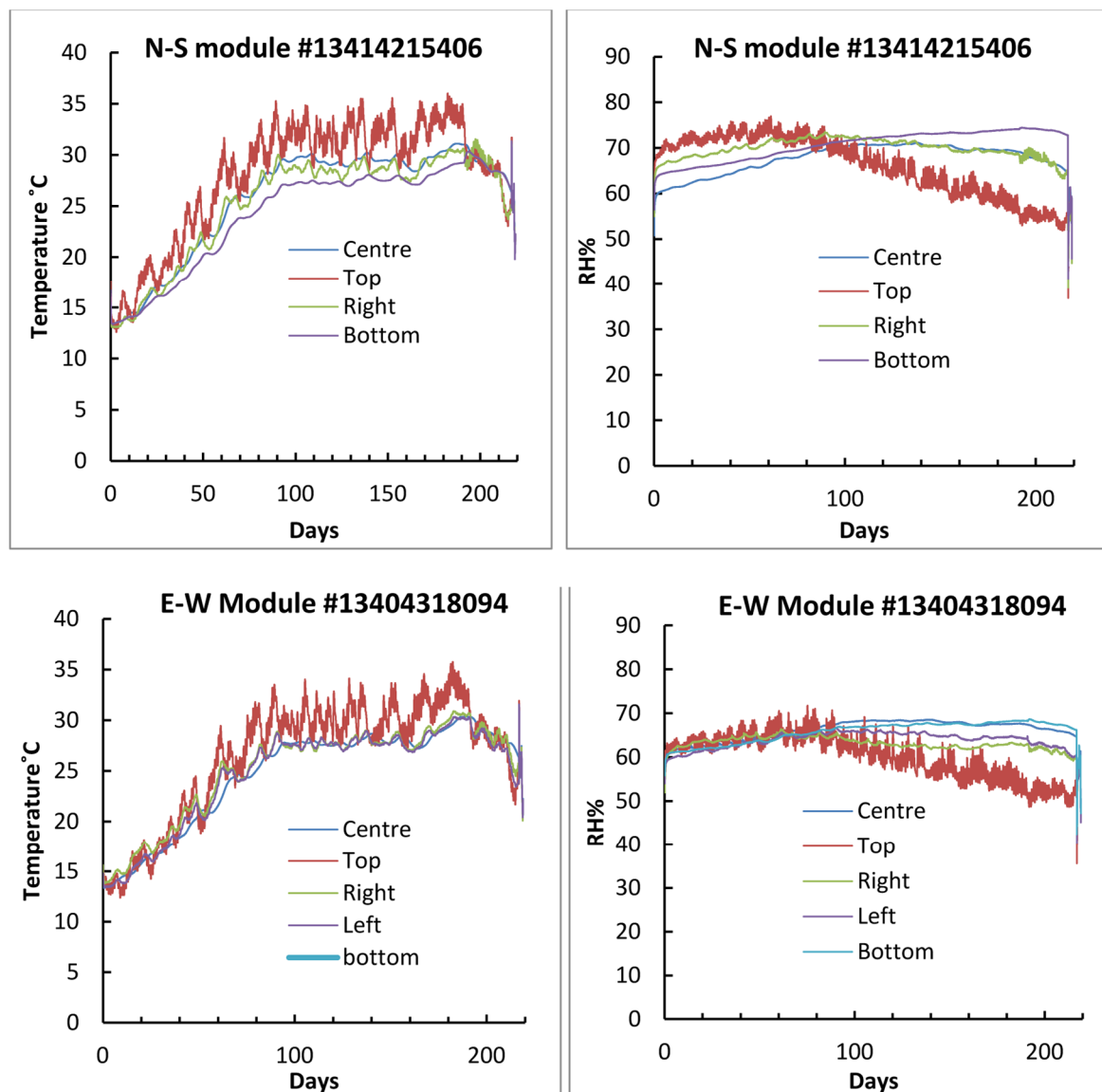


Figure 6. Temperature and humidity distributions in a round module. Warren, NSW. From 26 August 2014 to 1 April 2015. E-W: module stored with axis in east-west direction. N-S: module stored with axis in north-south direction.

Short term changes of temperature and relative humidity are shown in Figure 7a. The temperature and RH at the top of module show daily cycles of highs and lows. The temperature and RH at middle height and below had little change in the two weeks.

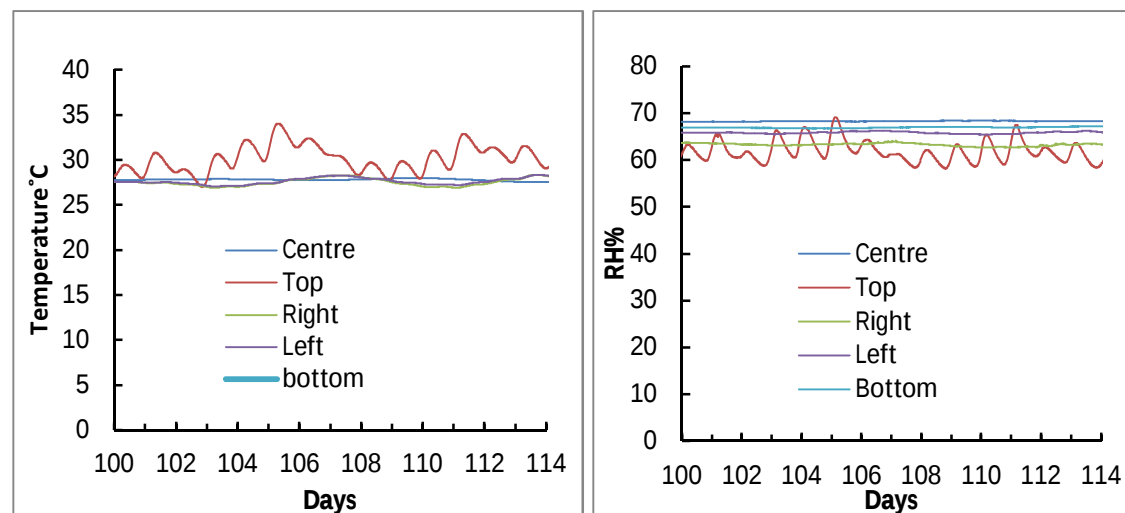


Figure 7a. Short term changes of temperature and relative humidity.

The changes in temperature and moisture conditions in the centre of a module over a storage period can be plotted in one diagram. Figure 7b shows the status of conditions in a module from the Warren carryover trial during 2014-15. Such a plot shows the range of conditions of the module over a period of time. The disadvantage of such a plot is that it does not give a time scale as in the previous plots.

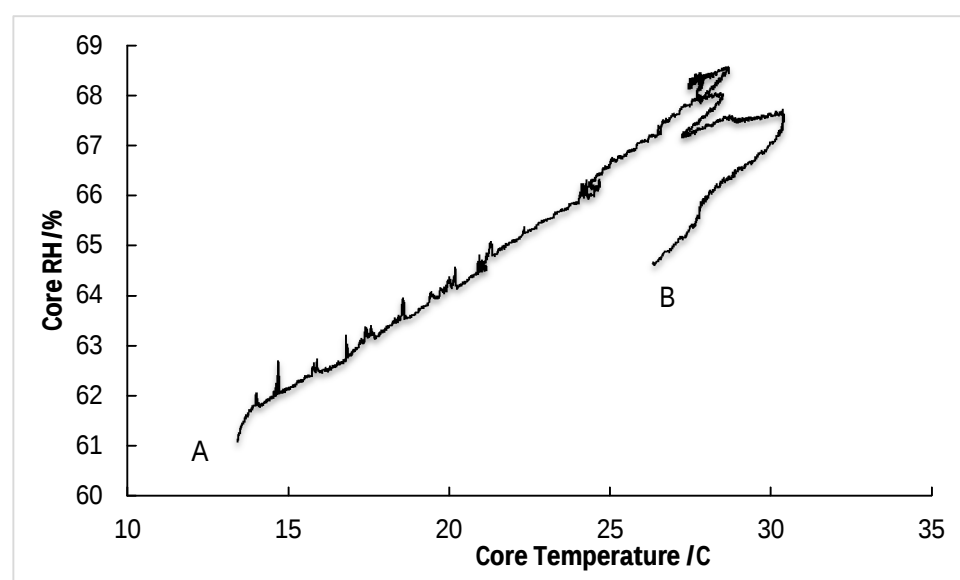


Figure 7b. History of temperature and humidity conditions in a module over a storage period. Point A stands for conditions on 26 August 2014 when measurement started; and point B stands for conditions on 1 April 2015 when measurement ended.

The orientation of round modules during storage had a small influence on the temperature and moisture conditions of the modules. In the trial, the initial core temperatures of all modules were nearly the same. The core temperatures of modules stored with axis in North-

South direction were about 2°C higher than those stored in the East-West direction during the hot months of the year. The difference may be attributed to the effect of the direction of the sun. Modules stored in the North-South direction have more exposure (on both sides of the module) to the sun. The module orientation did not seem to affect the module core relative humidity. The initial order of moisture contents in the modules was maintained throughout a seven-month period.

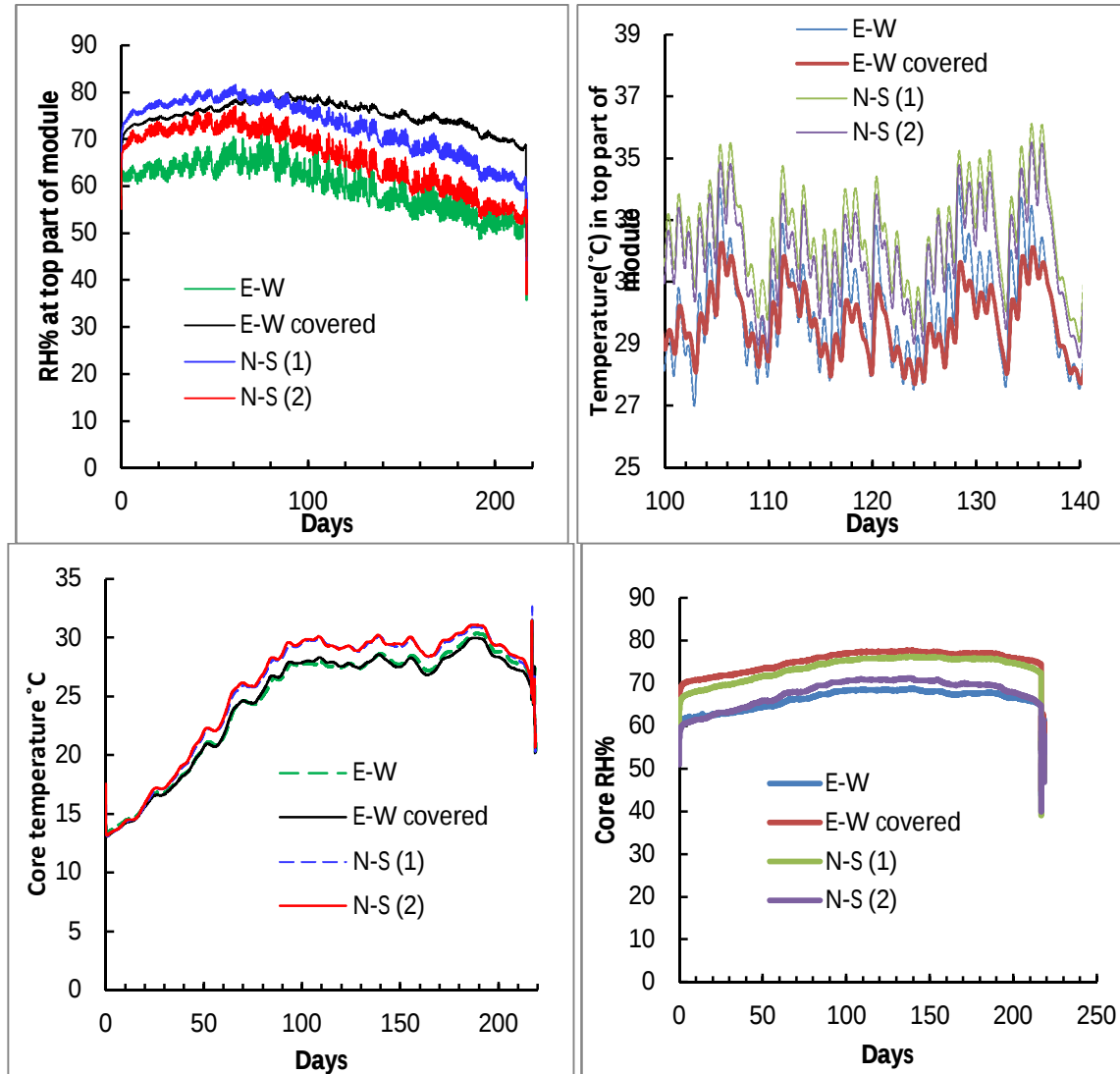


Figure 8. Influence of module orientation and cover on the temperature in the centre of round modules and relative humidity at the top of the module. Warren, NSW. From 26 August 2014 to 1 April 2015.

Covering round modules with a tarpaulin (Figure 9) can significantly reduce the fluctuations of temperature and RH and slows down the drying of cotton in the top part of the module (Figure 8). However, the temperature and RH in the centre of the modules were not significantly affected by the tarpaulin cover.



Figure 9. Round modules covered by tarpaulin.

4.3. Industrial ginning trials

Emerald trial 1 (3 March - 11 May 2015)

The maximum and minimum daily temperature and daily rainfall from BOM weather report are plotted in Figure 10a. The ambient temperature and relative humidity recorded by the sensor in the gin yard during the storage period are shown in Figure 10b. Traces of temperature and RH inside the modules during the storage period are presented in Figure 10c.

Module core temperature and RH were stable within one day and were unaffected by the fluctuations of ambient temperature and relative humidity. Module core temperature decreased as climate became cooler. Module core temperature as high as 48.6°C was recorded in Emerald in early March when the daily average ambient temperature was 31.2°C. The module core relative humidity was consistently lower than the daily average ambient relative humidity. In other words, the module keeps cotton drier than if the cotton is spread and ambient-conditioned in its loose form.

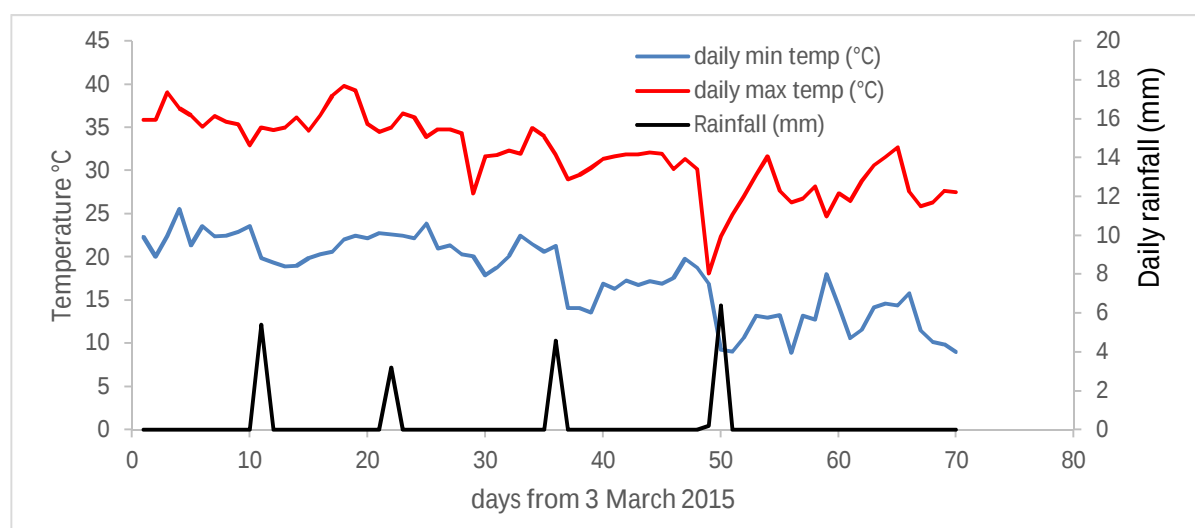


Figure 10a. Daily maximum and minimum temperatures and daily rainfall from BOM.

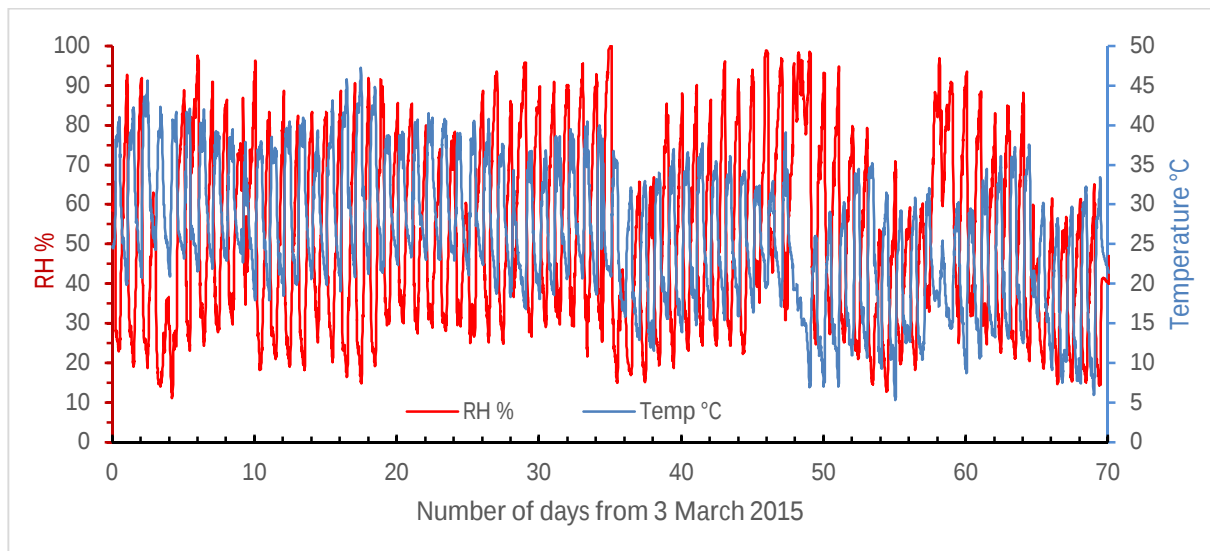


Figure 10b. Real-time ambient temperature and moisture traces (15 minute intervals) during 3 March - 11 May 2015.

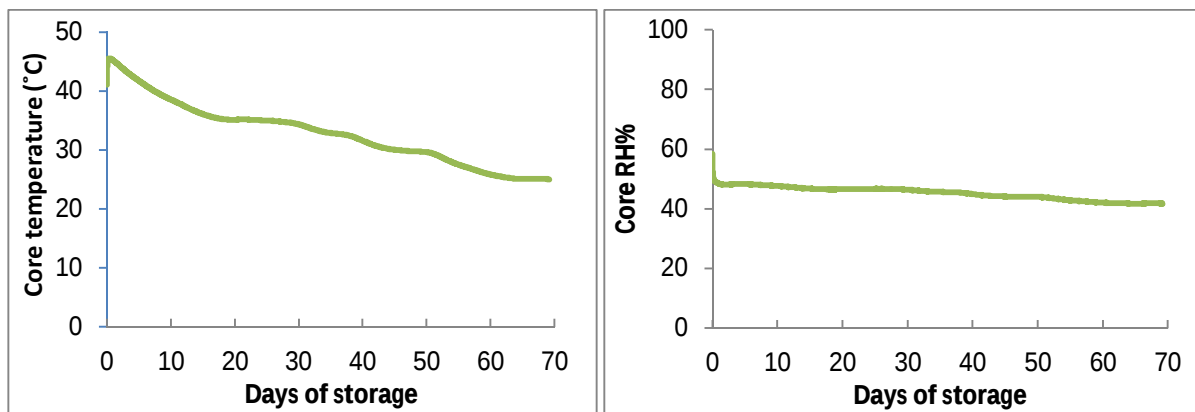


Figure 10c. Temperature and relative humidity at the centre of a round module stored in Emerald during 3 March - 11 May 2015.

