The *Journal of Cotton Science 24:211–228 (2020)*
http://journal.cotton.org,

ENGINEERING AND GINNING

The Effect of Round Module Storage Time and Ambient Conditions On Cotton Quality

Menghe Miao* and Stuart Gordon

ABSTRACT

The adoption of round module cotton pickers expanded rapidly in Australia after their introduction in 2008. The objective of this study was to monitor changes in fibre quality as a result of storage time and changes in conditions within modules. Temperature, relative humidity and moisture content of seed cotton in plastic-wrapped round modules, and the resulting fibre quality, were monitored for extended periods of time across three locations over three seasons. All modules observed across seasons and locations had initial moisture contents of less than 12%, which was consistent with recommended practice. Moisture levels and temperature in the modules during storage closely followed but trailed changes in ambient weather conditions. With modules typically picked during late summer through to mid-autumn, conditions inside the modules typically cooled and dried during storage. The direction of the open module face affected the rate of drying and/or cooling, as did covering modules with a tarpaulin. Fibre quality was largely stable across storage periods of up to three months, although colour (yellowness) and fibre elongation consistently degraded, even after one month of storage. Over longer periods properties such as length and strength were negatively affected although changes, whilst statistically significant, were often small or inconsequential in terms of the commercial premium paid for these properties. From this study we conclude current guidelines for cotton harvesting and storage are applicable to these new round modules. Interestingly, the 'negative' changes in fibre yellowness often increased the value of cotton in terms of its USDA colour grade.

M. Miao* and S. Gordon, CSIRO, 75 Pigdons Road, Waurn Ponds VIC 3216, Australia.
*Corresponding author: menghe.miao@csiro.au

Use of John Deere round module cotton pickers, and more recently stripper harvester versions, has grown quickly in Australia since their introduction in 2008. Today, more than 90% of the Australian crop is harvested with these machines. The harvesters make a round plastic-wrapped module that has reduced the labour and capital costs of harvest compared to the 'conventional' rectangle modules. Seed cotton in these new smaller modules is more densely packed (180-240 kg/m^3) than the larger conventional modules, which have densities between 135 and 185 kg/m^3. Both the size and density of the seed cotton module affect moisture transfer and temperature equilibration, which are also functions of the starting moisture of the picked seed cotton, the relative humidity (RH) and temperature of the environment during storage and the extent of any covering, e.g., the plastic wrap, that might limit moisture transfer. Stored in the open field or gin yard the round modules, which have open sides, are nominally more affected by changes in ambient conditions.

It is essential to consider atmospheric conditions when harvesting and storing seed cotton. Excess moisture at harvest can have detrimental effects on harvesting in terms of picking efficiency, module storage life and ginning conditions. Ginning in Australia is highly automated and either an excess or deficiency of moisture can have significant effects on process efficiency, fibre quality and lint turn-out. Seed cotton moisture content above 12% (wet basis) is considered too wet for harvesting because it causes slow harvest speeds, poor doffing (picking) efficiency and increased trash pick-up (Anthony and Mayfield, 1994; Mayfield *et al*, 1998; Anthony, 2004; van der Sluijs and Long, 2016).

Previously, safe storage of seed cotton in conventional modules was contingent upon making good quality modules, i.e., modules of uniform size and density with straight sides, kept dry with a well fitted tarpaulin and situated on raised earthen beds to allow good drainage after rain events. These rules still apply to round modules although with some different management requirements, chiefly around ensuring uniform size for handling and transport, and not allowing water from rainfall to build up in the bottom lip of the plastic wrapping.

There have been several United States (US) studies that have examined seed cotton moisture and module storage. Sorensen and Wilkes (1973) examined the effects of moisture on seed and fibre quality in the then new rectangle conventional modules. Lalor *et al* (1994) showed that seed cotton harvested and stored in conventional modules above 13% moisture content (wet basis) would suffer lint quality degradation during storage, while seed cotton in modules stored below 12% moisture should retain its inherent quality. And this century, Anthony (2006) showed colour degradation (spotting) occurs at moisture levels above 11% and that high moisture content caused yellowness to increase sharply at levels above 13% to 14%, especially when storage periods exceeded 45 days. Whilst the guidelines given by US researchers for seed cotton moisture at harvest and in modules for storage have largely been applicable to Australian conditions it is noted these studies apply to conventional modules, which are still the dominant method of transporting and storing seed cotton in the US *cf.* with the 90% adoption of the new round module harvester in Australia.

In this study, the temperature, RH and moisture inside round modules were monitored for set periods of time in three different cotton growing locations over three growing seasons. The objective of the study was to determine the conditions and storage period under which changes in fibre quality might occur.

MATERIALS AND METHODS

Modules monitored in this study were from commercial harvests of the same variety. Modules were harvested consecutively from the same field and transported within one week to the gin yard where conditions were then monitored until ginning. There were no pre-determined storage periods set in each year or location. Storage periods were determined on an *ad-hoc* basis in negotiation with the ginner and growers supplying the modules in each location. Modules stored for 12 months were required by the grower-ginner in that location for initiating gin start-up the following year.

Survey locations were selected to represent the breadth of Australian cotton growing areas, i.e., northern, central and southern growing areas, which also span the range of cotton growing climatic conditions. The three selected sites are shown in Figure 1. At least 50 modules in each location were stored and monitored for set periods. Typically, a round module weighs between 2100 and 2400 kg and produces 3.5 to 4.5 bales of lint, depending on module weight, lint turn-out and final bale weights at the gin. All modules were from the cotton variety Sicot 74BRF, which comprised >90% of Australia's cotton production in the years examined. The goal of this study was to measure the gross changes in fibre quality as a result of storage time and the temperature and moisture conditions inside the module irrespective of field treatments, e.g., defoliation periods, row configuration and irrigation applications, and module test positions and orientations. In all locations, some modules were ginned shortly after they arrived in the gin yard with the remainder stored in the gin yard and ginned after set periods of time. Table 1 lists the numbers of modules at each location and the time (days) in storage before ginning. In each location ginning was carried out at the same gin for the period of the survey. Gin-saw changes, breakdowns and other maintenance schedules that might have an impact on fibre quality were not noted; however, each of the gins operated according to Australia's best management practice (BMP) regime for ginning.