Forty two round modules were ginned at the beginning of the season (3 March) and produced 183 bales of lint. Twelve round modules were stored and ginned at the end of the season (11 May), resulting in 54 bales of lint. The higher yield obtained on 11 May 2015 may be associated with the lower HVI trash content in the resulting lint.

Table 1. Turn-out for shelf-life trials in Emerald, Queensland

	Total module weight (kg)	Total lint weight (kg)	Turn-out
3 March 2015	97,750	41,650	42.61%
11 May 2015	27,250	11,938	43.81%

The HVI results of the two batches ginned on 3 March and 11 May are presented in Table 2 and Figure 11. The stored cotton (ginned on 11 May) showed a lower length uniformity, lower elongation, higher strength, higher yellowness value (+b), higher reflectance (Rd) than the cotton that was ginned at the beginning of the season (3 March). All these differences were statistically significant although not large enough to cause price discounts. Interestingly, the increase in +b resulted in an improvement in the classing results, with the colour grade changing from 31 to 21, as shown in Figure 11. The reason for this improvement in grade, due to increased +b is shown by the arrow in the colour chart in Figure 11.

Table 2. Influence of module storage on fibre quality. Emerald, Queensland.

		Length	SFI	Strength	Elong.	Rd	+b
3/03/2015 (183 bales)	Ave	1.16	11.3	29.3	5.3	81.3	6.8
	StDev	0.01	0.52	0.7	0.12	0.4	0.23
	Max	1.19	13.3	32.3	5.7	82.6	7.9
	Min	1.12	9.3	28	4.8	79.9	6.3
11/05/15 (54 bales)	Ave	1.15	9.9	30	4.3	82.2	7.5
	StDev	0.01	1.31	0.39	0.21	0.43	0.2
	Max	1.19	14.4	31.5	4.9	83.4	8.2
	Min	1.14	5.9	29.1	3.7	81.1	7.1

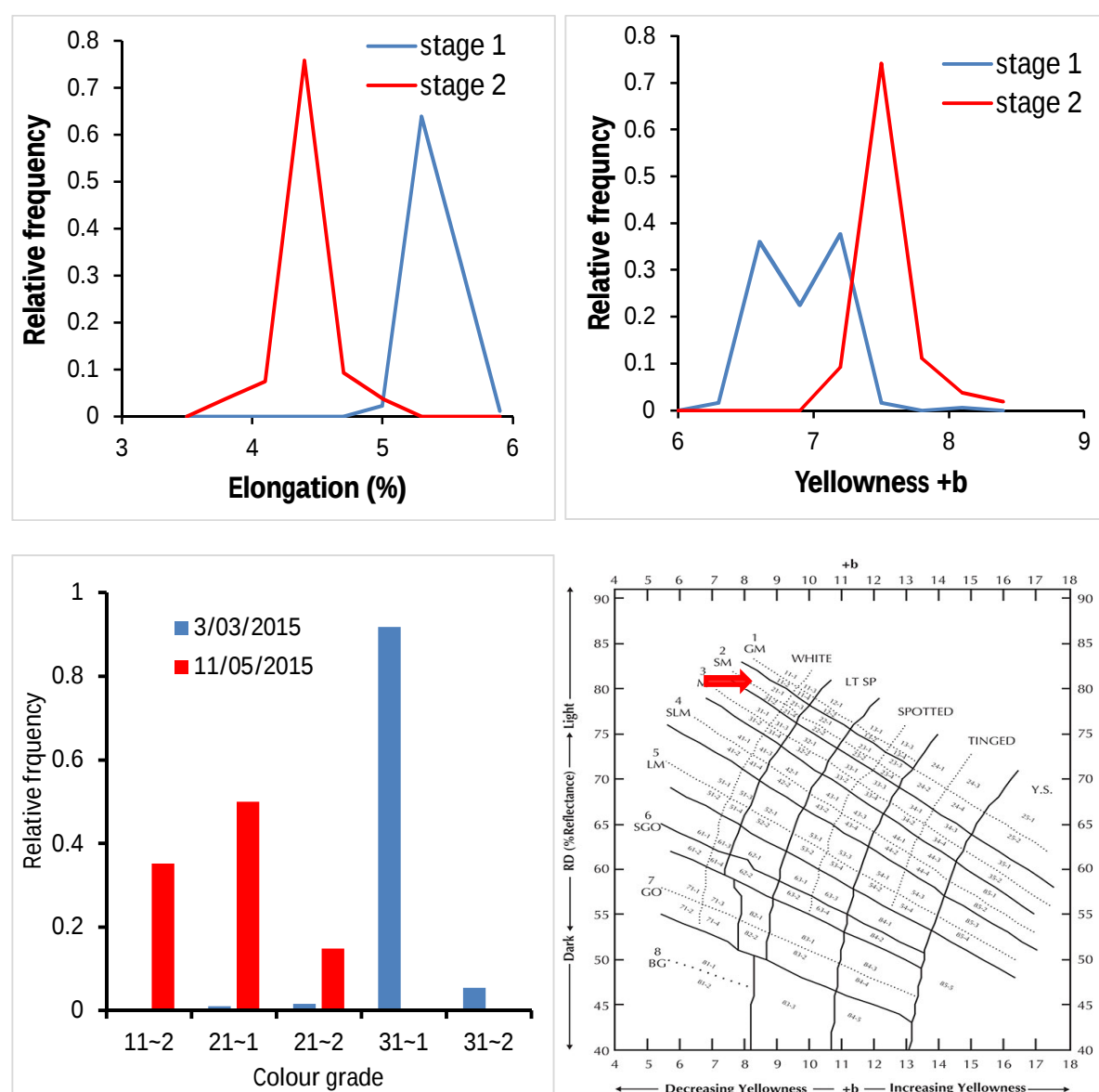


Figure 11. Influence of module storage on cotton quality after ginning. Emerald 2015.

Emerald trial 2 (17 March – 23 May 2016)

The maximum and minimum daily temperature and daily rainfall from BOM report are plotted in Figure 12a. The ambient temperature and RH recorded by our sensor in the gin yard during the storage period are shown in Figure 12b. Traces of temperature and RH inside the modules during the storage period are presented in Figure 12c. Figures 12b and 12c also show that within a module, the temperature and RH at the top region fluctuates significantly while conditions in the lower parts of the round change at a slow and constant rate over the storage period. The bottom region of a module is cooler and wetter (higher RH) than the middle part of the module.

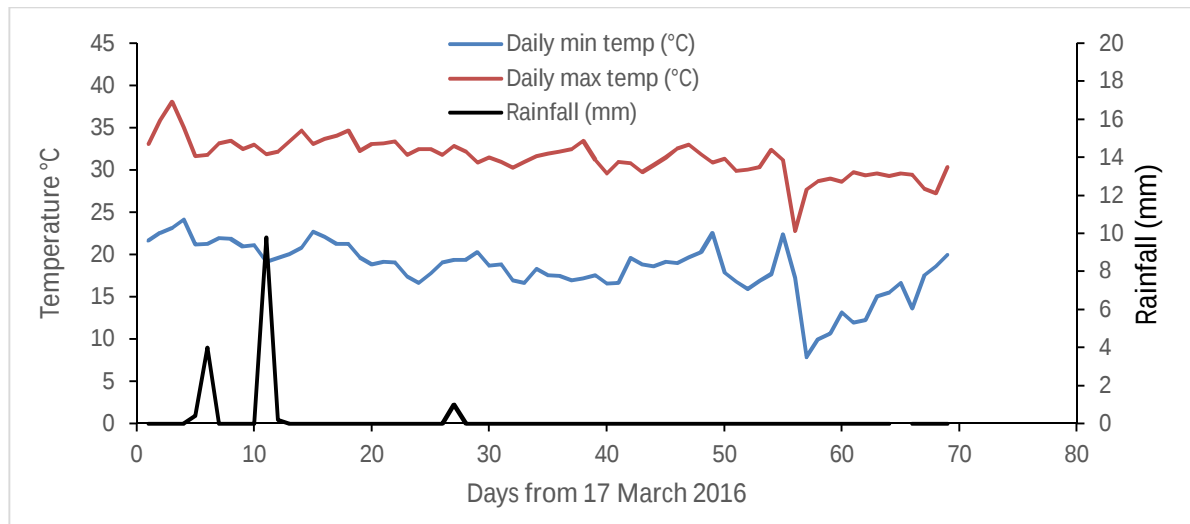
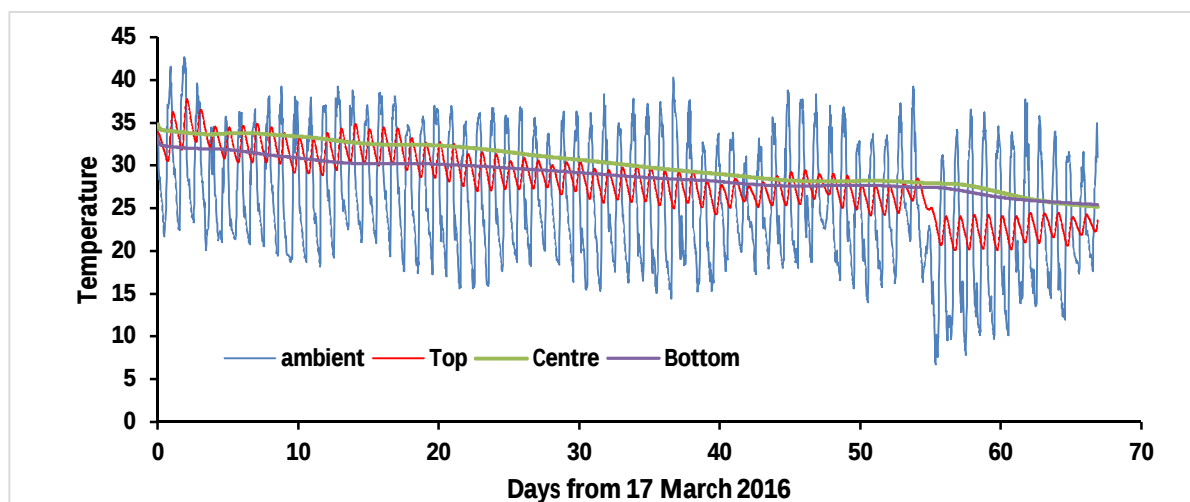


Figure 12a. Ambient temperature and relative humidity in Emerald from 3 March to 12 May 2015.



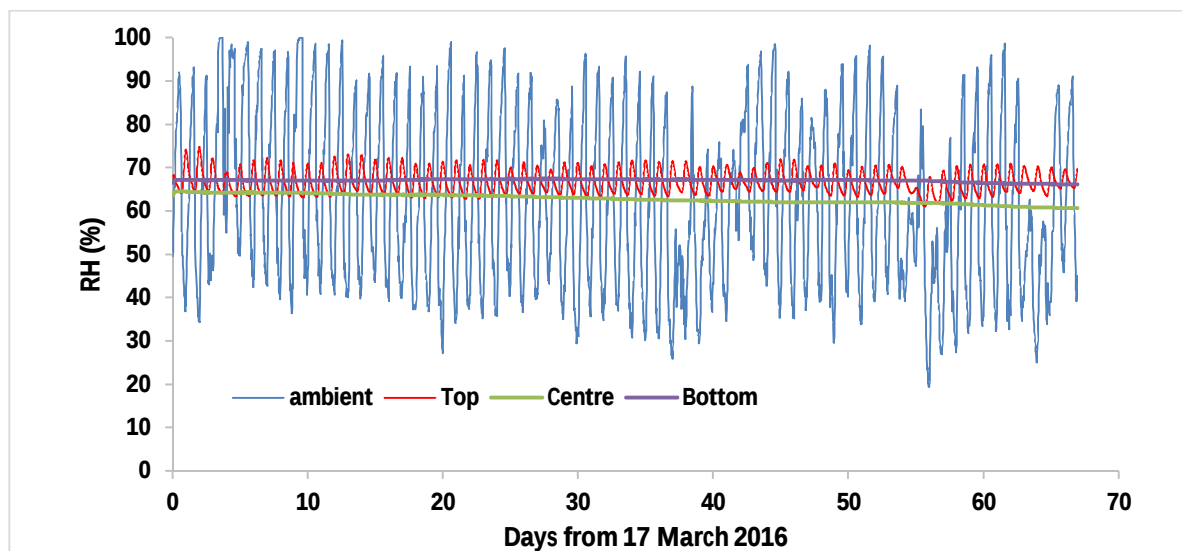


Figure 12b and c. Temperature and relative humidity in round modules. Emerald, 17 March – 23 May 2016.

The HVI results of the three batches ginned on 26 March, 28 March and 31 May are presented in Table 3. The first two batches were ginned within three days and hence any differences between them were caused by factors other than module storage time. The main differences between the two batches are average strength and Rd values.

In comparison, the stored cotton (ginned on 31 May) showed a higher +b value and slightly lower elongation (from 4.2% to 4.1%) than the two earlier batches ginned on 26 and 28 March. All the other HVI results from the stored modules were within the range of the two earlier batches ginned on 26 and 28 March.

In Figure 13, the HVI data for the two batches ginned on 26 and 28 March were merged together and their distributions of +b, elongation, strength and colour grade compared with those obtained from the batch ginned on 31 May. Again, an increase in +b resulted in an improvement in the classing results, with the colour grade changing from 31 to 21.

The changes in yellowness and elongation, from the 2016 trial in Emerald, confirmed the results from 2015, although the change in fibre strength in 2016 (increase) was opposite to that in 2015 (decrease). Fibre length and SFI decreased slightly in 2015, while there were no changes for these two parameters in 2016.

Table 3. Influence of module storage on cotton quality after ginning. Emerald, Queensland.

Ginning	No. bales		Length	Strength	SFI	Elong.	Rd	+b
26/03/16	664	Ave	1.18	30.9	7.8	4.2	81.3	7.1
		StDev	0.01	0.67	0.97	0.25	0.97	0.20
		Min	1.14	28.6	3.4	3.5	73.9	6.4
		Max	1.23	32.8	12.6	6	83.3	8
28/03/16	471	Ave	1.18	29.6	7.8	4.2	79.6	7.2
		StDev	0.01	0.56	0.74	0.21	1.18	0.19
		Min	1.14	28	5	3.5	73.4	6.4
		Max	1.23	31.6	12	5.3	82.1	8.1
31/05/16	80	Ave	1.18	30.3	7.8	4.1	80.3	8.1
		StDev	0.02	0.59	0.81	0.28	0.34	0.15
		Min	1.14	29.1	5.6	3.3	79.2	7.4
		Max	1.22	31.6	9.6	4.9	81.4	8.5

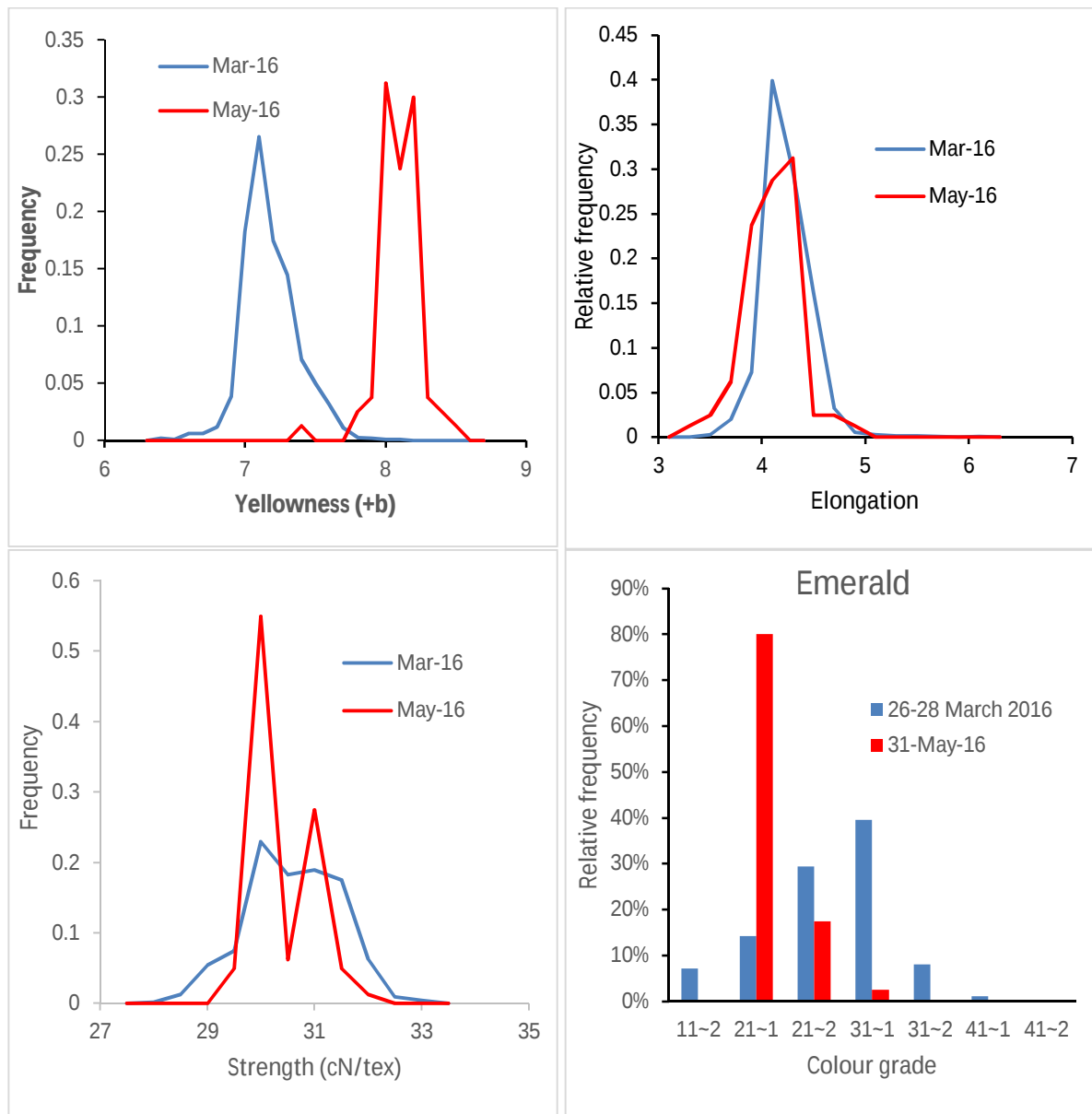


Figure 13. Influence of module storage on cotton quality after ginning. Emerald 2016.

Warren carry over (2014-15)

Carryover modules harvested in the 2014 season were stored for 220 days in Warren before being ginned at the start of the 2015 season. The HVI values after storage were compared with the values recorded on the same cotton ginned in the 2014 season.

Figure 4b shows the BOM daily maximum and minimum temperatures for Warren from 6 July 2014 to 7 April 2015. The temperature and moisture conditions in the centre of the same modules are presented in Figure 14. There were more than four months (130 days) of temperature $> 25^{\circ}\text{C}$ during which the RH was about 3% higher than the rest of the storage period.

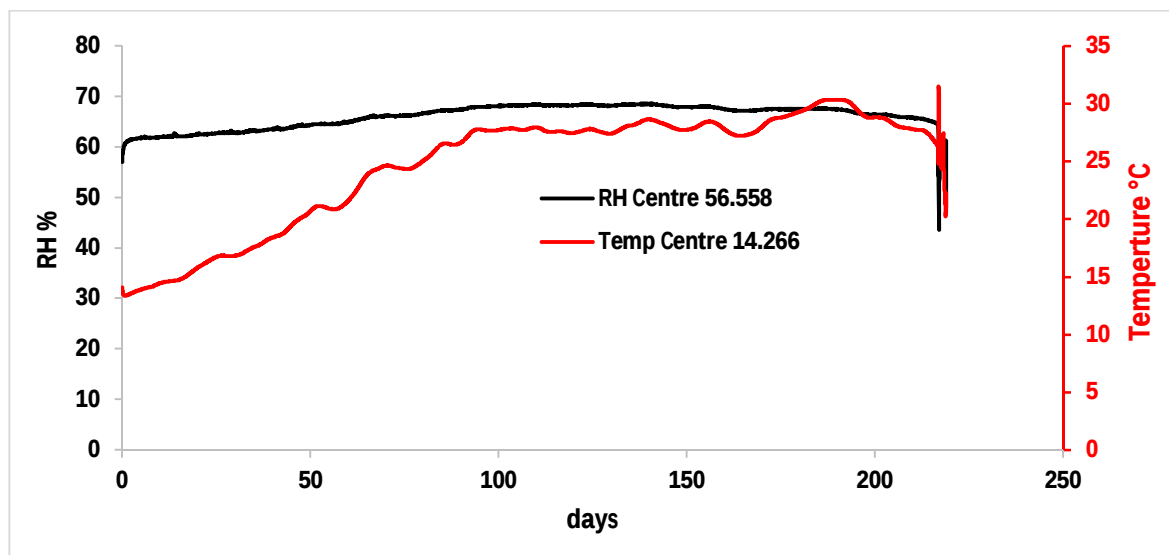


Figure 14. Core temperature and relative humidity of round module in Warren Carryover trial 2014-15.

The initial gin run on 6 July 2014 resulted in 389 bales of lint. The gin run of the carryover modules on 7 April 2015 produced 74 bales of lint. The average, standard deviation and range of values of the HVI test results from the two runs are presented in Table 4. Almost all the cotton quality indicators deteriorated to some extent, with the most noticeable changes being the deterioration of fibre elongation and +b. Fibre strength, length and SFI also worsened after the storage period (of nearly 10 months).

Table 4. Influence of module storage on cotton quality after ginning. Warren, NSW, 2014-15.

		Length	SFI	Strength	Elong.	Rd	+b
6/07/2014 (389 bales)	Ave	1.20	7.8	32.8	5.8	77.8	6.8
	StDev	0.01	0.58	0.58	0.47	0.67	0.20
	Min	1.15	6.6	30.8	4.9	75.3	6.1
	Max	1.24	9.8	34.6	6.7	80.3	8
7/04/2015 (74 bales)	Ave	1.17	9.2	31.4	5.0	77.5	7.3
	StDev	0.01	0.58	0.70	0.31	0.51	0.14
	Min	1.14	8.2	29.8	4.1	76.4	6.9
	Max	1.20	11.4	33.7	5.7	78.6	8.2

The distributions of the fibre quality attributes of the bales ginned on July 2014 and April 2015 are plotted in Figure 15 to show their change. Clearly, all the HVI quality attributes deteriorated to different degrees due to the storage, except for micronaire and Rd, which changed very little. Length, uniformity, strength and elongation decreased, while SFI and +b increased. Interestingly, the bales ginned in April 2015 received more favourable colour grades despite the increase in +b, as explained earlier in Figure 11.

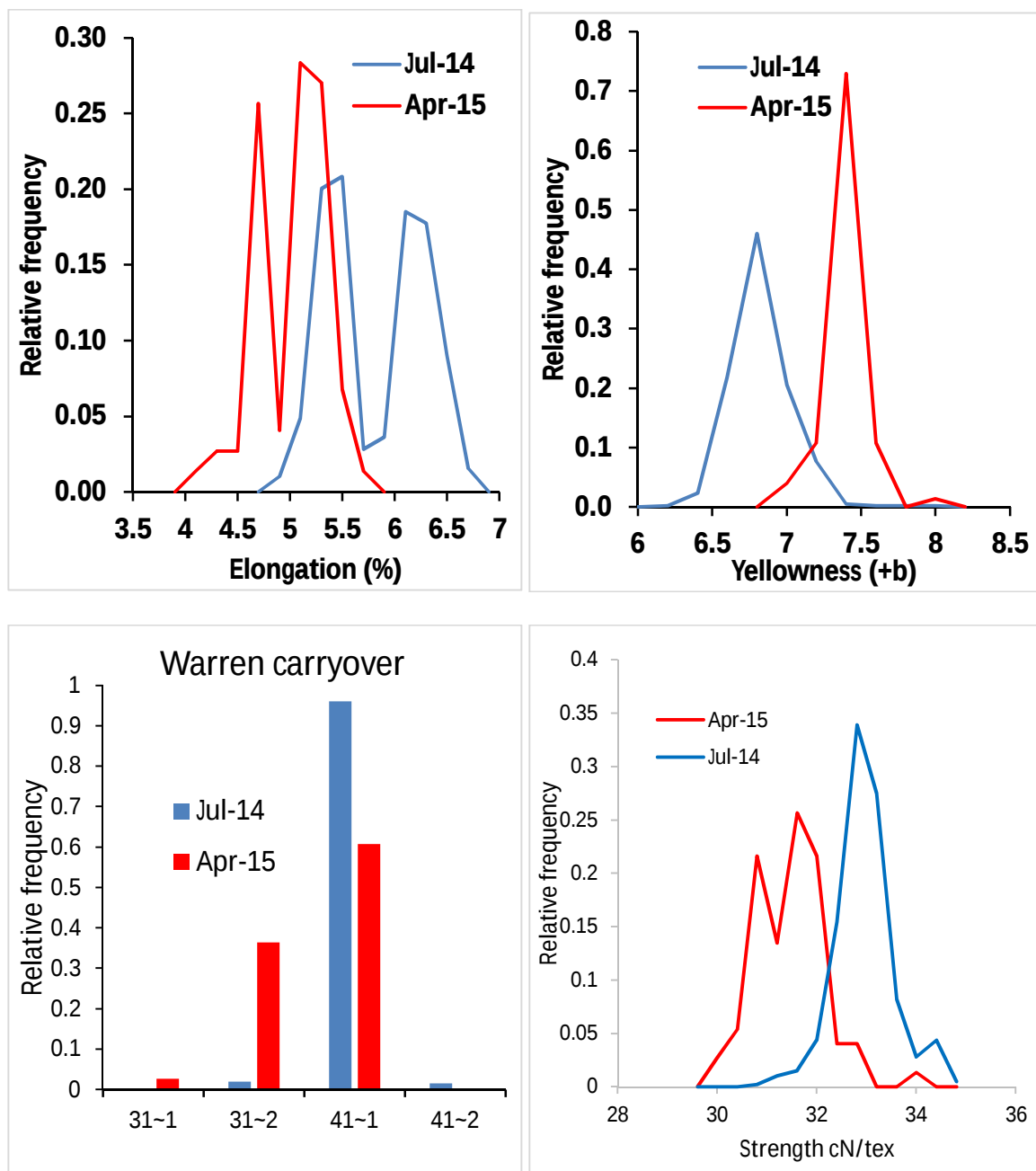


Figure 15. Influence of module storage on cotton quality after ginning. Warren, 2014-15.

Hay carryover (2015-16)

Carryover modules harvested in the 2015 season were stored for nearly 9 months in Hay before being ginned at the start of the 2016 season. The HVI values after storage were compared with the values recorded on the same cotton ginned in the 2015 season.

Figure 4c shows the BOM weather report of temperature and daily rainfall in Hay during the storage period from 14 June 2015 to 15 April 2016. There were many rain events during the storage period, including one daily rainfall over 80 mm. There were about 10 days with subzero minimum air temperature and more than 20 days with maximum temperatures higher than 40°C.

Temperature and moisture traces measured inside the round modules during the storage period are presented in Figure 16. Temperature fluctuated in the top region of the round module but only reached 30°C in one or two occasions during the nine months of storage.

The temperature peaks in the centre of the module were between 25°C and 30°C, in stark comparison with the high temperature of 45°C recorded in Emerald. During the summer months in Hay, the temperature in the bottom part of the module was about 2°C lower than that in the centre of the module, whilst the temperatures in the two parts of the module were almost the same in the cooler months.

In the winter months in Hay, the temperature at the top region of the module reached as low as 7° while the temperature at the centre and bottom regions of the module reached about 10°C. The relative humidity in the bottom part of the module was about 6% higher than that in the centre of the module over the whole period of storage time. In the top part of the module, relative humidity increased in the winter month, reaching values higher than that in the bottom region of the module and then decreased in the summer months.

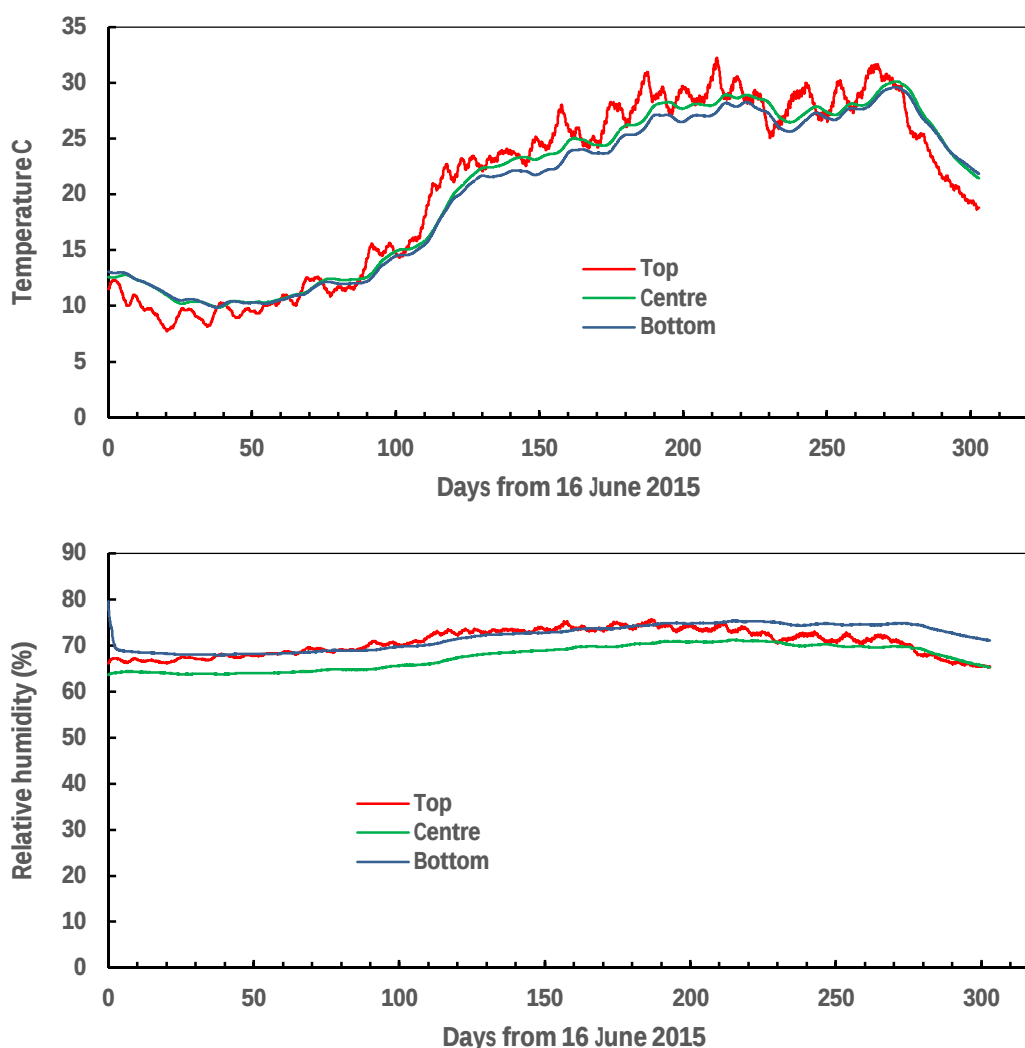


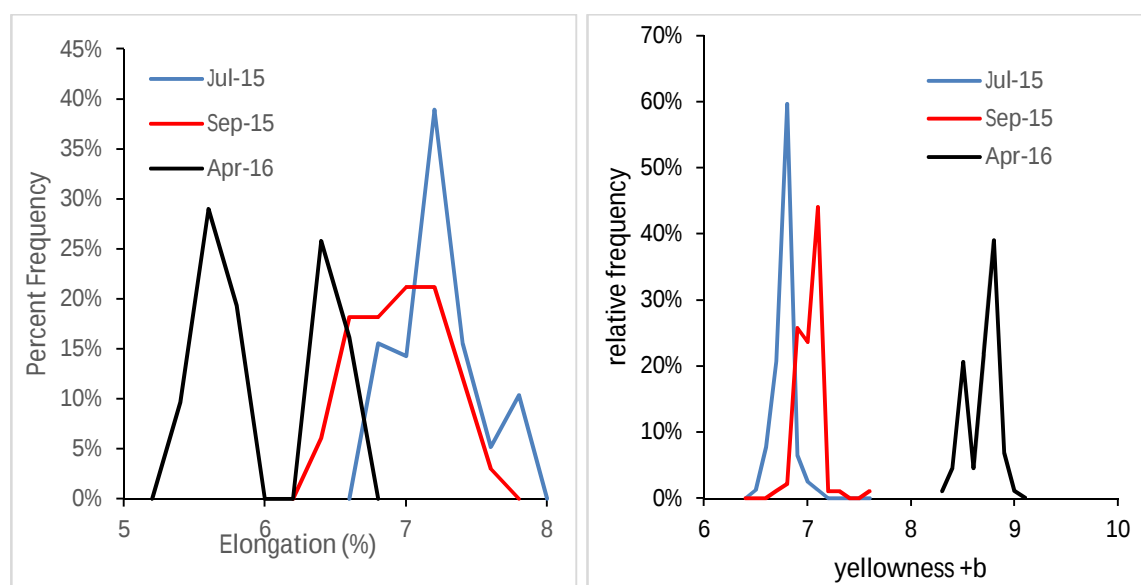
Figure 16. Temperature and relative humidity in round modules. Hay 2015-16.

The 66 modules monitored in this trial were ginned at three different times. Eighteen modules were ginned on 6 July 2015, 24 modules were ginned two months later on 12 September 2015 with the rest of the modules ginned on 15 April 2016. The HVI test results for the three storage periods are summarised in Table 5. The distributions of fibre strength, elongation and +b of the three gin runs are shown in Figure 17. The HVI results from Stage 2 show a small decrease in fibre elongation and a small increase in +b, similar to that observed in the previous trials. These changes further increased in Stage 3.

Table 5. Influence of module storage on cotton quality after ginning. Hay, NSW, 2015-16.

		Length	Micro.	Strength	SFI	Elong.	Rd	+b
Stage 1 9/07/2015 (77 bales)	Ave	1.20	4.0	30.5	9.2	7.2	81.8	6.8
	Stdev	0.02	0.06	0.87	0.85	0.28	0.31	0.09
	Min	1.16	3.80	28.5	7.8	6.7	80.8	6.5
	MMax	1.23	4.10	32.0	11.1	7.7	82.6	7.1
Stage 2 12/09/2015 (93 bales)	Ave	1.20	4.17	30.7	8.2	6.9	81.3	7.0
	StDev	0.01	0.10	0.52	0.64	0.30	0.39	0.12
	Min	1.18	3.80	28.9	7.1	6.4	79.9	6.7
	Max	1.23	4.40	32.6	10.2	7.6	82.5	7.6
Stage 3 15/04/2016 (86 bales)	Ave	1.20	4.15	30.9	8.6	5.9	81.1	8.7
	StDev	0.01	0.09	0.53	0.60	0.44	0.35	0.15
	Min	1.18	4.00	29.4	7.4	5.4	79.9	8.3
	Max	1.23	4.20	32.4	10.5	6.6	82.3	9.0

The distributions of elongation, +b, colour grades and strength values from the HVI tests on the bales in the Hay carryover trial in 2015-16 are plotted in Figure 17 to show their relative changes after storage. Elongation gradually decreased and +b increased as the storage time increased. The overall colour grade were similar. However, bales produced in stage 3 showed a marked improvement in the colour grade when compared to that of the two earlier gin runs.



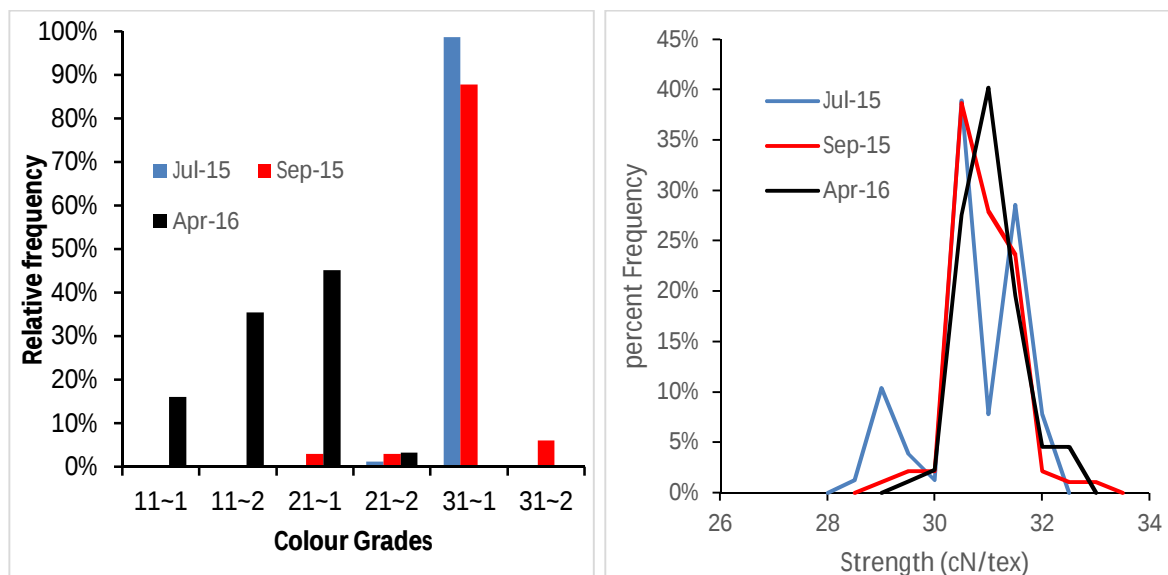


Figure 17. Influence of module storage on cotton quality after ginning. Hay, 2015-16.

The three-stage trials, with modules being carried over/stored for >6 months, elucidate the progressive nature of changes in cotton fibre quality during storage. The average elongation and +b from the three gin runs are plotted against module storage time in Figure 18. The average elongation followed a linear decreasing trend whilst +b values increased in an accelerated manner after two months storage.

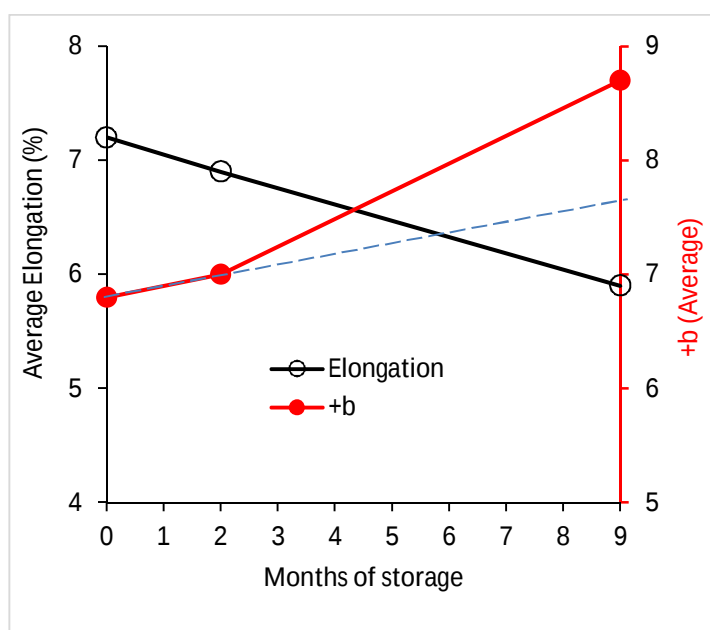


Figure 18. Progressive changes of cotton yellowness and elongation over a nine-month module storage period.

Hay trial 2: May-August 2016

Hay experienced a particularly wet ginning season in 2016. BOM weather record shows that the Hay area received a total rainfall of 132.8 mm in the period from 25 May to 25 August 2016. The rainfall would have a cooling effect on the modules, especially in the top region of modules. The rain water would flow on the surfaces of the two open ends of the modules.

The hydrophobicity of cotton fibre helps prevent the water from penetrating into the interior of the modules.