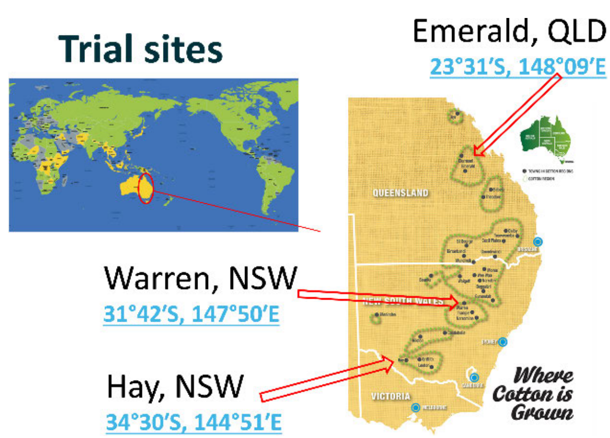


Figure 1. Geographic locations of the trials.

Table 1: Storage and ginning times of monitored modules at each location

Location and growing season	Storage start date	Storage end date	Days of storage	Total modules	No. of modules ginned at each phase: *Start (after harvest)* *Mid (1/2 storage period)* *End (end storage)*
Emerald, QLD 2014/15	3 March 2015	11 May 2015	69	54	Start = 42 End = 12
Emerald, QLD 2015/16	17 March 2016	23 May 2016	68	165	Start = 146 End = 19
Warren, NSW 2014/15	26 August 2014	1 April 2015	275	103	Start = 86 End = 17
Hay, NSW 2014/15	7 July 2015	15 April 2016	282	60	Start = 18 Mid = 22 End = 20
Hay, NSW 2015/16	25 May 2016	25 August 2016	93	124	Start = 63 Mid = 37 End = 24

Fibre quality by location and storage period was tested by Uster Technologies high volume instrumentation (HVI) lines operated by each gin company's respective classing office. It is noted each classing office was certified as operating according to Australia's BMP for classing. A one-in-three bale averaging system is applied to HVI results in Australia. This means that each module tested was represented by one or two HVI tests. Fibre length, represented as upper half mean length (UHML), short fibre index (SFI), strength, elongation, reflectance (Rd), yellowness (+b) and United States Department of Agriculture (USDA) colour grade were monitored for changes. An unpaired two-sample comparison approach was used to assess the change in fibre quality between the control sample (bales ginned immediately after modules arrived) and the treatment sample (stored bales in a trial). A Student's t-test was used to evaluate the significance of the differences between mean values.

Temperature and RH in selected modules from each location were monitored using a Hobo Pro V2 (U23-002) temperature and humidity sensor connected by cable to a weather-proof data logger with an optic USB interface to download data. The temperature accuracy of the sensors was ±0.21°C when operating in a 0°C – 50°C range, and the RH accuracy was ±2.5% when operating within a 10% – 90% RH range. The manufacturer designates a long-term drift of 0.1°C and 1% RH/year for these instruments. The sensors were new when used. No re-calibration was applied to the sensors across the two measurement periods, i.e., for just over two years. Sensor data loggers were positioned on the outside of the module with the sensor inserted into the middle of the module (to a depth of 1100 mm) at a desired position using a purpose-built spike and drive shaft, as shown in Figure 2. To test the variability of conditions inside the module, sensors were inserted into different positions from the side of the module – top, core (centre), bottom and sides, with the top, bottom and side positions being 20 cm in from the module wrap, as shown in Figure 3. One sensor was also set up 1-m above ground attached to a nearby post in an open space. The data recorded by this sensor was used to represent the ambient conditions in the gin yard. Variations in the moisture (content) of modules at each location were also assessed initially using a Delmhorst C-2000 resistance probe moisture sensor with an 830-T/C (module) electrode. Variations between modules could be quite large depending on the timing of harvest (morning dew vs. later in the day), position of the measurement (top vs. bottom), how close the measurement was to the plastic wrap (both condensation and radiant heat affected measurements at the top of the module near the plastic wrap) and the direction of the module's open face to the prevailing weather. For example, differences in moisture between the 30+ Warren modules measured during spring (September 2014) were reasonably large. Moisture values ranged between 7% and 12% (the upper limit) depending on the above factors.

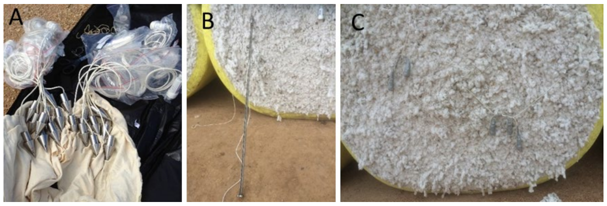


Figure 2. Temperature and RH sensors with data logger for continuous monitoring of round modules; (a) spike heads with sensor embedded and cable to data logger, (b) rod for driving spike into module and (c) sensor data loggers covered with plastic bag and grey tape against weather on outside of module.

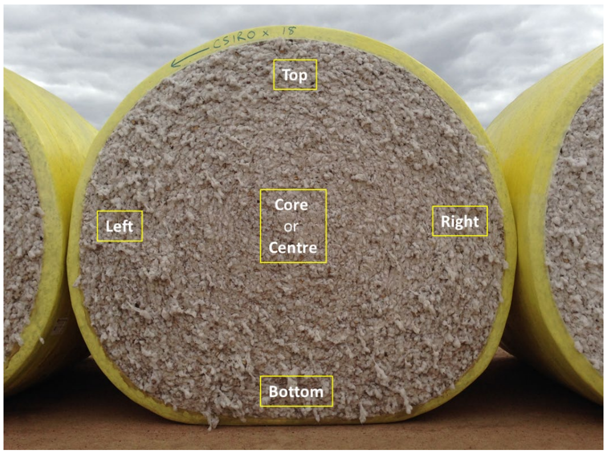


Figure 3. Diagram of side profile of round module showing location of temperature and humidity sensors.