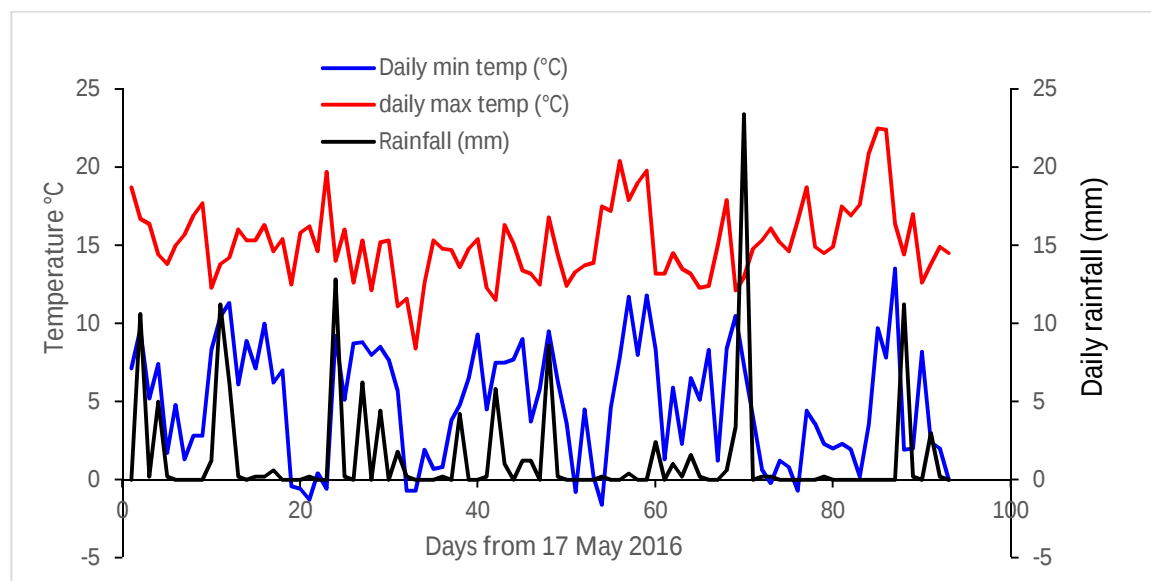


Figure 19. BOM weather report for Hay, 25 May – 25 August 2016

In this trial, all cotton was harvested on the same day (4 May 2016) from the same field. The modules were ginned three times, i.e., after storing for 21 days, 41 days and 113 days, respectively. These were much shorter intervals than those in the Hay carryover trial during 2015-16.

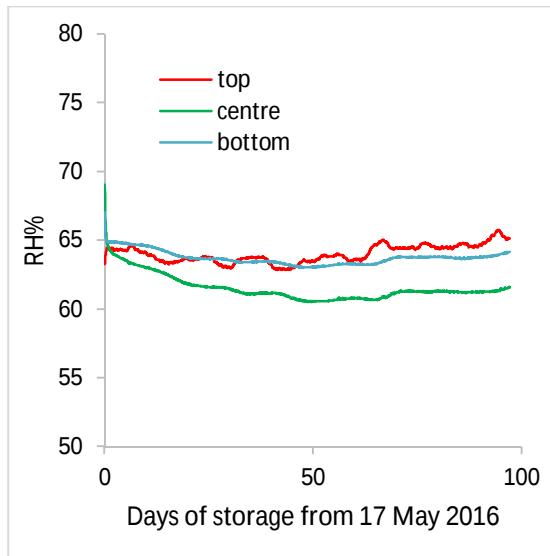
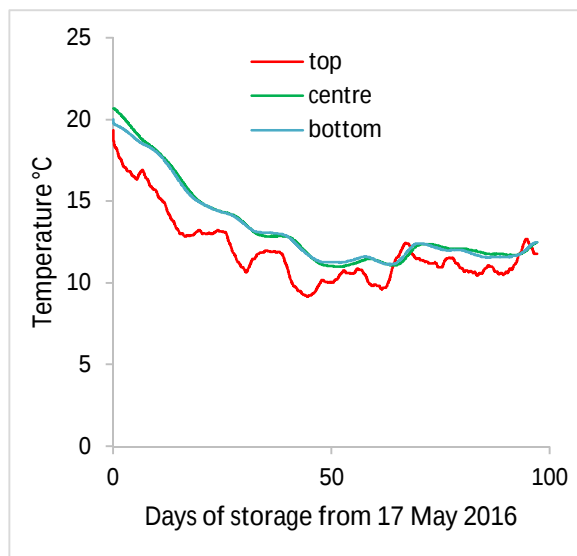
Table 6. Ginning schedule for Hay 2016 trial (Picking date 4 May 2016)

Ginning stage	Stage 1	Stage 2	Stage 3
No. days from picking to ginning	21	41	113
No. round modules ginned	70	42	24

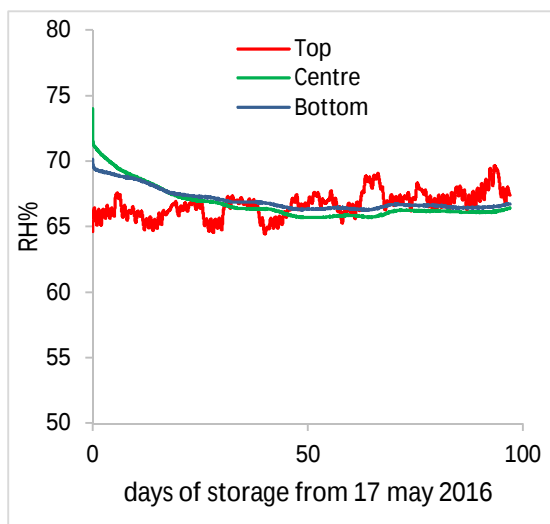
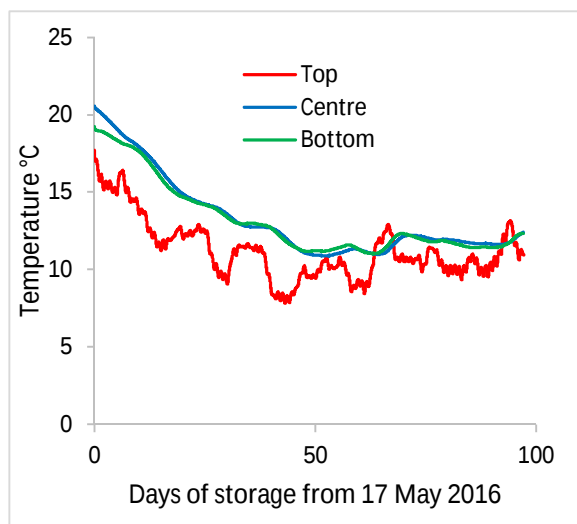
Temperature and moisture traces measured from three round modules during the storage period are provided in Figure 20. The temperature profiles for the three modules were very similar. The modules got cooler with time in the first two months of storage although the range of ambient temperatures for the period (Figure 20) was mostly stable. During the storage period, the temperature in the top region of the modules fluctuated in a range below the temperature in the centre and bottom regions of the modules, which is in the reverse order found in summer modules. This lower temperature in the top part of modules can be attributed to the frequent rainfalls.

It was noted that many of the stored modules were flooded at the bottom due to the rainy weather conditions during this season. The position of the bottom sensors in the module was about 20cm above the ground. The flooding could have an effect on the temperature and RH in the bottom region of the modules. This might be the case for Module A, in which the bottom region got gradually wetter than the centre of the module over the storage time. On the other hand, the bottom region maintained its RH difference from the centre regions in module C throughout the storage period. It should also be noted that at the beginning of the

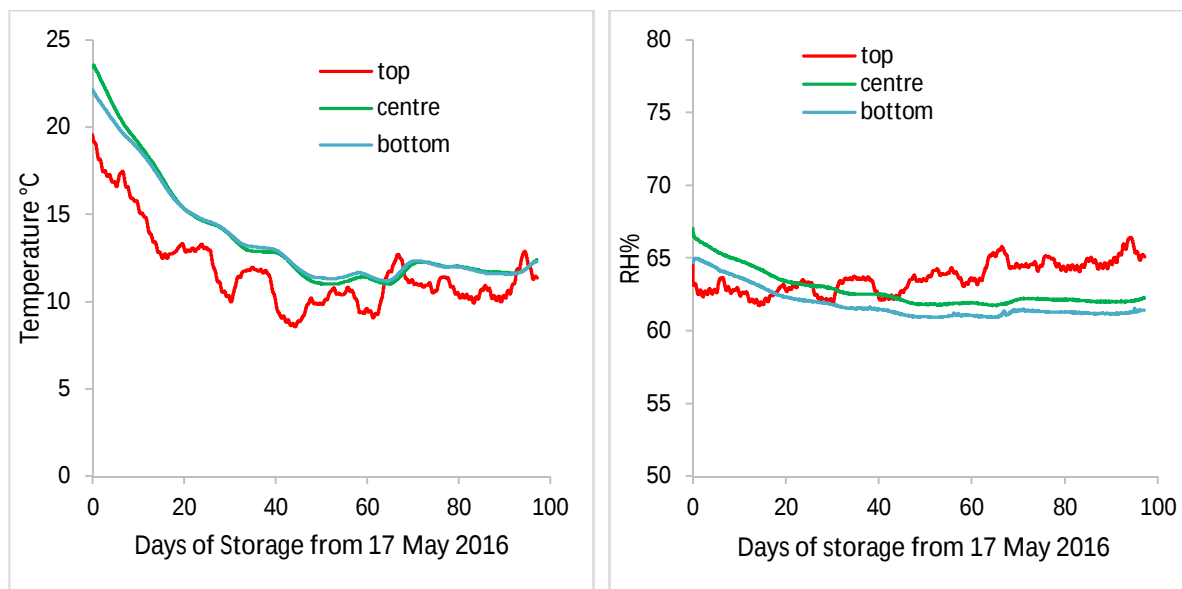
storage period, Module B had a 5% higher RH than Modules A & C. The RH level in the bottom part was similar to that in the centre of module B throughout the storage period.



Module A



Module B.



Module C

Figure 20. Temperature and relative humidity in three modules. Hay 2016.

The HVI results from the three gin runs are summarised in Table 7. The average elongation and +b from the three gin runs are plotted in Figure 21. There was a general trend of slight decrease for average elongation and a general trend of slight increase for average +b. These changes were consistent with all the other trials, and especially in the Hay carryover trial (Figure 18) but at much smaller magnitudes due to the shorter storage duration and lower module temperature.

Table 7. Influence of module storage on cotton quality after ginning. Hay, NSW, 2016.

		Length	Micro.	SFI	Elong.	Strength	Rd	+b
Stage 1 282 bales 25 May 2016	Ave	1.21	4.4	8.6	5.8	31.8	81.8	7.3
	StDv	0.01	0.07	0.72	0.69	0.65	0.37	0.14
	Min	1.18	4.3	7.1	4.9	30.0	80.4	6.7
	Max	1.25	4.5	11.2	8.0	33.7	82.8	7.9
Stage 2 169 bales 14 Jun 2016	Ave	1.22	4.3	8.9	5.9	32.0	81.7	7.5
	StDv	0.01	0.05	0.65	0.60	0.66	0.56	0.19
	Min	1.18	4.2	7.6	4.9	30.1	78.5	6.6
	Max	1.26	4.5	10.8	7.0	34.0	82.8	8.5
Stage 3 104 bales 25 Aug 2016	Ave	1.22	4.3	8.4	5.6	32.0	81.3	7.6
	StDv	0.01	0.06	0.59	0.70	0.62	0.68	0.20
	Min	1.18	4.3	7.0	5.0	30.2	76.0	6.3
	Max	1.25	4.7	9.7	7.3	33.9	82.4	8.0

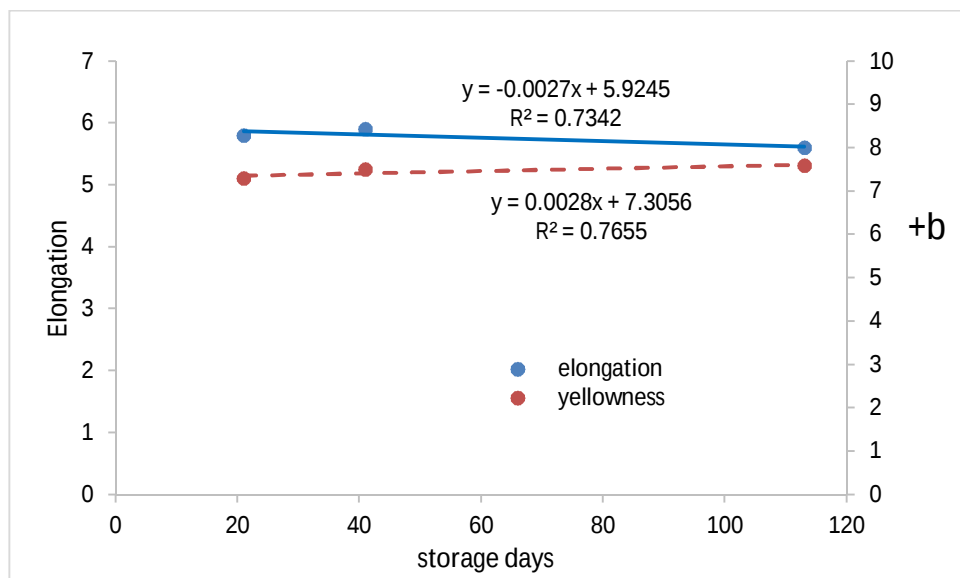
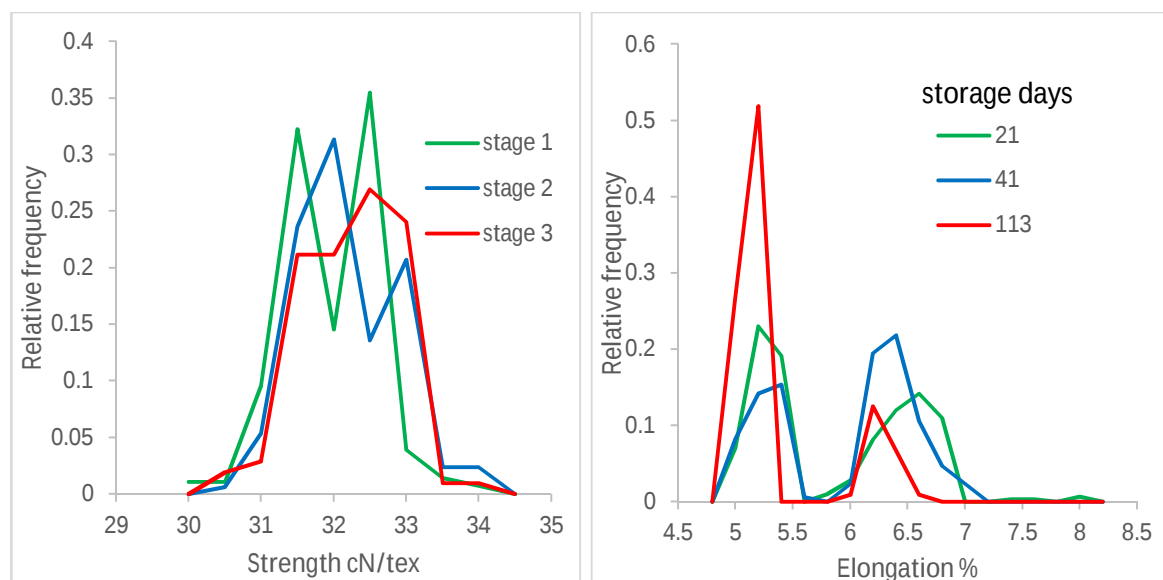


Figure 21. Changes of cotton yellowness and elongation over the module storage period from May to August 2016.

The distributions of strength, elongation, +b and colour grades of the HVI results for the bales from the three ginning stages are plotted in Figure 22. The strength and elongation distributions did not shift significantly. The +b showed a gradual move to the right (increase) as the storage time increased. As storage time increased, the proportion of bales of colour grade 21 increased and the proportion of bales in colour grade 31 reduced, which were consistent with the colour grade changes found in all the other trials.



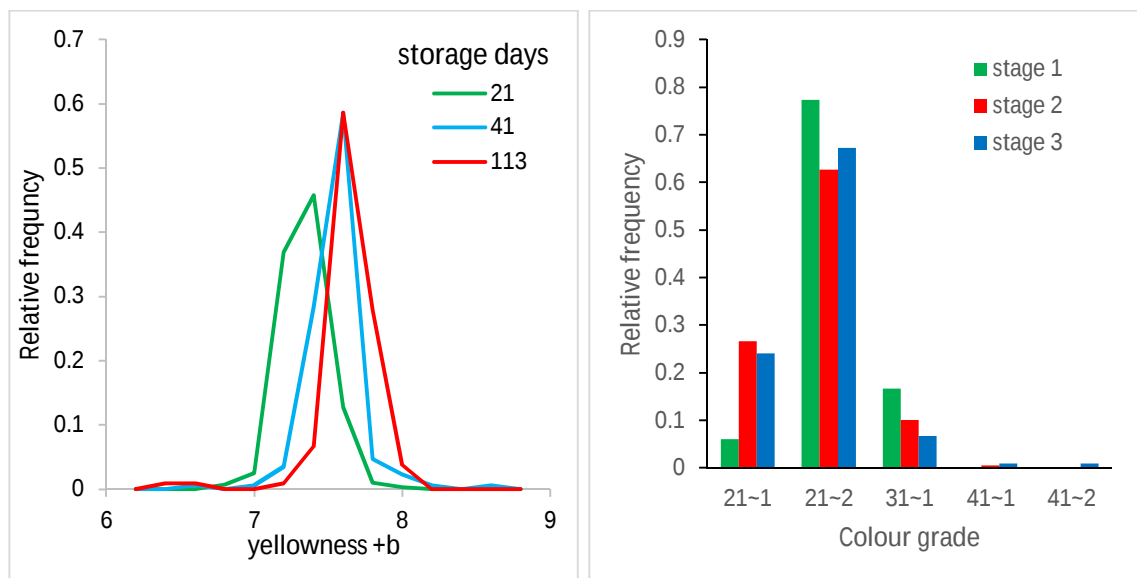


Figure 22. Influence of module storage on cotton quality after ginning. Hay, 2015-16.

4.4. Module flooding during storage

In the industrial trials in Warren and Hay, we observed a considerable number of flooded modules, causing serious damage to the cotton in localised areas of the modules (Figure 23). The rotten cotton was manually removed in the module feeding bay and dumped as waste, although it was a relatively small percentage of the total cotton processed.



Figure 23. Cotton damage due to flooding.

As illustrated in the diagram below, when the wind blows in the direction of the module axis in heavy rain, the rain water flows down along the face of the module and was diverted to flow inside the module along the plastic wrapper lip. Rain water from the top surface of the module can also find its way to the wrapper lip area. The water is trapped there by the wrapper lip, causing the cotton to rot.

The trapped water seemed to travel only a few centimetres upward in the module and thus damage was limited only to a small quantity of cotton, as indicated in the miniature ginning experiment reported in the next section.

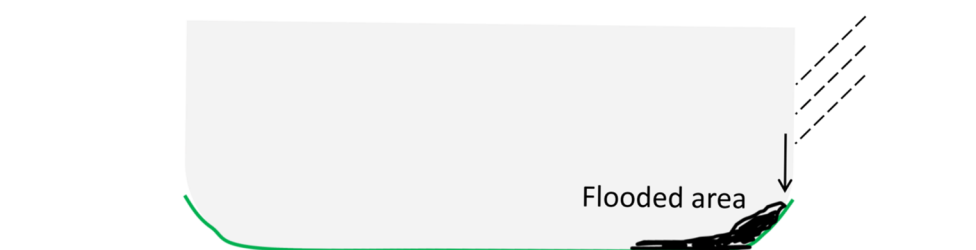


Figure 24. Water trapped in lower wrapper lip.

4.5. Impact of seed cotton location in round module

We have attempted to identify whether changes in fibre quality can be related to the location of the seed cotton in the module, e.g., fibre located in the centre compared with fibre at the top and bottom regions of the module.