Values of temperature and RH inside the module were recorded using the Hobo Pro loggers at 15 or 30 minute intervals for the entire storage period, which in some cases extended more than ten months. Data loggers were sealed from the weather in plastic bags and water-proof tape. The sensors were fitted into test modules usually within two weeks after harvest, when the modules had been relocated from the field to the gin yard. Data-loggers were downloaded periodically throughout the storage period in order to preserve the captured data and to check that sensors were still working. Weather data (daily minimum and maximum temperatures and rainfall) from each location for the storage periods examined were collected from the Australian Bureau of Meteorology (BOM) (Table 2).

RESULTS AND DISCUSSION

Temperature and relative humidity distributions inside and out of sample modules

Emerald QLD. Emerald has a humid subtropical climate with warm to hot summers and mild, dry winters. Maximum daily temperatures range from 34°C in January to 22°C in July, while minimum temperatures range from 22°C to 7°C. The average annual rainfall is 561.2 mm with the highest monthly falls from November through to February.

Table 2: Bureau of Meteorology data for each location

Location and growing season	Storage months	Min. temp. (°C)	Max. temp. (°C)	Rainfall (mm)	Relative Humidity 9.00 am (%)	Relative Humidity 3.00 pm (%)
Emerald, QLD 2014/15	Mar15	21.7	35.9	8.6	54.2	32.1
	Apr15	16.0	29.6	11.2	49.9	29.5
	May15	12.5	22.5	0.2	45.5	23.0
Emerald, QLD 2015/16	Mar16	22.0	33.3	20.8	68.4	46.2
	Apr16	18.6	32.0	1.0	61.4	34.4
	May16	15.8	29.5	0.0	58.4	33.5
Warren, NSW 2014/15	Jul14	3.7	16.6	34.0	*80	*50
	Aug14	3.6	18.6	26.8	70	50
	Sep14	6.7	22.9	9.8	60	40
	Oct14	11.2	29.9	2.6	50	40
	Nov14	16.0	34.0	6.2	50	30
	Dec14	17.9	33.2	79.6	50	30
	Jan15	18.3	31.9	59.2	50	30
	Feb15	22.0	35.1	0.8	60	40
	Mar15	15.9	31.8	11.2	60	40
	Apr15	16.2	24.8	114.4	70	40
Hay, NSW 2014/15	Jul15	2.9	13.6	21.2	97.5	59.8
	Aug15	5.1	15.0	39.0	97.0	57.7
	Sep15	4.5	20.2	17.8	91.6	37.1
	Oct15	12.0	30.0	21.8	70.0	19.5
	Nov15	13.9	29.7	96.9	76.0	23.8
	Dec15	16.9	33.0	23.9	59.1	16.6
	Jan16	18.2	32.7	40.7	69.9	21.8
	Feb16	17.0	33.3	6.7	63.9	19.0
	Mar16	17.2	32.0	0.4	61.7	22.0
	Apr16	11.5	26.6	18.4	71.9	27.0
Hay, NSW 2015/16	May16	8.6	20.0	55.8	93.9	48.5
	Jun16	5.1	14.4	49.8	98.9	70.0
	Jul16	5.6	14.2	30.0	98.5	71.8
	Aug16#	-	-	-	-	-

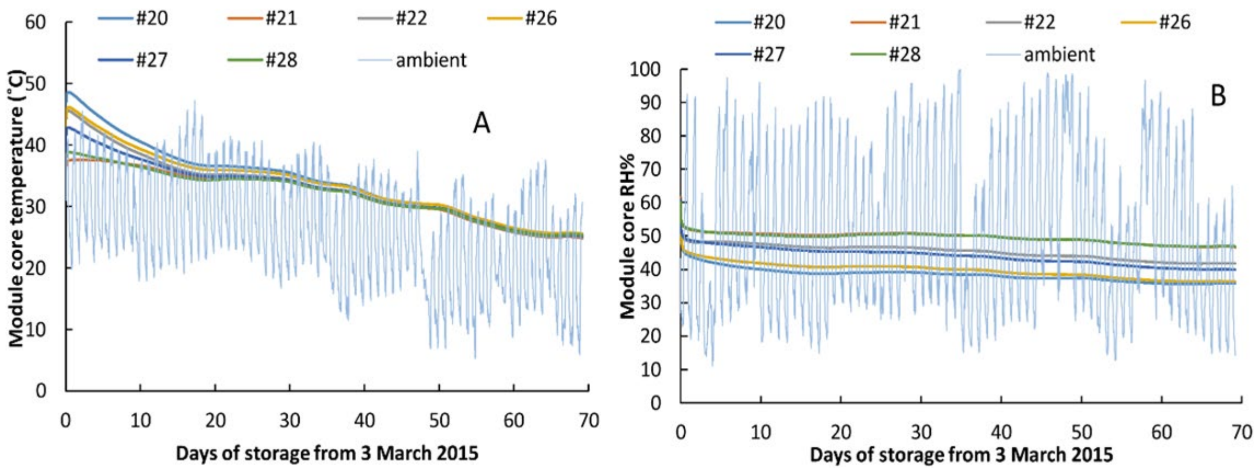
* no BOM RH values available for Warren NSW. Values shown are recorded from the BOM's annual average daily 9 am and 3 pm RH values– see http://www.bom.gov.au/jsp/ncc/climate_averages/relative-humidity/index.jsp

no data available

The core temperatures (measured in the centre of the modules) at this location were as high as 49˚C, recorded in the morning early March 2015. The ambient daily mean maximum temperature in March was the hottest since 1998, at 35.7˚C. Storage conditions in Emerald were very hot and dry in both years from start to finish with 2014/15 being the drier both in terms of rainfall and RH. The high initial core temperatures are a result of the high radiant heat on the crop at harvest; the ambient daily mean maximum temperature during February 2015 was 34.1˚C. The variation in temperature and RH between modules reflects the ambient temperature and RH at the time of harvest [Figures 4(a) and (b)].