Samples of about 3 kg of seed cotton were taken from different locations in the Warren carryover modules ginned in April 2015. The samples were ginned in a miniature gin located at the ACRI and the lint quality was tested at Auscott. The HVI results are presented in the table below. Extreme values are highlighted in red (worse by more than one standard deviation from the grand mean) and blue (better by more than one standard deviation from the grand mean).

Samples in the category of “Top of Module” were taken 20 cm below the top surface of the wrapper. Samples in the category of “Bottom of Module” were taken 20 cm above the ground level of the wrapper. The samples from “Middle of modules” showed wider distributions of quality indicators (more red and blue numbers in the table) than the samples taken from “Top of Modules” and “Bottom of Modules”.

Under the “Special locations” category, the sample “@wrapper bottom” refers to seed cotton in direct contact with the bottom wrapper, and the sample “@wrapper top” refers to seed cotton in direct contact with the top wrapper, in unflooded modules. The sample “direct above flood” was taken from a location about 4-5cm above the rotten cotton in a flooded module. Obviously, these areas are more problematic than the normal areas under the headings of “Top of the Modules”, Bottom of the Modules and “Middle of modules”.

The results indicate that cotton directly in contact with the plastic wrapper was more likely to deteriorate than cotton located further away from the wrapper in the module. However, caution is required to draw any conclusions from this experiment because of the small number and size of samples (3 kg) used, and the consistency of the miniature ginning process, in contrast with the industrial trials that involve hundreds of bales of ginned cotton.

Table 8. Quality of cotton taken from different locations of round module.

	UHML	UI	SF	Strength	Elongation	Rd	+b
	[in]	[%]	[%]	[g/tex]	[%]		
Top of module							
E-W top	1.22	83.46	7.21	31.59	4.92	72.23	6.12
E-W covered top	1.22	83.38	6.69	31.51	4.62	70.35	6.15
N-S top	1.22	83.43	7.26	32.05	4.87	71.28	6.99
ave	1.22	83.42	7.05	31.72	4.80	71.29	6.42
Stdev	0.000	0.040	0.316	0.291	0.161	0.940	0.494
Middle of module							

N-S centre	1.2	82.97	7.85	31.02	4.71	72.8	6.58
E-W covered Centre	1.23	83.97	6.69	33.18	4.97	63.87	7.42
E-W covered right	1.22	83.54	7.16	30.75	4.51	70.54	6.7
N-S centre	1.26	84.88	5.58	32.28	4.35	69.95	6.35
N-S right	1.22	83.13	7.33	32.34	4.66	72.6	6.43
N-S right	1.25	84.19	5.96	31.93	4.93	70.78	6.73
E-W right	1.22	83.14	7.45	31.28	5.17	74.09	6.81
E-W left	1.2	84.31	6.89	31.94	5.31	70.9	6.59
ave	1.23	83.77	6.86	31.84	4.83	70.69	6.70
Stdev	0.021	0.680	0.767	0.796	0.328	3.089	0.328
Bottom of module							
E-W bottom	1.23	83.51	6.59	32.36	4.85	72.41	6.49
N-S bottom	1.22	83.61	6.81	32.59	4.51	70.78	6.98
N-S bottom	1.23	84.18	6.62	33.58	4.71	70.13	6.25
ave	1.23	83.77	6.67	32.84	4.69	71.11	6.57
Stdev	0.006	0.361	0.119	0.648	0.171	1.175	0.372
Special locations							
@wrapper bottom	1.21	82.23	8.28	32.01	5.23	62.82	6.56
direct above flood	1.23	83.89	6.41	32.93	4.47	73	7.42
@wrapper top	1.26	84.4	5.85	30.53	4.78	70.18	8.22
Average (All)	1.22	83.65	6.88	32.02	4.8	70.52	6.72
StDev (All)	0.019	0.885	0.867	0.916	0.307	3.271	0.552

4.6. Miniature modules conditioned in climate chamber

Seed cotton was filled in miniature modules of 30cm diameter and 80cm-long to the density of 300 kg/m³, which is approximately the same as the seed cotton density in industrial round modules. The two ends of the mini-module were covered by nets so that moisture exchange can take place. A mini-module is shown in Figure 25. The mini-module was conditioned in a Vötsch VC 4033 environmental chamber. A temperature and humidity sensor was buried in the centre of the mini-module to monitor the change of conditions during the conditioning period.



Figure 25. Miniature modules and environmental chamber.

Cotton was wetted to an intended moisture content, i.e., 6.7%, 12% and 17%, by spraying an amount of distilled water onto the seed-cotton and then pressing the seed cotton into a miniature module (300kg/m³ density). The module was then conditioned at chosen temperature and RH for a predetermined number of days, followed by oven drying at 100°C for five hours. The treated cotton and its control (stored at 22°C, 50%RH) were processed on the miniature gin at ACRI. The lint was tested by HVI at the Auscott classing facility.

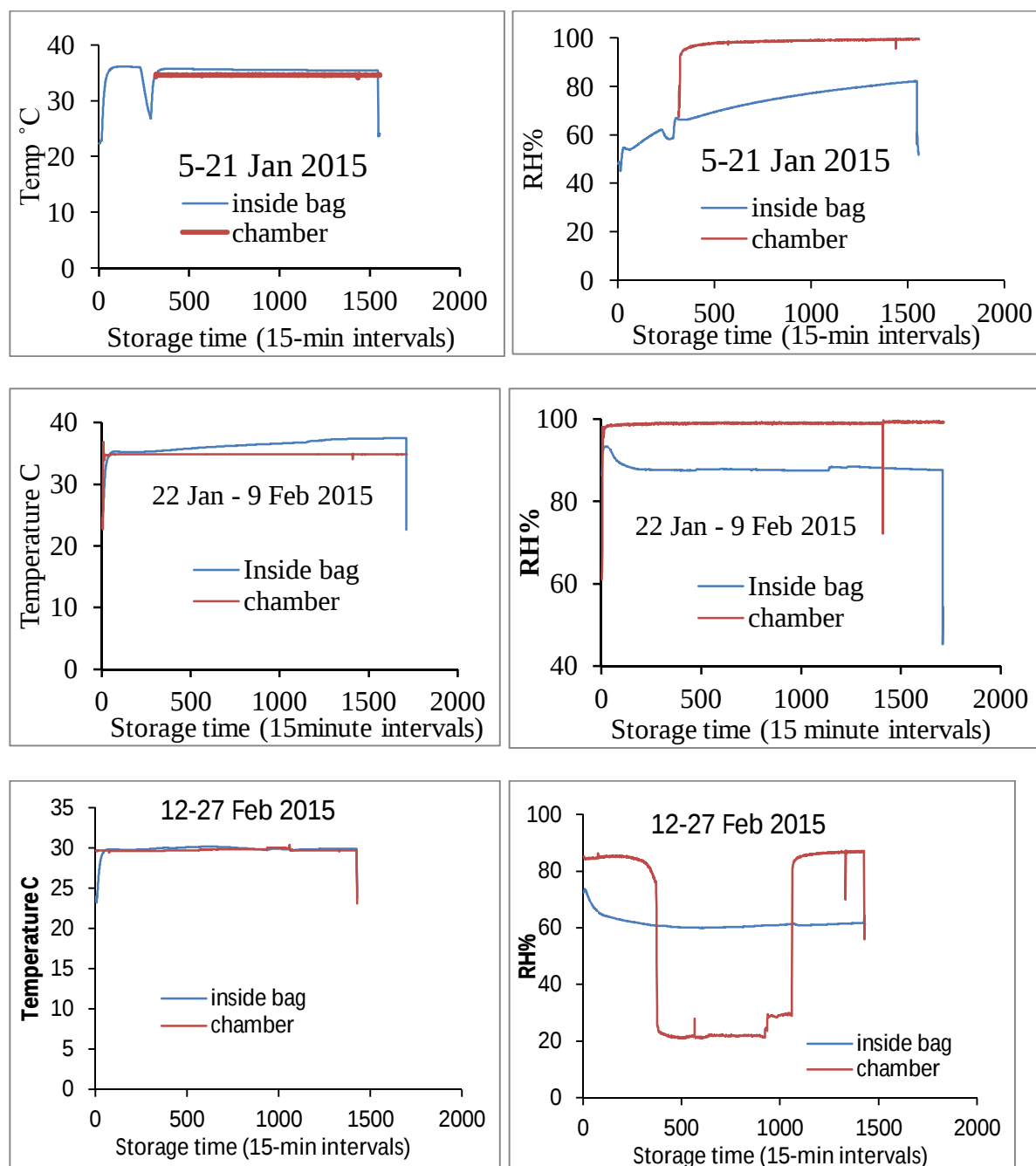


Figure 26. Temperature and moisture changes in mini-modules during storage. (NB: chamber sensor late start for trial 5-21 Jan 2015)

Three levels of moisture regain, 6.7% (as is), 17% and 12%, were used in the experiment. The temperature and RH in the conditioning chamber and inside the mini-modules are presented in Figure 26. The HVI results of the fibre produced from these samples are presented in Table 9. All the three treatments increased +b. High RH in the chamber treatment on dry (6.7%) and relatively dry seed cotton (12%) did not cause any significant

deterioration of other lint quality. High regain in cotton (17%) and high humidity conditioning (95%) caused damage to cotton quality: increased SFI and reduced strength, in addition to +b. This was considered to be a result of increased microbial activity in the cotton, as revealed by the continuous temperature rise inside the miniature module despite the conditioning chamber temperature was kept to a constant.

Table 9. HVI results from Mini-module laboratory experiments.

ID	Regain %	Temp °C	RH %	UHML [in]	SFI [%]	Str [g/tex]	Elgn [%]	Rd	+b
Average of control				1.23	6.72	31.94	6.13	73.05	7.18
StDev of control				0.02	0.81	1.16	0.36	1.22	0.63
5-21 Jan 15	6.7	35	95	1.24	6.52	32.05	5.09	72.48	8.31
22 Jan -9 Feb 15	17	35	95	1.18	9.41	30.67	6.23	68.81	9.58
12-27 Feb 15	12	30	85(22)	1.21	7.36	31.64	5.91	70.73	9.00

4.7. Further laboratory experiments

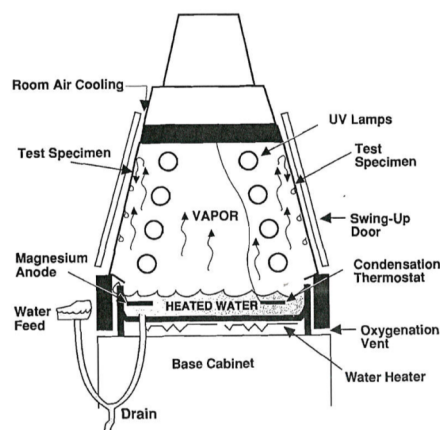
Preparation of carded web

Cotton from a bale ginned in 2015 season was used. The cotton was opened and carded on the small scale processing equipment located in CSIRO's cotton spinning mill. The resulting cotton webs were cut into rectangular shapes to fit into a standard specimen holder used in the UV accelerated weathering tester.

UV weathering

A QUV accelerated weathering tester (Figure 27) was used for laboratory simulation of the damaging effect of environmental exposure on the carded cotton. Ultra-violet damage due to sunlight exposure is simulated by fluorescent UV tubes under water vapour and condensation. The UV tubes were switched on for 12 hours and off for 12 hours each day to simulate cycles of day and night.

The carded webs were treated in the UV accelerated weathering tester for up to 41 days. Samples were removed after 9, 16, 23, 30 and 37 days from the tester. Each sample consists of five rectangular specimens. An untreated sample was used as reference. The temperature and relative humidity in the chamber were recorded every 15 minutes (Figure 27).



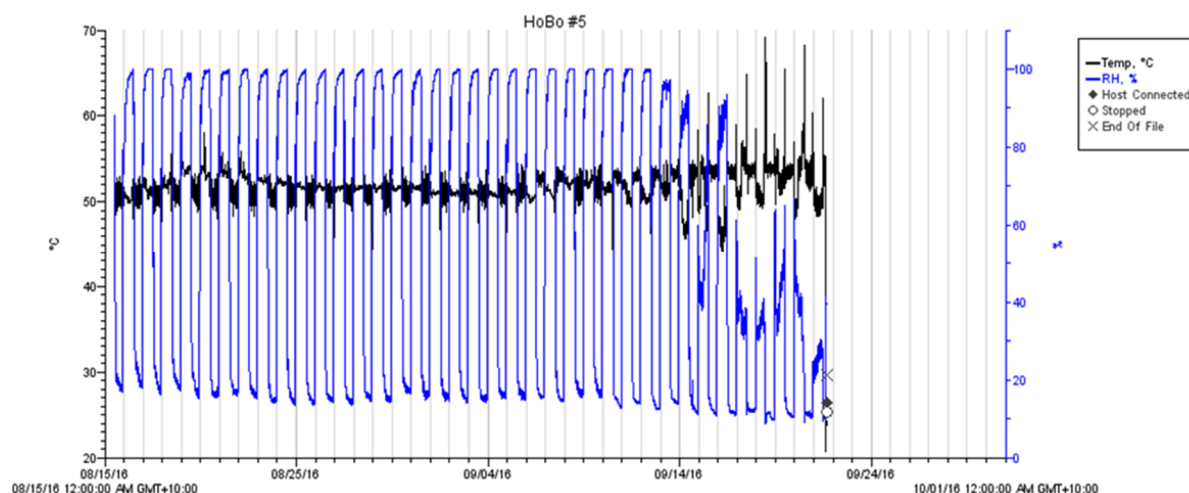


Figure 27. Top: QUV accelerated weathering tester. Bottom: Temperature and relative humidity (RH) in UV accelerated weathering treatment. The low RH periods correspond to “daytime” when the UV light is switched on. The drop in RH in the last few days of the experiment was caused by an issue in the water supply to the tester.

Climate chamber conditioning

Another set of carded cotton samples were conditioned in the Vötsch VC 4033 climate chamber. The chamber was set to a constant temperature 35°C and a constant RH 85%. Traces of the actual temperature and RH in the chamber were recorded, as shown in Figure 28.

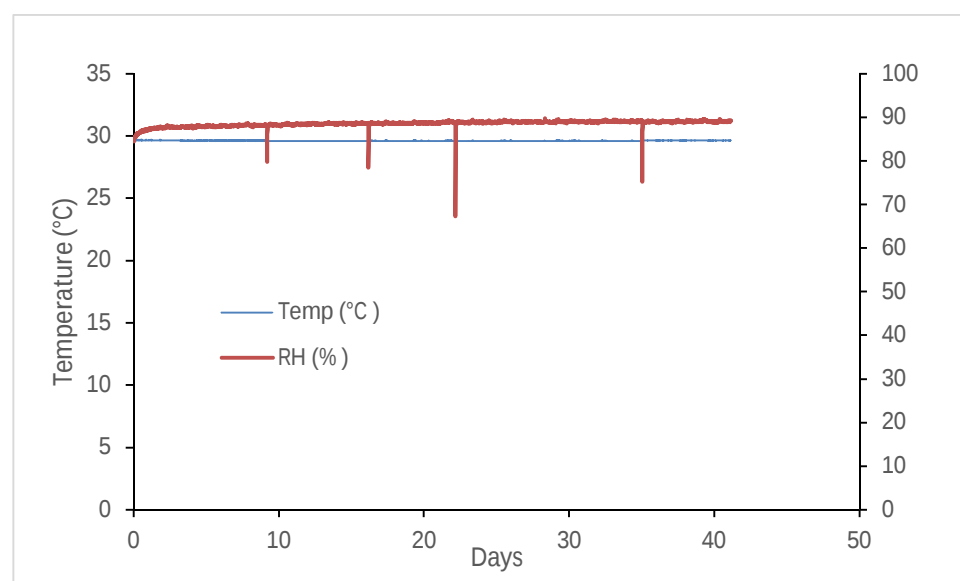


Figure 28. Temperature and RH traces in climate chamber treatment.

Influence on fibre tensile properties

Single fibre tensile tests were conducted using a Favimat Fibre Analyser. One hundred and twenty five fibres from each sample were analysed.

Figure 29 shows that fibre strength decreased dramatically by UV weathering. The fibre strength was halved after nine days of weathering. After 37 days of UV exposure, only about 1/3 of the original fibre strength still remained. On the other hand, the strength of the samples treated in the climate chamber increased slightly as the duration of conditioning increased. The

effects of these treatments on fibre elongation were similar to their respective effects on fibre strength.

The severe effect of UV exposure on cotton fibre elongation may provide a possible explanation for the elongation reduction due to storage of round modules identified in the industrial trials. The plastic wrapper does not provide effective UV shielding to the seed cotton in the module. The seed cotton situated on the top layer and ends of the round module is exposed to UV radiation during storage.

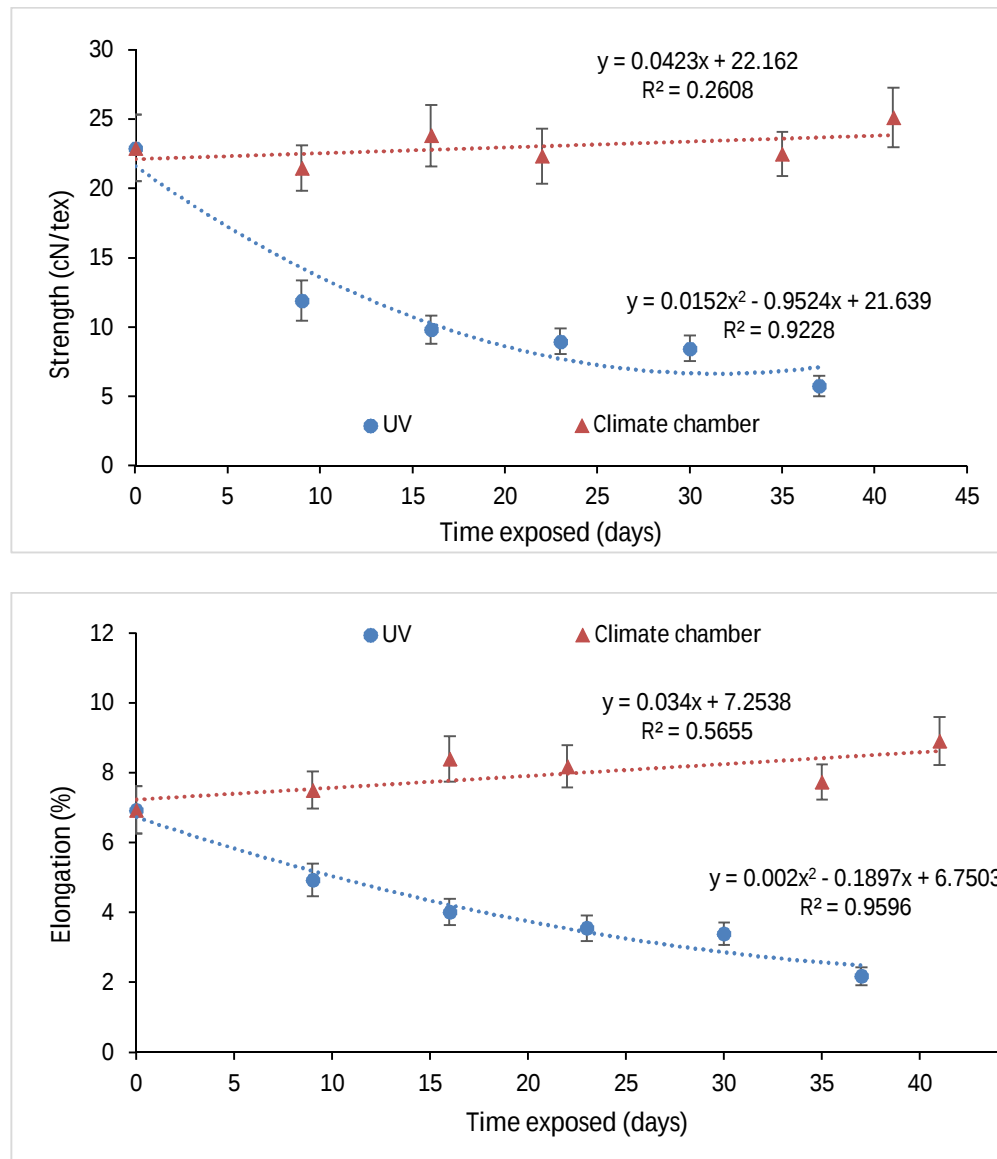


Figure 29. Effects of UV weathering and climate chamber conditioning on fibre strength and elongation.