Modules with higher initial core temperatures had correspondingly lower RH values. Regardless of the ambient temperature, module core temperature and RH were largely insulated from the daily fluctuations in ambient temperature and humidity. Conditions at the top of the module fluctuated as a result of direct exposure to solar (radiant) heat, while conditions in lower parts of the module were more stable within a day (see Figure 5).

Module core temperature decreased as the weather in Emerald, and other locations, became seasonally cooler, however the module core temperature was always higher than the average daily ambient temperature. The initial differences in core temperature between modules harvested at different times disappeared after a one-month time period, as shown in Figure 4(a). There was less change in moisture and the differences in RH between modules did not change significantly during storage, as shown in Figure 4(b). Initial differences in module RH were attributed to moisture conditions at harvest time, e.g., higher RH in the morning or in the evening occurred as a result of dew, rather than rain events. The decreasing RH over the storage periods indicating loss of moisture from the module.



Figures 4. Plots of core temperature (a) and RH (b) for six different modules and ambient conditions at Emerald QLD from 3 March to 11 May 2015. Ambient conditions are represented by the highly fluctuating thin blue lines.

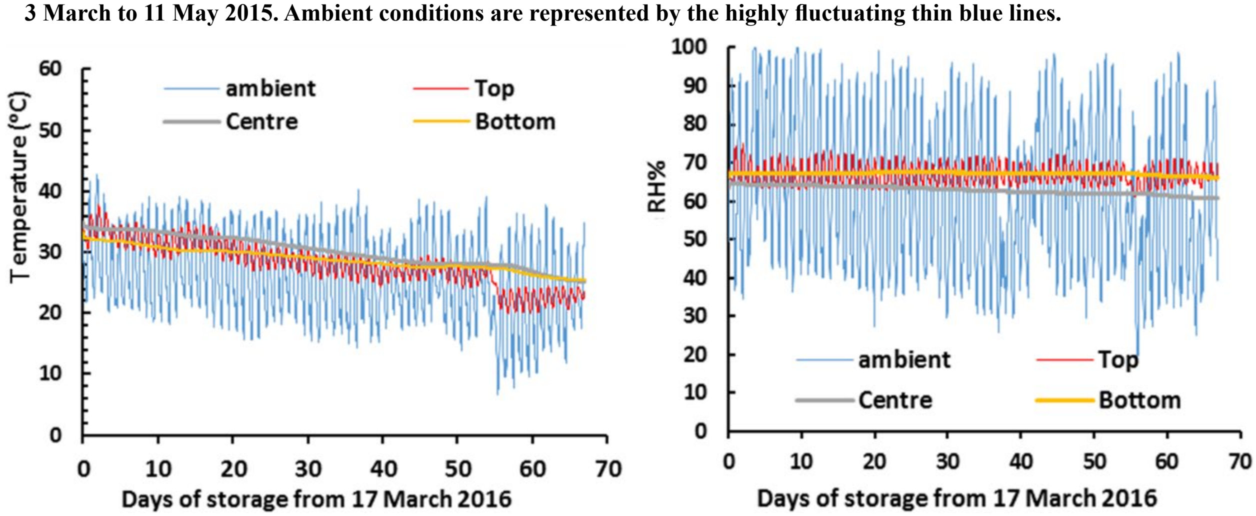


Figure 5. Plots of temperature (a) and RH (b) at different positions in one module with ambient conditions at Emerald QLD from 17 March to 23 May 2016.

Storage conditions in Emerald were similar in both years, although the second year was warmer and drier in the last month (Figure 6). Interestingly, the initial core conditions of the modules in the second year were 5 to 10˚C cooler and had 10 to 15% higher RH than the first year, which was very hot and dry at the start. This difference was attributed to cooler and slightly moister conditions during harvest, with 2016 having at least 10% higher RH through the same period.

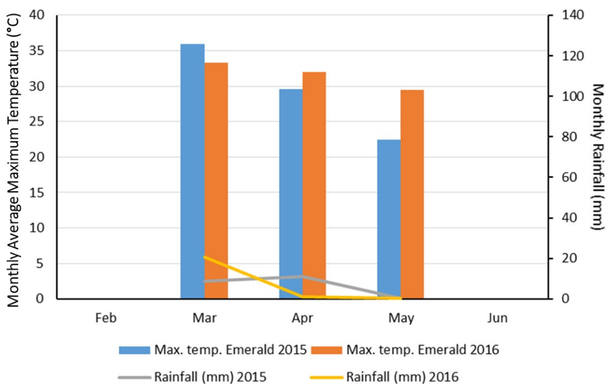


Figure 6. Monthly average maximum temperature and monthly rainfall totals in Emerald QLD during the storage period. Based BOM data.

Warren NSW. Warren falls in the warm temperate climate zone of NSW's central western tablelands. It has a humid subtropical climate that borders a semi-arid climate further west. Summers are warm to hot and winters cool to cold with some morning frosts. The annual rainfall is 516.3 mm with the highest monthly accumulation during late summer and mid-spring.

Figure 7 shows temperature and RH variations in modules at the Warren location for a long storage period from late August 2014 through to early July 2015. In this location, module conditions were tested with different module orientations during storage: North-South (N-S) and East-West (E-W), with the N-S direction giving one face of the round module the greatest exposure to solar radiation.

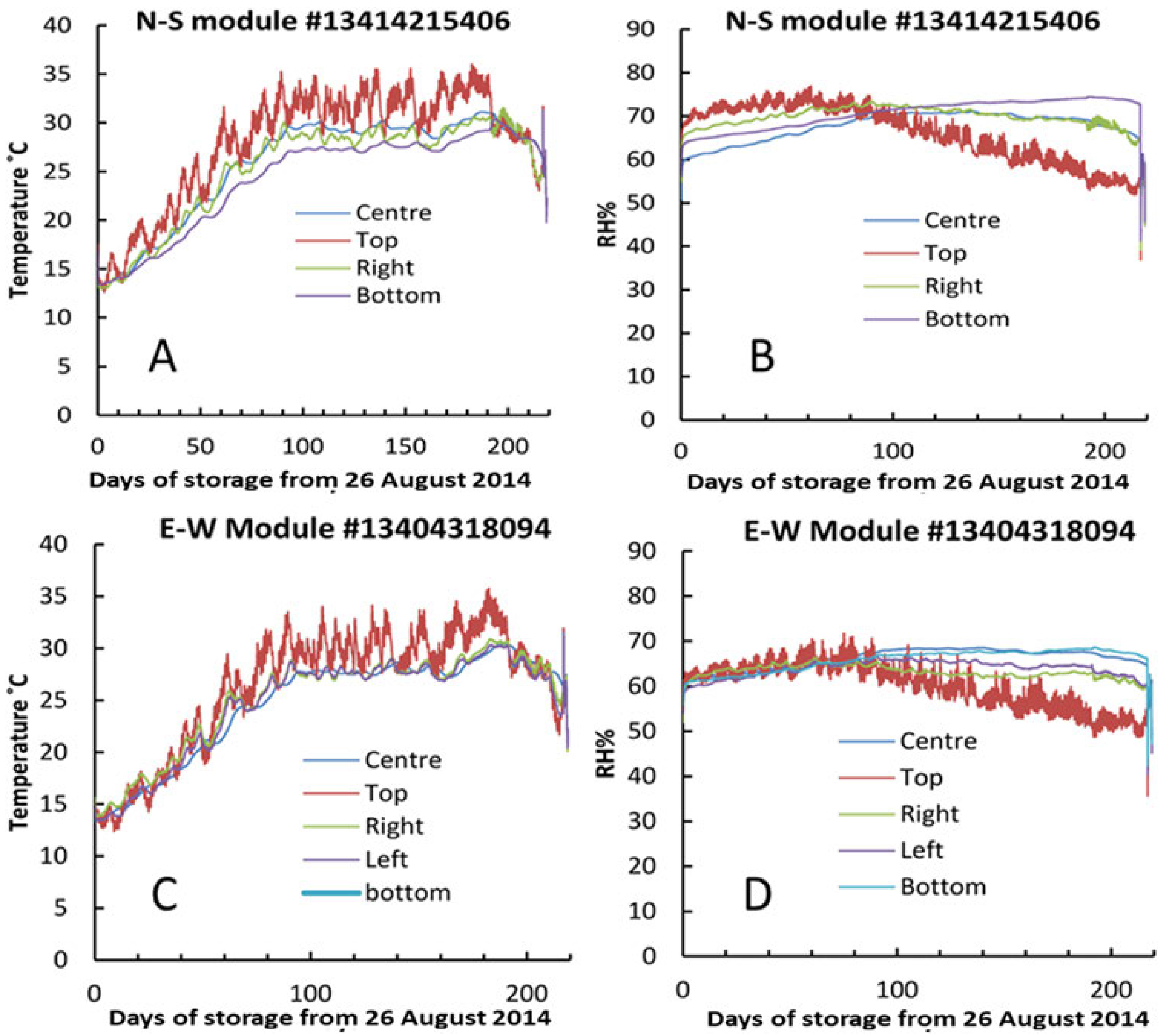
The orientation of modules at the Warren location only had a small influence on temperature and RH in the top part of the modules, as shown in Figures 9(a) to (f). Initial core temperatures were nearly the same, however, the core temperatures of modules stored in the N-S orientation were about 2˚C higher during the hotter months of the year than those stored in the E-W direction, see Figure 9(e). Orientation did not seem to affect the core RH, with the initial order of RH in the modules remaining unchanged throughout the seven-month period, as shown in Figure 8(f).

Seed cotton at the top of the Warren modules dried at a higher rate over the longer storage period than the rest of the module, resulting in an uneven distribution of RH through the module. The bottom region of modules in both orientations was cooler and tended to have higher RH than the rest of the module over the longer storage period.

Covering round modules with a tarpaulin (see Figure 9) significantly reduced temperature and RH fluctuations and slowed drying of the seed cotton in the top part of the module, (Figures 8 (a)-(d)). However, temperature and RH in the module core were not substantially affected by the tarpaulin cover, as shown in Figures 8 (e) and (f).

Figure 10 shows the RH-temperature relationship in the core of a module from Warren NSW during the 2014-15 storage period. The plot shows the corresponding core temperature and RH in the module at given times during the storage period. Through the spring months (September to November), both temperature and RH increased, which indicate both heat and moisture were added to the module from ambient air. During the summer months (December to February), the temperature and RH in the module fluctuated within a small range because daily changes of ambient conditions were buffered by the insulting effect of the seed cotton in the module. From March (autumn), the temperature and RH in the module started to drop, following the change of the ambient conditions.

In summary, during the 10-month long storage period in Warren across 2014-15, conditions inside the modules started cool at 12-15°C with RH varying from 60% to 70% between modules. Ambient and module core temperatures increased steadily into spring and summer ranging from 25˚C to 30˚C before falling in autumn just as the 2015 ginning season started. Relative humidity also increased leading into the summer as a result of the increased water carrying capacity of the warmer air. In December 2014 and January 2015, Warren received high rainfall as per the weather pattern in this location but there were no spikes in the RH of the module core. The RH inside modules started to decrease after 150 days as temperatures in the module increased with summer, and conditions inside the modules started to dry. The loss of moisture by the seed cotton was however slow at around 0.1% of the module RH per day.