Influence on fibre colour

A GretagMacbeth Color-Eye 7000A spectrophotometer was used to measure the Rd and +b values of the carded web samples. Ten measurements were made for each sample and the average value from the ten measurements was plotted in Figure 30.

The Rd of the carded sample showed a consistent trend of increase with prolonged climate chamber conditioning. UV weathering slightly increased the Rd of the carded web. Both UV

weathering and climate chamber conditioning had very strong effects on the +b of the carded web. Climate chamber conditioning increased +b whilst UV weathering decreased +b.

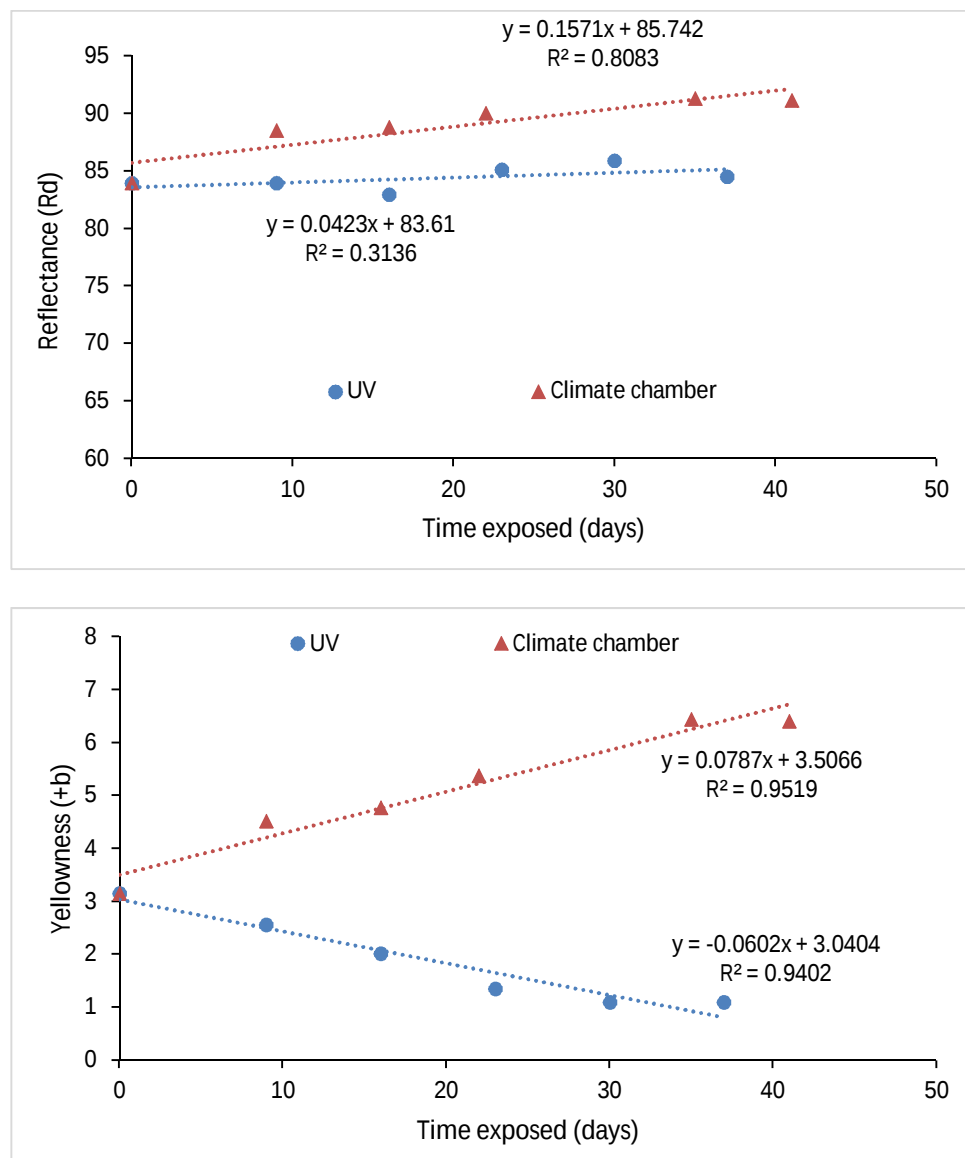


Figure 30. Effects of UV weathering and climate chamber conditioning on fibre colour attributes.

Influence on microbial activity

The pH value of cotton has been used as an indicator of microbial activity on cotton fibre [1]. The presence of micro-organisms decreases the quantity of organic acids in the fibre thus increases the pH of liquid extract of the fibres. The test provides an indication of the level of micro-organism presence. On the other hand, not all the bacteria and fungi are cellulolytic and cause cotton degradations.

The pH measurement method used for this study was proposed by Wakeham and Skau [2]. A 0.50 g sample of fibre is wetted with 3.0 mL of distilled water, which is macerated with a spatula until the fibre is uniformly wet and is then left for 15 min. The pH of the water is measured.

The seed cotton samples used in this experiment was conditioned in the climate chamber along with the carded web mentioned above.

The test results in Figure 31 show a slight increasing trend of pH value with time in the sample conditioned in the climate chamber, suggesting a small increase in microbial activity. On the other hand, UV weathering reduced the pH value, indicating a sterilisation effect. The pH level in the seed cotton sample was always higher than in the carded web, which may be explained by the presence of micro-organisms in the seed and trash present in the seed cotton sample.

[1] Allen SJ, Auer PD, Pailthorpe MT (1995). Microbial Damage to cotton. *Textile Res. J.*, **65**(7), 379-385.

[2] Wakeham HRR, Skau EL (1943). Determination of the pH of Textile Materials. *Industrial and Engineering Chemistry*, **10**(15), 616-618.

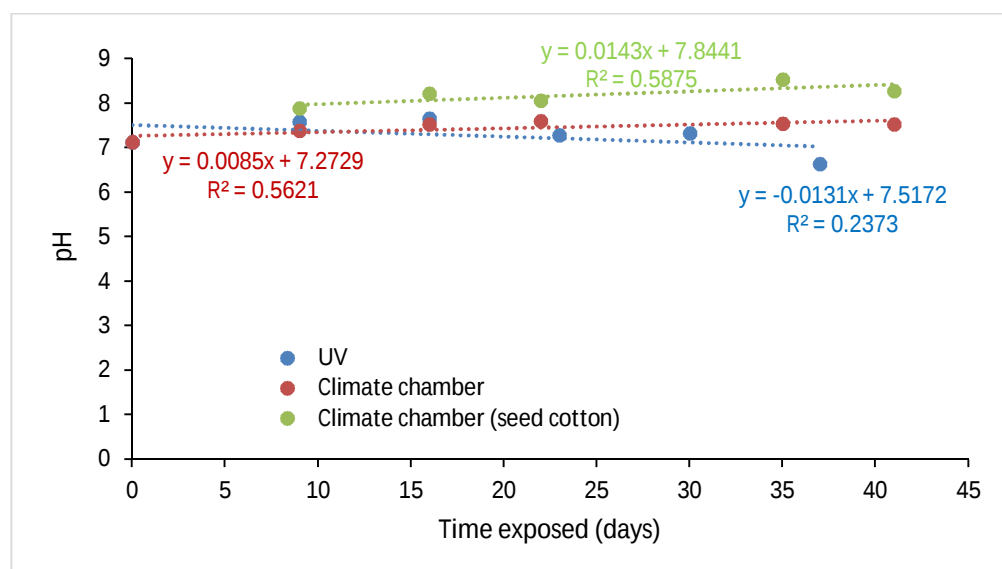


Figure 31. Effects of UV weathering and climate chamber conditioning on fibre pH value.

4.8. Trends from industrial database

The project team was provided with an industrial database containing the picking and ginning dates and HVI test results on a large number of cotton bales. The database includes 222,793 bales from the 2015 season and 222,337 bales from the 2016 season. The cotton in the databases were grown in five major Australian cotton growing regions, including Moree, Warren, Narrabri, Trangie, and Hay, and processed in six gins. All HVI testing on the bales were conducted by the same testing house.

The database contained different varieties of cotton, including some trial varieties. We focused on the 74BRF cotton variety, which constitutes the vast majority of cotton bales in the database.

Electronic version of the weather conditions from Bureau of Meteorology stations near these gins were provided.

2015 season database

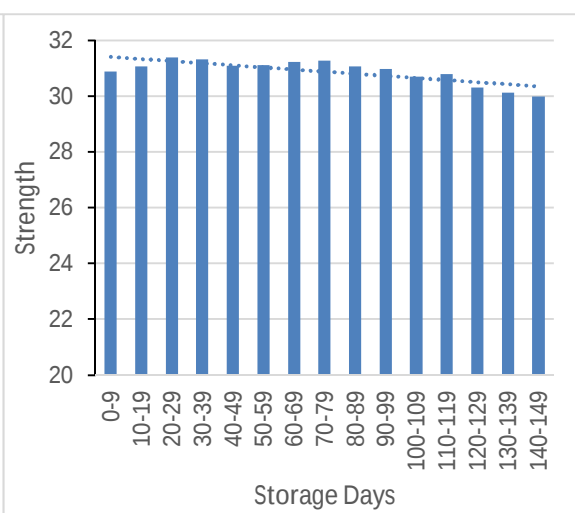
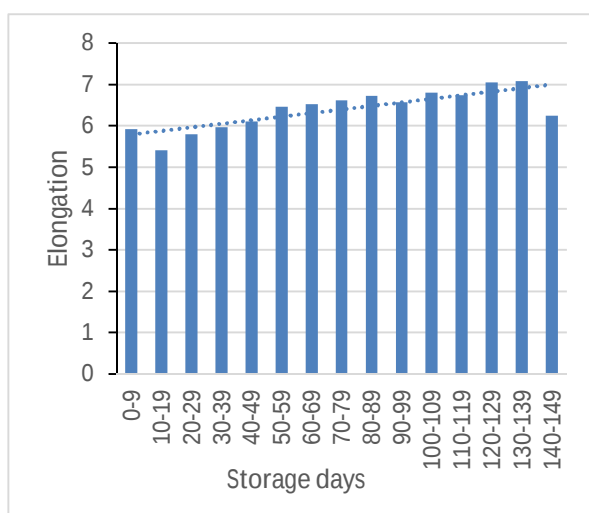
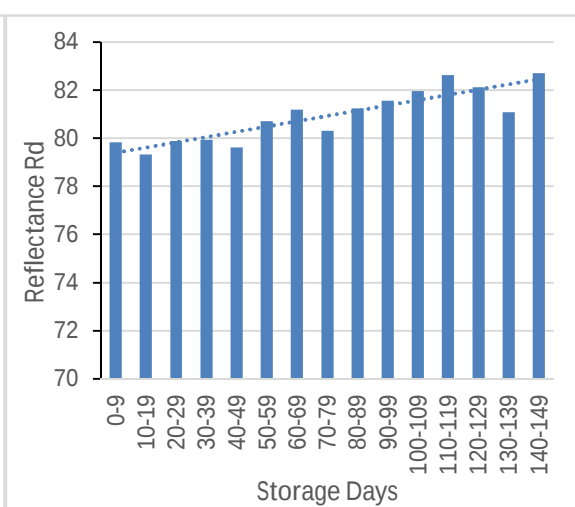
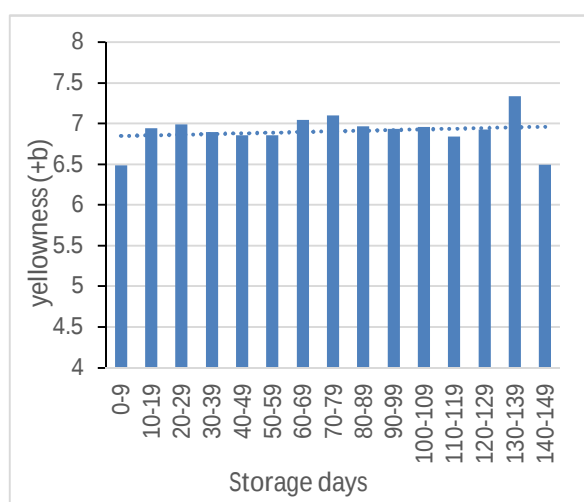
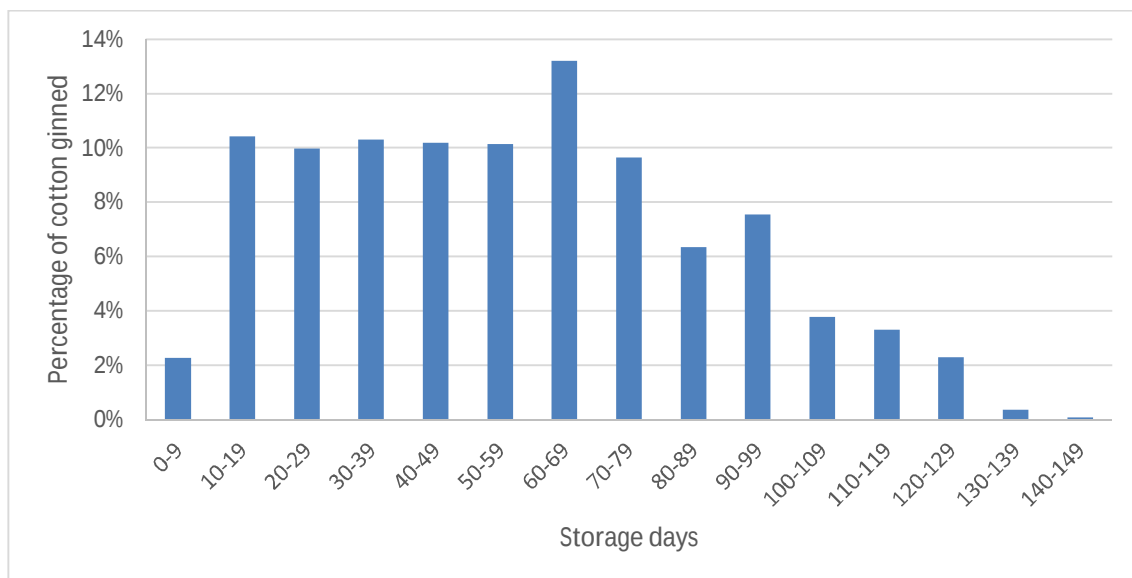
The HVI data of cotton produced from modules stored for different durations are summarised in Table 10 and Figure 32 (multiple charts). The longest storage time in the database was about 150 days, but the majority of cotton was stored less than 120 days before being ginned. Some general trends from the 2015 season were:

- Yellowness (+b) did not show significant change with increasing module storage time.
- Reflectance (Rd) increased by up to about 2 units with increasing storage time.
- Fibre elongation increased by 1% with increasing storage time.
- Fibre strength decreased by 1 cN/tex with increasing module storage time.
- There was little change in fibre length with increasing module storage time.
- Short fibre index (SFI) decreased by 1% decrease with increasing module storage time.
- Micronaire value decreased by 0.1 unit with increasing module storage time.
- Trash (area) decreased by 0.02 unit with increasing module storage time.

As the bales in the database represented different varieties, although mostly all was Sicot 74BRF, regions, harvest dates, gins and ginning dates, the contribution of storage time to these trends was not significant. The changes in yellowness and elongation identified in the industrial ginning trials, by following modules grown in the same field and processed by the same gin, were not reflected in the trends identified from the 2015 database.

Table 10. HVI properties of cotton bales ginned from modules stored for different durations.

No. days storage	No. of bales	+b	Rd	Strength	Elong.	Length	SFI	Mic	Trash Area
0-9	5051	6.49	79.84	30.90	5.93	1.20	9.57	3.97	0.32
10-19	23191	6.94	79.35	31.08	5.42	1.19	9.45	4.17	0.33
20-29	22167	6.99	79.89	31.41	5.81	1.20	9.53	4.10	0.31
30-39	22907	6.90	79.95	31.34	5.97	1.19	9.73	4.08	0.32
40-49	22668	6.86	79.63	31.09	6.11	1.19	9.65	4.12	0.33
50-59	22546	6.86	80.73	31.11	6.48	1.19	9.39	4.09	0.31
60-69	29353	7.05	81.22	31.23	6.54	1.19	9.30	4.19	0.29
70-79	21471	7.10	80.33	31.27	6.62	1.20	9.54	4.20	0.31
80-89	14104	6.97	81.25	31.07	6.74	1.20	9.36	4.06	0.29
90-99	16776	6.94	81.58	30.99	6.58	1.20	9.25	4.06	0.29
100-109	8412	6.96	81.96	30.72	6.81	1.21	8.80	3.91	0.31
110-119	7373	6.84	82.64	30.80	6.75	1.20	8.81	3.99	0.27
120-129	5090	6.93	82.13	30.32	7.06	1.20	8.76	4.01	0.30
130-139	834	7.34	81.08	30.14	7.09	1.19	8.80	4.08	0.32
140-149	196	6.50	82.73	29.99	6.26	1.22	8.34	4.03	0.31
Total	222139								