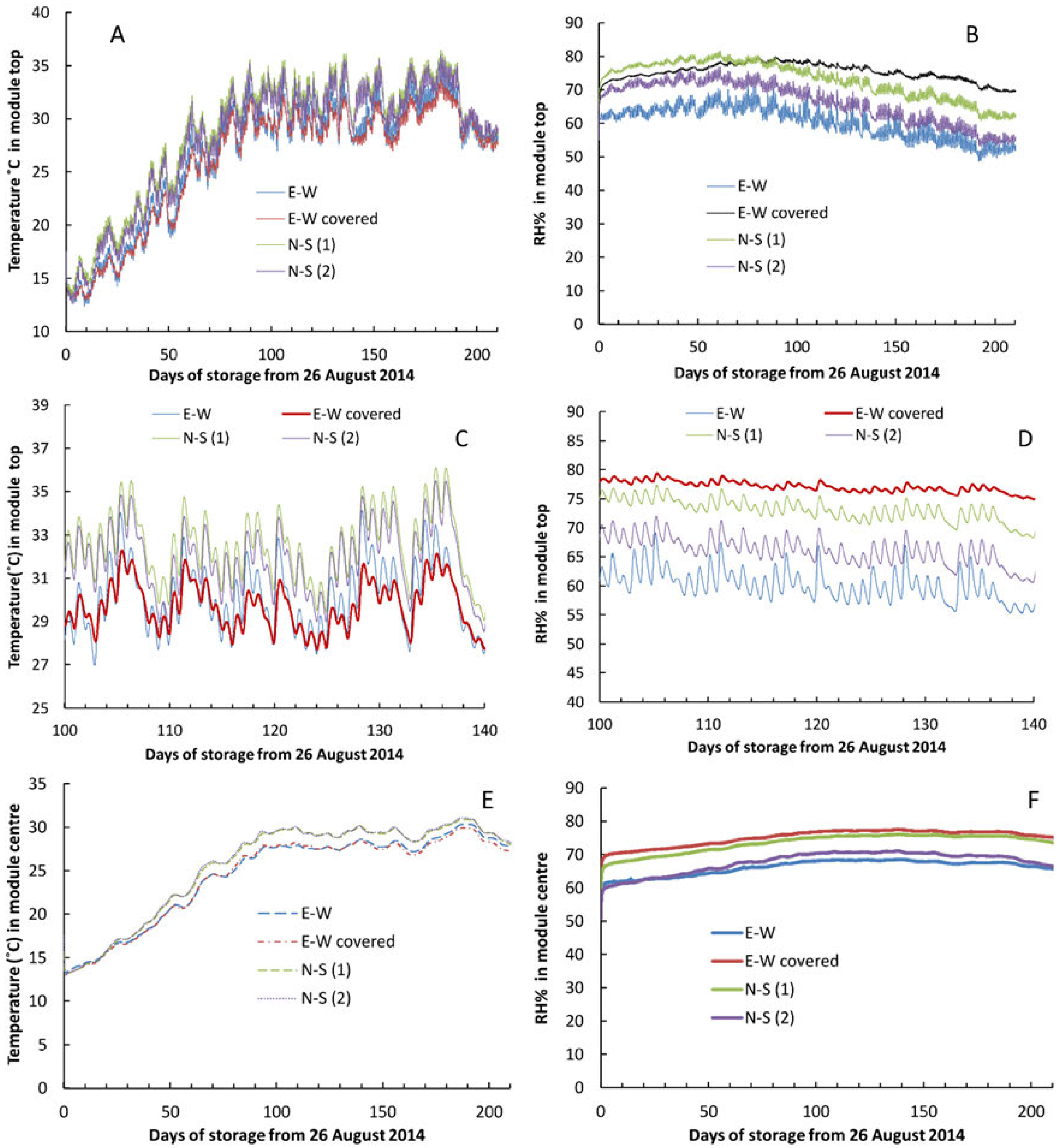


Figures 7. Plots of temperature (a) and (c) and RH (b) and (d) at different positions in a module stored in N-S and E-W directions respectively at Warren, NSW from 26 August 2014 to 1 April 2015.

Hay NSW. The climate of Hay is considered temperate. The average daily summer maximum temperature is 32°C, with average daily winter maximum temperatures being 16°C. The annual rainfall is comparatively low with an average of 367.4 mm with monthly amounts relatively consistent throughout the year, although the highest monthly amounts occur on average in May and June.

Temperatures and conditions in Hay NSW in both trial years were cooler and wetter than average, particularly during the winter months. Temperatures recorded in the tops of modules during 2015 and 2016 were as low as 7 to 8°C while the temperature at the core and bottom regions of the module reached about 10°C. Relative humidity in the bottom part of the module was about 6% higher than in the core over the entire storage time. The wet winter (>130 mm of rain) in 2016 did not change these scenarios, although the bottom of the modules in that year became saturated.

Figure 11 shows the module conditions at different positions within the module during the long storage of 2015-2016. The circled period in each case compares with the same shorter winter storage period in 2016 as shown in Figures 12. Over the longer period, RH increased in the winter month in the top part of the module, reaching values higher than that in the bottom region by spring, but then decreasing rapidly in summer. Figure 13 compares the tempertaures and rainfall in Warren and Hay for the two storage periods surveyed. The storage periods were similar in terms of conditions although Hay was a little cooler and wetter in the winter and spring.



Figures 8. Plots showing the influence of module orientation and cover on the temperature and RH at the top and core of the modules. Warren, NSW. From 26 August 2014 to 1 April 2015. Note that two uncovered modules in the N-S orientation, N-S(1) and N-S(2), were monitored.

Figure 9. Modules stored with tarpaulins at Warren NSW.

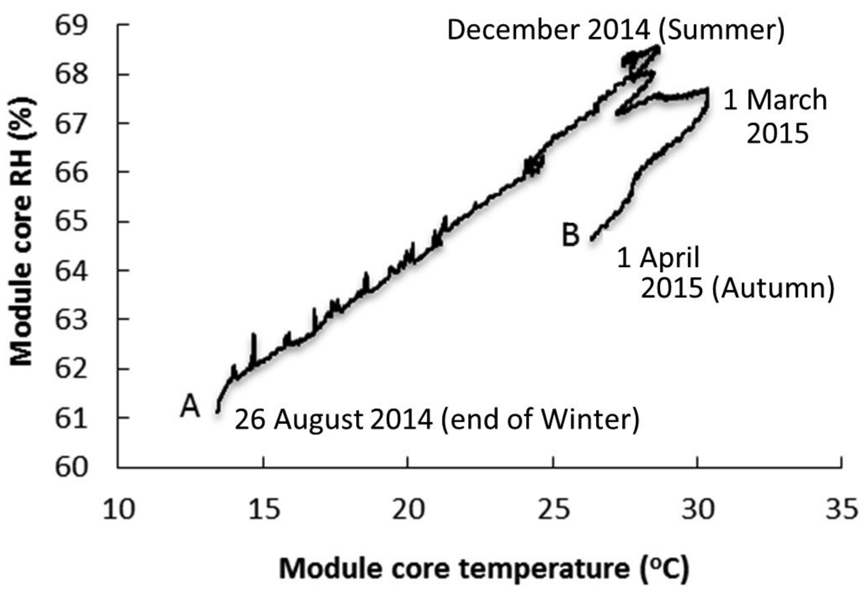
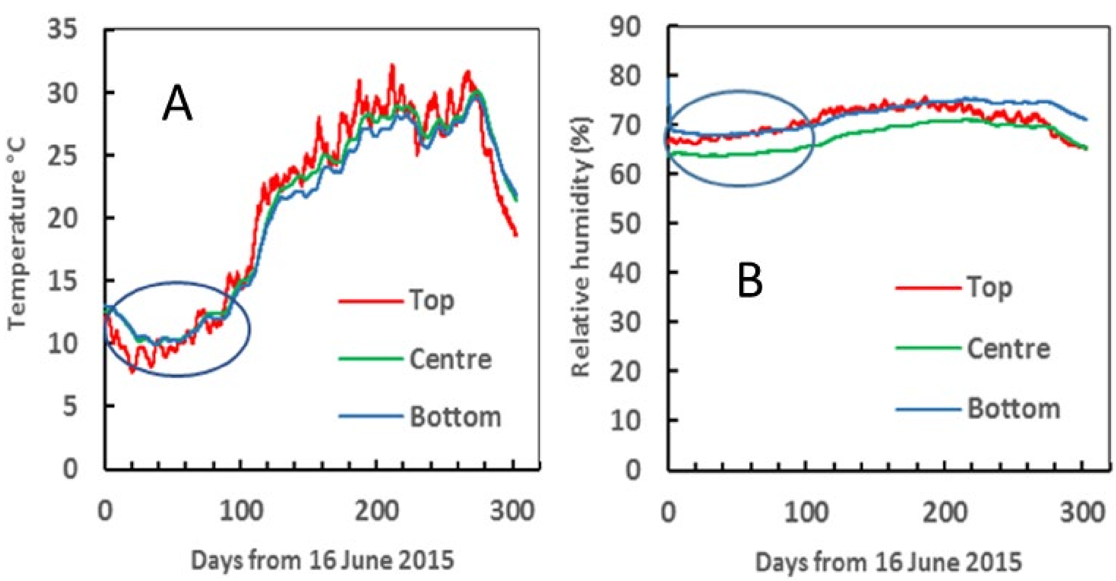


Figure 10. History of temperature and RH conditions in module core over a storage period. Point A stands for conditions on 26 August 2014 when measurement started; and point B stands for conditions on 1 April 2015 when measurement ended.



Figures 11. Plots of temperature (a) and RH (b) at different positions in one module at Hay NSW from 16 June 2015 to 15 April 2016.