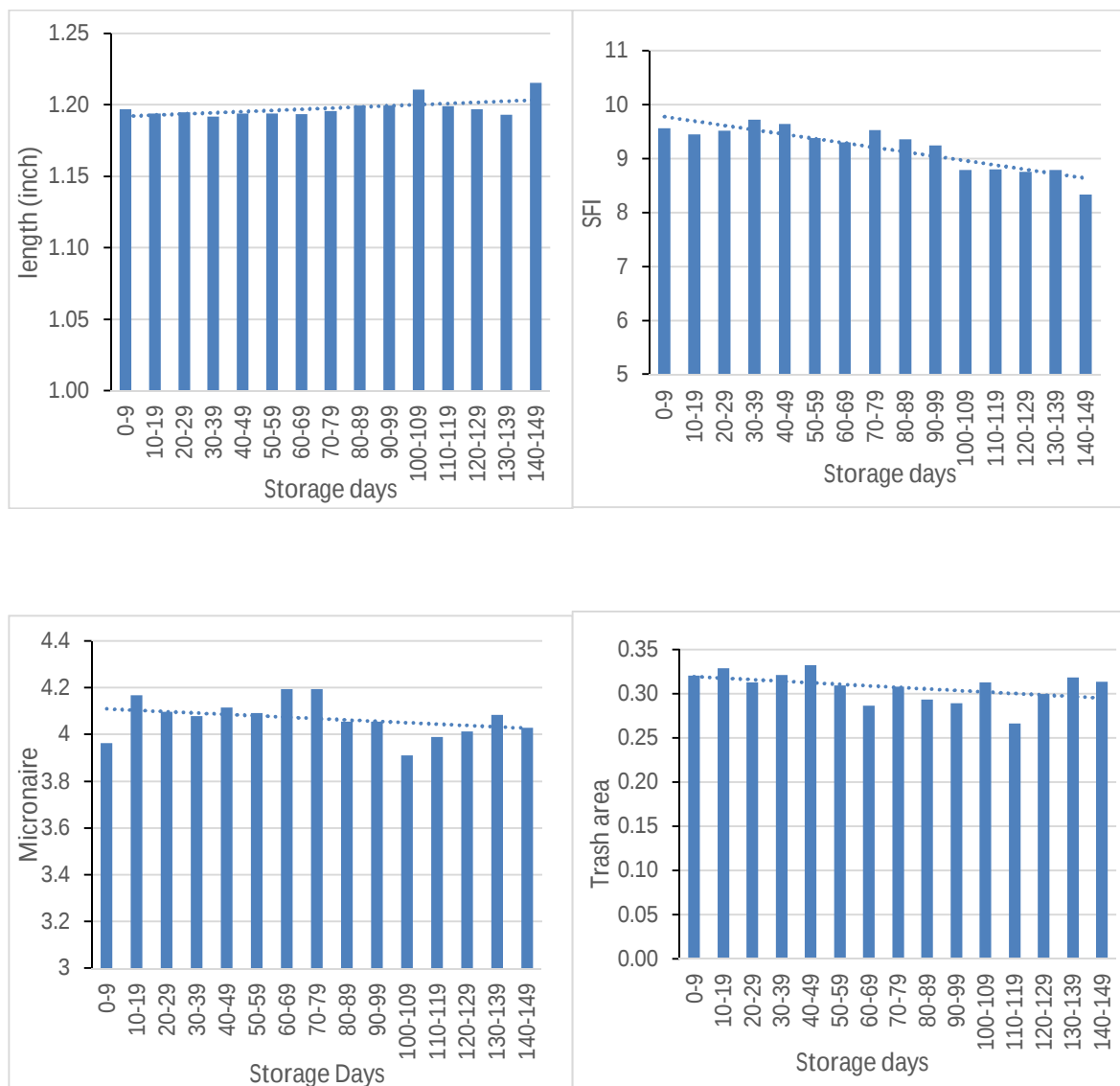


Figure 32. Trend plots from 2015 season

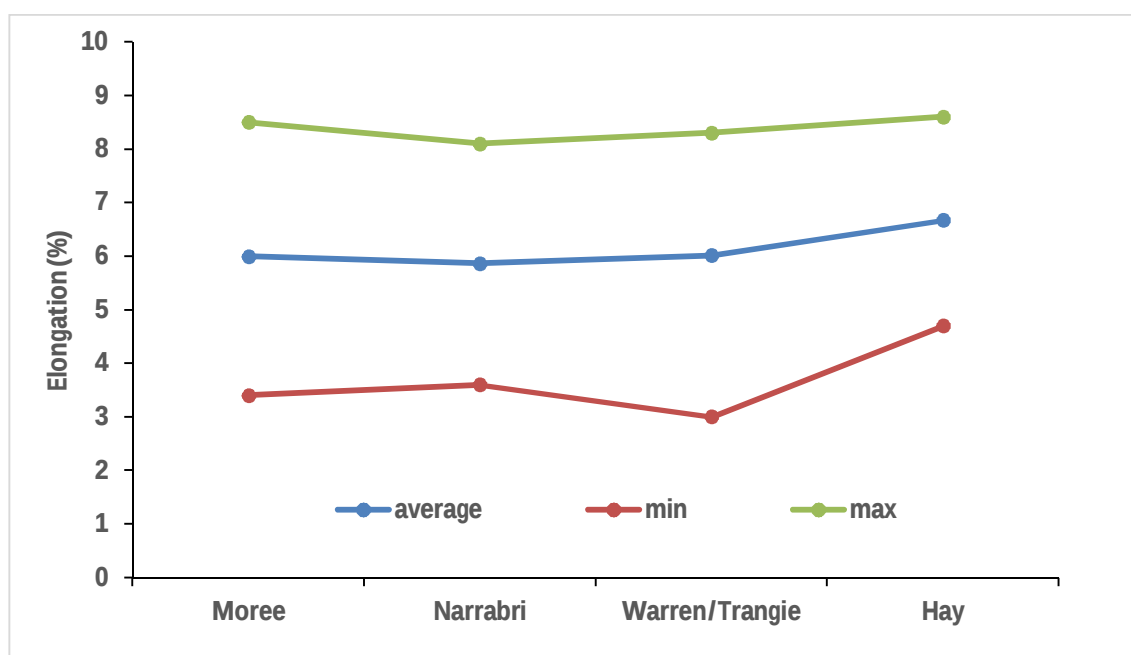


Figure 32a, Fibre elongation by region, 2015.

Trends for colour grades

In this analysis, cotton bales were divided into three categories according to their colour grade, see below:

- 0 standard, colour grades between 41 and 21
- --- grade 41 and below (discounted grades)
- +++ grade 21 and above (premium grades)

The percentages of the three categories were plotted according to the month of harvesting, the month of ginning and the duration of module storage (see Figure 33 – multiple charts). It should be noted that the numbers of bales harvested during the first month and last month were much smaller than in the other months. If we exclude these months, we find a trend of increase in premium colour as picking time and ginning time progressed along, and the percent of discounted colour grade bales reduced as the season progressed.

In the plot according to storage time, the percent of discounted colour grade bales reduced and the percent of premium colour grade bales increased as storage time increased. This was consistent with the increase of reflectance with storage time illustrated in Figure 32. In contrast, the increase trend of colour grade change we found in the industrial ginning trials was accompanied by the increase of yellowness, rather than reflectance.

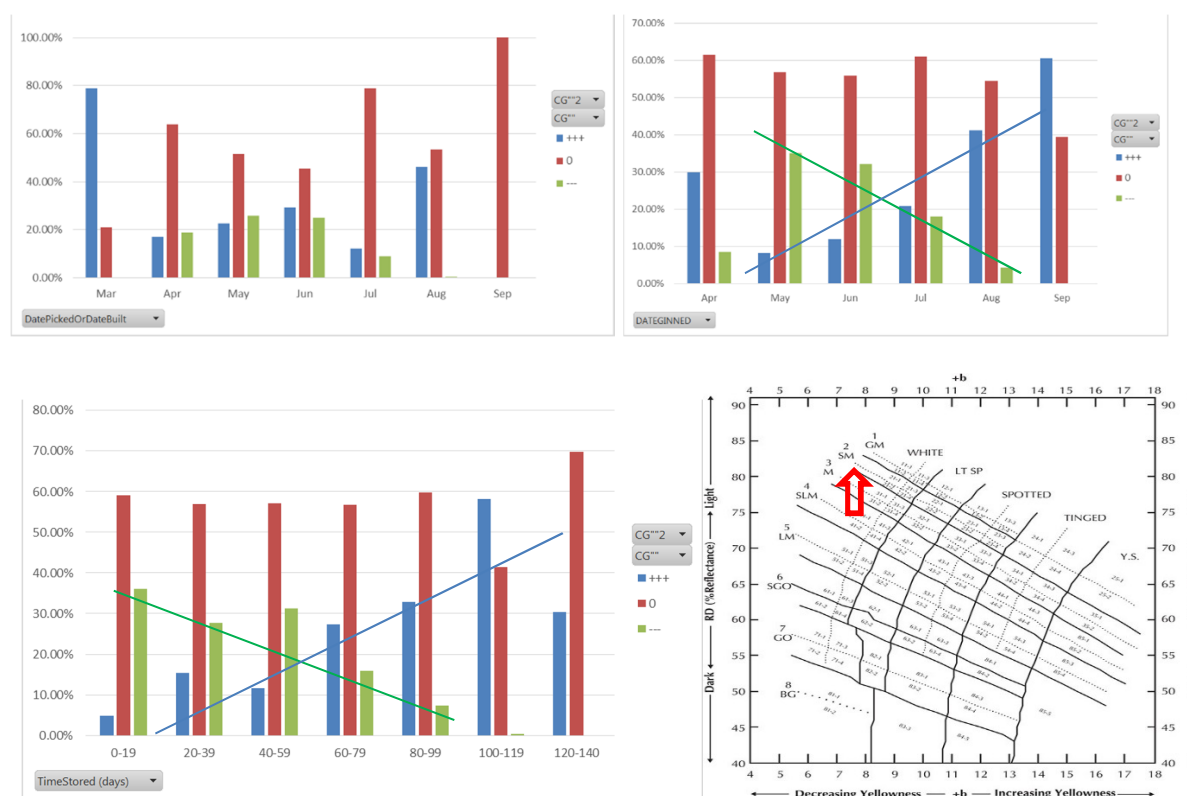
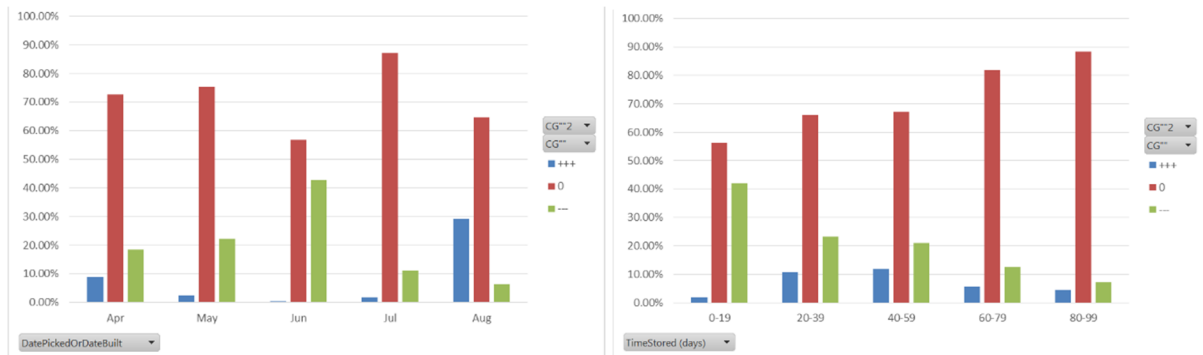


Figure 33. Change of colour grade in relation with date of picking, date of ginning and module storage time.

To investigate this anomaly further, the colour grade data for each cotton growing area was analysed to take into account of the difference in picking commencement dates (see Figure 34 – multiple charts). First of all, the proportions of discounted colour grade bales in Warren and Hay were much lower than in Moree, Narrabri and Trangie. In Moree, cotton picked in June had the highest proportion of discounted colour grade, and the proportion of discounted colour grade decreased with the storage time. In Narrabri, cotton picked in May had the

highest proportion of discounted colour grade, and the proportion of discounted colour grade was much lower for modules stored more than 80 days. In Trangie, the proportion of discounted colour grades increased with delays in picking date and with prolonged storage time. These observations of the colour grade data in different cotton growing areas do not seem to point to any consistent trends.

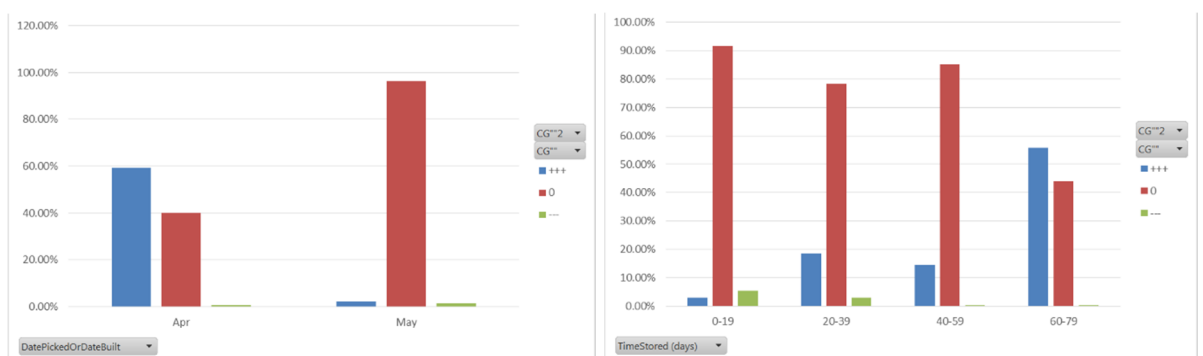
We attempted to trace cotton that were grown in the same field but ginned after storage times in the database. We did not have any success with this attempt. This is because cotton grown in the same field is usually ginned on the same day or in a few consecutive days.



Moree



Narrabri



Warren



Trangie



Hay

Figure 34. Change of colour grade in relation with date of picking and module storage time in each cotton growing area.

Impact of a rain event on cotton quality

The months of April and May are typically dry in the Macquarie Valley (@Warren). However, on April 21st and 22nd 2015, there was a heavy rain event in the Macquarie valley (43 mm on the 21st and 16 mm on the 22nd, according to BOM weather station in Trangie). Harvesting was stopped due to the rain and resumed five days later on April 26th, when the field had dried enough to enable harvesting. The change of fibre quality between cotton harvested prior to the rain event (4249 bales) and cotton harvested after the rain event (8831 bales), all from the same cotton field, was examined. Table 11 presents the average values and the standard deviations of fibre quality attributes for cottons picked before and after the rain event.

The important changes include: yellowness decreased by 1.1 unit, SFI increased by 0.75% and trash by area increased by nearly 0.1 unit (from 0.22 to 0.31). The change in yellowness of cotton picked before and after the rain is shown in Figure 35. Two possible contributing factors to the decrease of yellowness may be “washing down” of dust from the seed cotton by rain water and the additional UV radiation in the five days following the rain. The increases in SFI and trash content are likely to be effects of increased moisture at ginning and/or increased fibre entanglement and breakdown of plant matter, e.g., leaves and bract, and the wax enveloping the fibre, caused by the rain.

Table 11. Impact of a rain event on cotton fibre quality.

Picking date		< 21/04/2015 (before rain)	> 26/04/2015 (after rain)	Change	
Number of bales		4249	8831	difference	%
Yellowness (+b)	Ave	7.75	6.67	-1.07	-13.9%
	StdDev	0.22	0.22		
Reflectance (Rd)	Ave	82.84	81.15	-1.69	-2.0%
	StdDev	0.81	1.02		
Elongation (%)	Ave	5.8	5.92	0.12	2.1%
	StdDev	0.41	0.44		
Strength (cN/tex)	Ave	32.26	31.83	-0.44	-1.4%
	StdDev	0.85	0.85		
Length (inch)	Ave	1.21	1.2	-0.01	-1.0%
	StdDev	0.02	0.02		
SFI	Ave	9.01	9.76	0.75	8.4%
	StdDev	0.82	0.88		
Trash (% area)	Ave	0.22	0.31	0.1	43.9%
	StdDev	0.07	0.08		

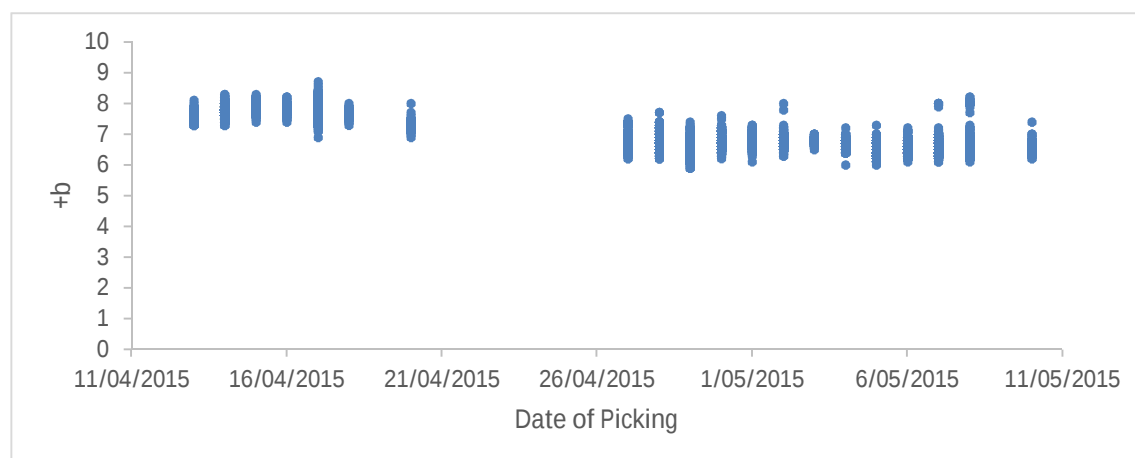


Figure 35. Yellowness of cotton picked before and after a rain event.

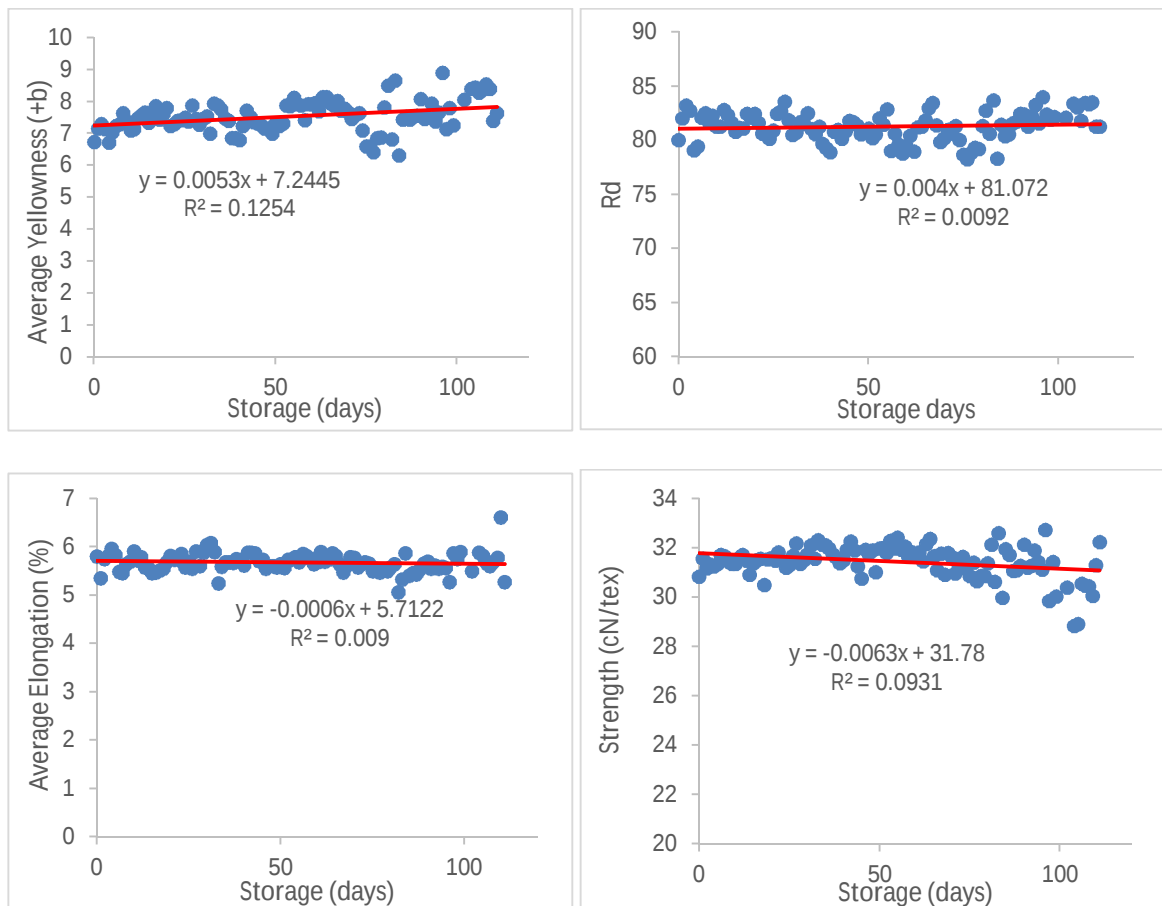
2016 season database

The HVI properties of cotton produced from modules stored for different durations in the 2016 season are summarised in Figure 36 (multiple charts). The longest storage time in the database was about 120 days. Some general trends from the 2016 season were:

- Yellowness (+b) increased by up to about 0.6 unit with increasing module storage time. The increase of yellowness in the 2015 season was smaller.
- Reflectance (Rd) kept almost unchanged with increasing storage time. The finding from the 2015 season was a clear increase trend.

- Fibre elongation showed a slight decrease (about -0.07%) with increasing storage time. This is opposite to what was found in the 2015 season.
- Fibre strength decreased by about 0.7 cN/tex with increasing module storage time. This is consistent with the finding from the 2015 season.
- There was a reduction in fibre length (-0.024 inch) with increasing module storage time.
- Length uniformity showed a very slight decrease (1%) with increasing module storage time.
- Micronaire value decreased by 0.07 unit with increasing module storage time.
- Trash (area) remained unchanged with increasing module storage time. The trend from the 2015 season was a trend of decrease.

These data trends in 2016 season are not all consistent with those derived from the 2015 database. This might be attributed to the variation in weather conditions (between years), cotton growth and ginning, any of which might have a more significant effect on cotton quality than module storage time.



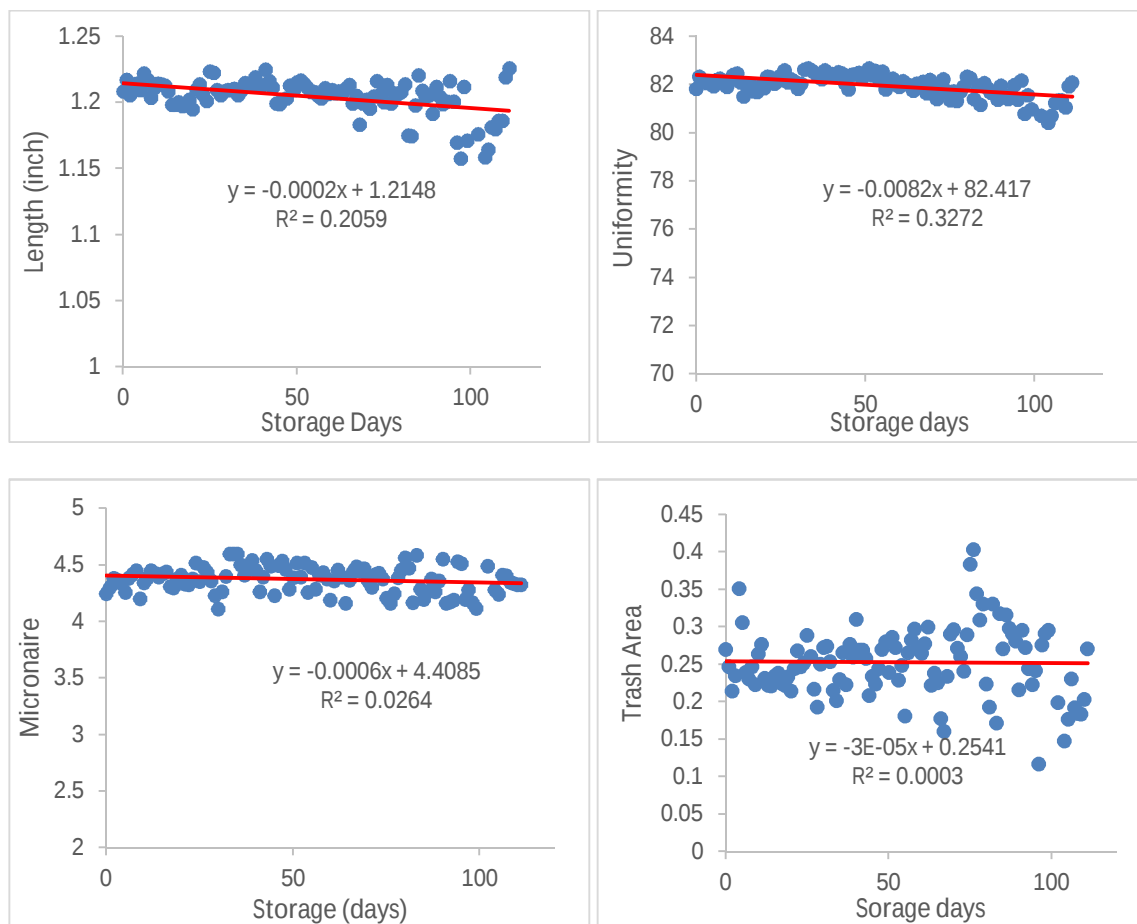


Figure 36. Trend plots from 2016 season.

We also analysed the colour grade distribution according to growth region for 2016 season (Table 12 and Figure 37). Cotton produced in the Warren/Trangie region in 2016 showed the best colour grades, followed by Moree/Narrabri and then Hay. This is in stark contrast with findings from the 2015 season, in which Hay produced the best colour grade cotton.

Table 12. Colour grade distributions by region, 2016.

Colour grades	Moree & Narrabri	Warren & Trangie	Hay	Total
11-1	19.6%	37.4%	12.8%	21.2%
11-2	7.1%	9.5%	9.0%	8.4%
11-3	0.0%	0.0%	0.0%	0.0%
11-4	0.0%	0.0%	0.0%	0.0%
12-1	0.0%	0.0%	0.0%	0.0%
12-2	0.0%	0.0%	0.0%	0.0%
13-1	0.0%	0.0%	0.0%	0.0%
21-1	31.5%	31.4%	9.0%	23.0%
21-2	13.6%	7.6%	5.6%	9.2%
21-3	0.1%	0.0%	0.0%	0.0%
21-4	0.1%	0.0%	0.0%	0.0%
22-1	0.0%	0.0%	0.0%	0.0%
22-2	0.0%	0.0%	0.0%	0.0%
23-2	0.0%	0.0%	0.0%	0.0%
23-4	0.0%	0.0%	0.0%	0.0%
31-1	11.6%	7.7%	11.0%	10.5%

31-2	5.5%	1.1%	6.4%	4.8%
31-3	0.0%	0.1%	0.0%	0.0%
31-4	0.0%	0.1%	0.0%	0.0%
32-1	0.0%	0.0%	0.0%	0.0%
32-2	0.1%	0.4%	0.0%	0.1%
33-1	0.0%	0.0%	0.0%	0.0%
33-2	0.0%	0.0%	0.0%	0.0%
33-3	0.0%	0.0%	0.0%	0.0%
33-4	0.0%	0.0%	0.0%	0.0%
41-1	8.9%	1.2%	39.0%	18.5%
41-2	1.6%	1.3%	5.1%	2.9%
41-3	0.0%	0.1%	0.0%	0.0%
41-4	0.0%	0.0%	0.0%	0.0%
42-1	0.1%	0.3%	0.0%	0.1%
42-2	0.0%	0.1%	0.0%	0.0%
43-1	0.0%	0.0%	0.0%	0.0%
44-3	0.0%	0.0%	0.0%	0.0%
51-1	0.1%	0.9%	2.0%	1.0%
51-2	0.0%	0.8%	0.0%	0.2%

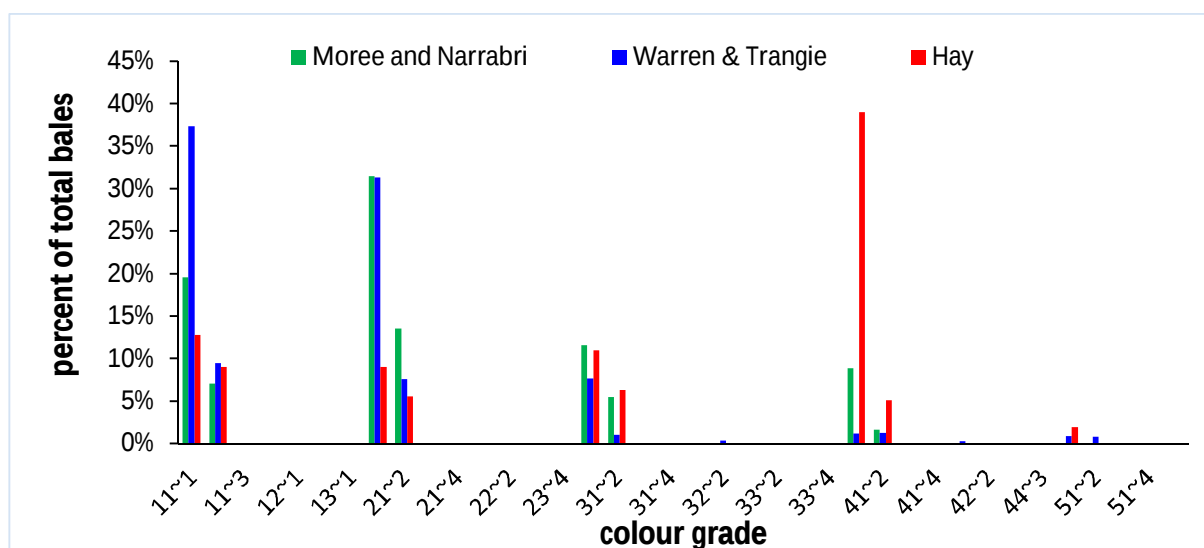


Figure 37. Colour grade distributions by region, 2016.

Outcomes

- Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

In this project, we studied round modules of seed-cotton harvested and stored according to industry guidelines (moisture content < 12%) for different periods of storage. Our conclusion is that the plastic wrapper that envelopes the round module does not significantly change the temperature and moisture conditions of seed-cotton over extended periods of storage. The current guidelines on cotton harvesting and storage based on experience from traditional square modules are adequate and applicable to the round modules.

We did however observe some consistent trends between fibre quality and storage across three different cotton growing regions and two seasons. Cotton yellowness (+b) increased

and fibre elongation decreased as modules storage periods were prolonged. For the bulk of Australian cotton the small increase in yellowness can have a positive impact on cotton colour grade as a result of the superior whiteness of Australian cotton. The increased yellowness allows strict middling cotton to be classed into a higher grade. This 'improvement' extended to round modules stored for up to ten months until the beginning of next ginning season.

Fibre elongation tended to be lower after extended periods of storage. Note that HVI elongation is currently not a certified property and it does not attract a price discount or premium, however it is a property that is well regarded by fine count spinners.

The increase of yellowness can be reproduced in controlled experiments under laboratory conditions. On the other hand, our laboratory experiments showed that UV radiation can cause simultaneous deterioration of both elongation and strength. The plastic wrapper does not provide effective UV shielding to the seed cotton situated on the top layer and the ends of the round module during storage. However, the decrease of elongation in the industrial trials was not always accompanied by a decrease of fibre strength. Further study is needed to address the cause of this reduction in elongation.

6. Please describe any:-

- a) technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);**

Not relevant to this project.

- b) other information developed from research (eg discoveries in methodology, equipment design, etc.); and**

The method and equipment used for continuous monitoring of module conditions can be employed by industry and in future research.

- c) required changes to the Intellectual Property register.**

No.

Conclusion

7. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

Mapping of temperature and moisture in round modules during storage

We employed a continuous module monitoring system including a temperature & humidity sensor connected by cable to a data logger. Relative humidity (RH) and temperature inside the module were recorded by the data logger every 15 to 30 minutes for up to ten months without intervention.

The temperature and relative humidity in the top part of the round module fluctuate significantly while conditions in the rest of the module remain relatively stable. After long periods of storage, moisture in the top part of the module decreases and eventually the bottom part of the module becomes the wettest region. Covering the modules with a tarpaulin reduces the fluctuation of temperature and relative humidity and slows down the drying of cotton in the top part of the module. The orientation of modules during storage also has an influence on the conditions of the modules. In the nine-month examination in Warren, core temperatures of modules stored with axis in North-South direction were about 2°C higher than those stored in an East-West direction during the summer months.

There was no clear relationship between the storage temperatures and moisture, and fibre quality from the seed-cotton picked under BMP guidelines.

Effect of module storage on cotton quality - industrial ginning trials

Twelve monitored ginning trials were conducted in three regions (Emerald, Warren and Hay) over two seasons (2015 and 2016). Monitored runs were carried out on between 12 and 150+ modules (664 bales). HVI results on all bales produced from the monitored modules were collected and analysed. Several cotton quality attributes (length uniformity, strength, elongation and colour (+b)) displayed statistically significant changes between modules ginned at the beginning of the trial and that ginned at the end of the storage period. Carry over modules (modules harvested in one year and ginned in the next year) that experienced up to ten months of storage (winter, spring and summer) provided very useful information on the effect of storage time.

Two consistent trends emerged from these monitored ginning trials. These were increases in yellowness (+b) and decreases in elongation with module storage time. Note that whilst these trends were apparent across all trials, the scale of differences could not be attributed to storage period alone. The trials, particularly those on carry-over cotton, demonstrated that average yellowness and elongation experienced progressive changes with storage time. Interestingly, the increased yellowness (+b) lead to a positive impact on colour grade as Australian cottons are “super-white”. The reduction in elongation may be caused due to UV exposure of the cotton at the top and ends of the round module. This hypothesis should be confirmed by further investigation.

Module flooding

Rain water on the end and top surfaces of the module can flow downwards along the plastic wrapper lip, causing flooding in the bottom region of the module. In the industrial trials in Warren and Hay, we observed a considerable number of flooded modules that suffered serious damage to the cotton at the bottom of the modules. The rotten cotton was manually removed from the module feeding bay during ginning and discarded as waste.

Fibre quality in relation to location in round module

Small samples of seed cotton (3 kg) were taken from different locations in the modules and were ginned on a miniature gin. The resulting fibre was tested by HVI. The results seem to suggest that cotton directly in contact with the plastic wrapper at the top (UV radiation) and bottom of the module (higher moisture) were more likely to suffer degradation.

UV radiation and climate conditioning - laboratory experiments

Ultra-violet radiation weathering can dramatically reduce the strength and elongation of cotton fibre. Fibre strength was halved in fibre samples after nine days of UV radiation exposure in a weathering chamber. After 37 days of UV exposure, only about 1/3 of the original fibre strength remained. On the other hand, climate conditioning (temperature 35°C and 85%RH) for 41 days to promote microbial activity did not cause noticeable damage to fibre strength or elongation. However, there was an increase in yellowness after the climate conditioning treatments.

The reflectance (Rd) of the carded cotton samples showed a consistent trend of increase with prolonged climate conditioning. UV radiation slightly increased the reflectance of the carded web. Both UV radiation and climate chamber conditioning had very strong effects on the yellowness (+b) of the carded web. Climate chamber conditioning increased yellowness whilst UV radiation decreased yellowness.

The pH value of cotton was used as an indicator of microbial activity on cotton fibre in the UV radiation and climate conditioning experiments. The pH value increased slightly as the

time of climate conditioning prolonged, suggesting a slight increase in microbial activity. On the other hand, UV radiation reduced the pH value, indicating a sterilisation effect.

Trends from industrial database

Trend analysis was conducted on a large industrial database that contained harvesting and ginning dates and HVI test results of 222,793 bales of cotton from the 2015 season and 222,337 bales from the 2016 season. The cotton in the databases were grown in five growing regions and processed by six gins in Moree, Warren, Narrabri, Trangie and Hay.

Some trends between cotton quality indicators and module storage time were identified from each of the two seasons. However, the trends identified from the 2015 season database were not repeated in the 2016 season. The inconsistency might be attributed to the complex nature of weather conditions during cotton growth and picking and ginning conditions, any of which can have a more significant effect on cotton quality than module storage time.

The effect of a rain event in the Macquarie Valley was investigated. Harvesting was stopped due to the rain and resumed after four days. By comparing the HVI data of cotton harvested before and after the rain, it was found that yellowness decreased by 1.1 unit, SFI increased by 0.75% and trash by area increased by 0.1 unit.

The main take home message from this project is that round module storage has a detectable influence on the yellowness and elongation of the cotton fibre. The change in yellowness turns out to be a positive effect on colour grade due to the superior whiteness of Australian cotton. The reduction in elongation may be associated with a combination of exposure to UV radiation and microbial activity but further research is required to confirm these effects. On the whole, the industry guidelines for moisture content at harvesting and module storage conditions used for conventional modules are applicable for round modules.

Extension Opportunities

- 8. Detail a plan for the activities or other steps that may be taken:**
(a) to further develop or to exploit the project technology.

Results from this project will be extended to the Cotton Info Team and industry.

- (b) for the future presentation and dissemination of the project outcomes.**

Two to three journal papers will be prepared from this research.

- (c) for future research.**

The main recommendation is to further investigate the effect of module storage time on fibre elongation. The deterioration of elongation due to storage of round modules revealed in this project has not been explained sufficiently by the controlled experiments conducted within this project although laboratory experiment using small samples has shown a link between UV exposure and fibre tensile properties (strength and elongation).

Another recommendation is to find a solution for module flooding caused by the plastic wrapper at the bottom of the modules. This problem is specific to round modules although it only happens in the wetter weather conditions experienced in the southern cotton growth regions and the quantity of cotton loss is relatively small.

It is also worthwhile to assess degradation of the plastic wrapper used on round modules during module storage, which may have an influence on plastic film contamination to the cotton.

**9. A. List the publications arising from the research project and/or a publication plan.
(NB: Where possible, please provide a copy of any publication/s)**

The work has been presented in

- (1) Beltwide Conference in New Orleans January 2016,
- (2) Australian Cotton Conference in Gold Coast August 2016.

We plan to publish 2 - 3 papers in research journals and at least one article in a trade magazine (Australian Cottongrower or Spotlight).

B. Have you developed any online resources and what is the website address?

No.

Part 4 – Final Report Executive Summary

Provide a one page Summary of your research that is not commercial in confidence, and that can be published on the World Wide Web. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

The use of round module builder pickers has grown very quickly in Australia. As the round module is wrapped in a plastic polyethylene film, concern has been expressed about the effect the film has on moisture and heat retention and on fibre quality. Connected to this question is the question of whether it is adequate to follow the current harvesting and module storage guidelines, which were developed for the conventional square module. A literature survey showed that published work on fibre quality damage in this context is almost exclusively due to storage of extremely wet cotton harvested above the recommended moisture content (12%). This study focused on seed cotton picked according to the recommended moisture content. In our trials, all round modules had less than 9% moisture content.

We adopted a number of approaches to investigate the effect of module storage time on cotton quality, including continuous monitoring the moisture and temperature history of modules picked from the same field and comparing quality of cotton ginned at different times (up to ten months of storage), ginning small samples of seed cotton taken from different parts of round module, UV radiation and climate conditioning of cotton fibres, and analysis of large databases of HVI bale results with their harvest and gin dates.

The temperature and relative humidity at the top part of the round module fluctuates significantly while conditions in the rest of the module remain relatively stable. After long periods of storage, moisture in the top part of the module decreases and eventually the bottom part of the module becomes the wettest region, although this in part can also be due to the effects of rain and water build-up in the bottom lip of the module wrap. Covering the modules with a tarpaulin reduces the variation in temperature and relative humidity and slows down the drying of cotton in the top part of the module. The orientation of modules during storage has an influence on the conditions of the modules. Core temperatures of modules stored with axis in North-South direction can be about 2°C higher than those stored in the East-West direction during the summer months.

Twelve module monitoring trials were conducted in three regions (Emerald, Warren and Hay) over two seasons (2015 and 2016). Several cotton quality attributes (length uniformity, strength, elongation, and colour) displayed statistically significant changes between modules ginned at the beginning of the storage period and that ginned at the end of the storage period. Not all these changes could be assigned to the effect of storage time.

Two consistent trends emerged from these monitored ginning trials. These were increases in yellowness (+b) and decreases in elongation with module storage time. Note that whilst these trends were apparent across all trials, the scale of differences could not be attributed to storage period alone. The trials, particularly those on carry-over cotton, demonstrated that average yellowness and elongation experienced progressive changes with storage time. Interestingly, the increased yellowness (+b) lead to a positive impact on colour grade as Australian cottons are “super-white”. The reduction in elongation may be caused due to UV exposure of the cotton at the top and ends of the round module. This hypothesis should be confirmed by further investigation.

Ultra-violet radiation weathering can dramatically reduce the strength and elongation of cotton fibre. Fibre strength was halved in fibre samples after nine days of UV radiation exposure in a weathering chamber. After 37 days of UV exposure, only about 1/3 of the original fibre strength remained. On the other hand, climate conditioning (temperature 35°C and 85%RH) for 41 days to promote microbial activity did not cause noticeable damage to fibre strength or elongation. However, there was an increase in yellowness after the climate conditioning treatments.

Analysis was carried out on a large industrial database that contains picking and ginning dates and HVI test results of 222,793 bales of cotton from the 2015 season and 222,337 bales from the 2016 season. The cottons in the databases were grown in five growing regions, including Moree, Warren, Narrabri, Trangie and Hay, and processed by six gins. Some trends between cotton quality indicators and module storage time were identified from each of the two seasons. However, the trends identified from the 2015 season database were not repeated in the 2016 season. This inconsistency is attributable to the complex nature of weather conditions, cotton growth and ginning, any of which can have a more significant effect on cotton quality than module storage time. The effect of a rain event in the Macquarie Valley was investigated. Cotton harvested after the rain showed lower yellowness, higher short fibre index and trash content.

On the whole, round module storage has a small but detectable influence on the yellowness and elongation of the cotton fibre. The industry guidelines for traditional square modules on moisture content for picking and module storage conditions are applicable for round modules.

For more information, contact Dr Menghe Miao, CSIRO Manufacturing, phone (03) 5246 4055, email: menghe.miao@csiro.au