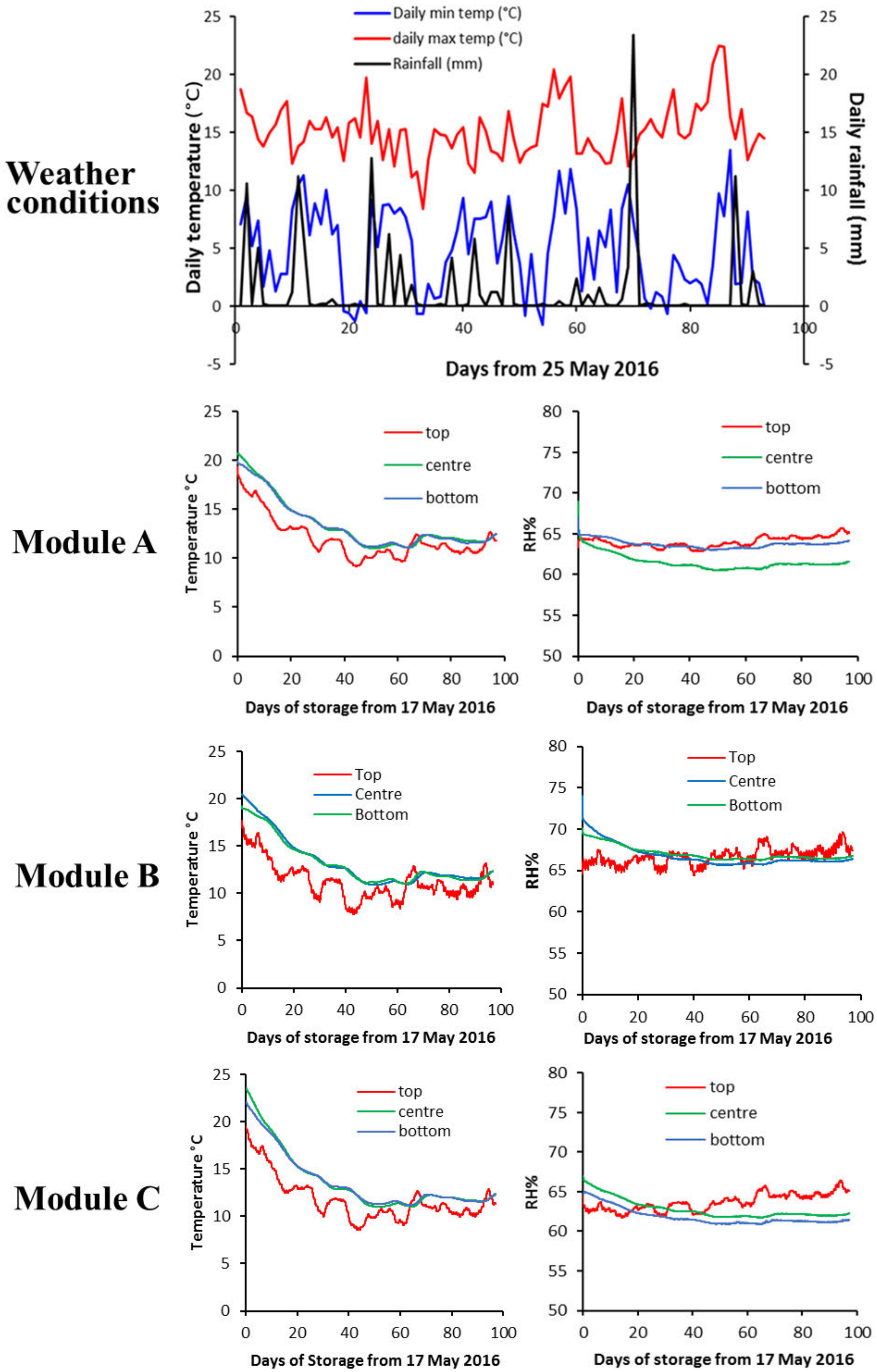


Figure 12. BOM weather report for Hay, 25 May – 25 August 2016 and Plots of temperature and RH at different positions in Modules A, B and C at Hay NSW from 25 May 2016 to 15 August 2016.

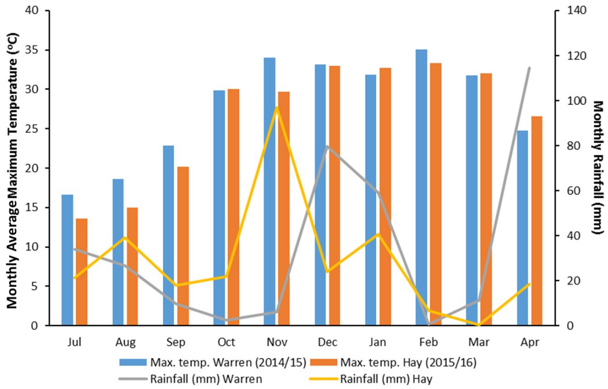


Figure 13. Monthly average maximum temperature and monthly rainfall totals in Warren and Hay NSW during extended storage periods. Based on BOM weather reports.

Effect of storage on fibre quality

Emerald location. Fibre quality results before and after storage at Emerald in 2014/15 and 2015/16 are presented in Tables 3 and 4. Large negative changes were measured in yellowness (+b) and elongation over the two-month storage period in 2014/15; but only yellowness changed similarly in 2015/16. Short fibre index was reduced in the first year and unchanged in the second year. Reflectance (Rd) was increased in the first year but reduced in the second year. Changes in other fibre properties across both years were small (<3%) and whilst statistically significant in many of the cases, were inconsequential from a practical and commercial perspective. Interestingly, the increase in +b resulted in an improvement in the overall colour grade results, with the USDA classing grade value changing from 31 to 21, as shown in Figures 14(c) and (d). The improvement in grade is shown by the arrow in the USDA colour chart in Figure 14(d). The negative changes in +b and elongation were also seen in other locations, suggesting a definite effect from storage, although there were no strong associations with the recorded variations in temperature or RH (moisture).

The improvements in strength, SFI and Rd in the first year at Emerald were puzzling, given that other locations in this study showed storage had a negative effect on these properties. As per this observation, Figure 15(a) shows a shift in strength values in the second year after storage, with a proportion of bales moving from values >31.5 cN/tex to values < 30 cN/tex. It is assumed the positive changes in SFI and Rd were most likely associated with a change in ginning practice, e.g., a reduction in the number of lint cleaners and/or heat applied according to seed cotton moisture level over the storage period, and the gin conditions at the beginning of each ginning season (immediately after annual maintenance) being different from that at the end of the season. The improved strength result in the first year was difficult to attribute.

Warren location. Modules in Warren NSW were harvested in the 2014 season and stored for 275 days before being ginned at the start of the 2015 season. Fibre quality values after storage were compared with the values recorded on the same cotton produced and ginned from the 2014 season. HVI results from Warren NSW are presented in Table 5. All fibre properties deteriorated to some extent, with notable changes being the deterioration in elongation (-14%) and +b (+7%). Fibre strength (-2.5%), length (-4.2%) and SFI (+15%) also deteriorated after the ten-month storage period as expected, although Rd deteriorated only by <0.5%. All changes were statistically significant.

The distributions of selected fibre quality attributes of bales ginned in July 2014 and April 2015 are plotted in Figure 16. Length, strength and elongation all decreased, while SFI and +b increased, largely as expected. Interestingly, the bales ginned in April 2015 received more favourable USDA colour grades, as shown earlier in Emerald QLD with an increase in +b.

Table 3. Fibre quality results, Emerald QLD season 2014-15

Ginning date		UHML (in.)	SFI (%)	Strength (cN/tex)	Elong. (%)	Rd	+b
3 Mar 2015 (183 bales)	Ave	1.16	11.3	29.3	5.3	81.3	6.8
	SD	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 May 2015 (54 bales)	Ave	1.15*	9.9*	30*	4.3*	82.2*	7.5*
	SD	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

*** Significantly different, tested using t-test of unpaired means (two-tailed P value) P<0.001**

Table 4. Fibre quality results, Emerald QLD season 2015-16

Ginning date		UHML (in.)	SFI (%)	Strength (cN/tex)	Elong. (%)	Rd	+b
26 Mar 2016 (664 bales)	Ave	1.18	7.8	30.9	4.2	81.3	7.1
	SD	0.01	0.97	0.67	0.25	0.97	0.20
	Min	1.14	3.4	28.6	3.5	73.9	6.4
	Max	1.23	12.6	32.8	6	83.3	8
31 May 2016 (80 bales)	Ave	1.18	7.8	30.3*	4.1*	80.3*	8.1*
	SD	0.02	0.81	0.59	0.28	0.34	0.15
	Min	1.14	5.6	29.1	3.3	79.2	7.4
	Max	1.22	9.6	31.6	4.9	81.4	8.5

***Significantly different, tested using t-test of unpaired means (two-tailed P value) P<0.001**

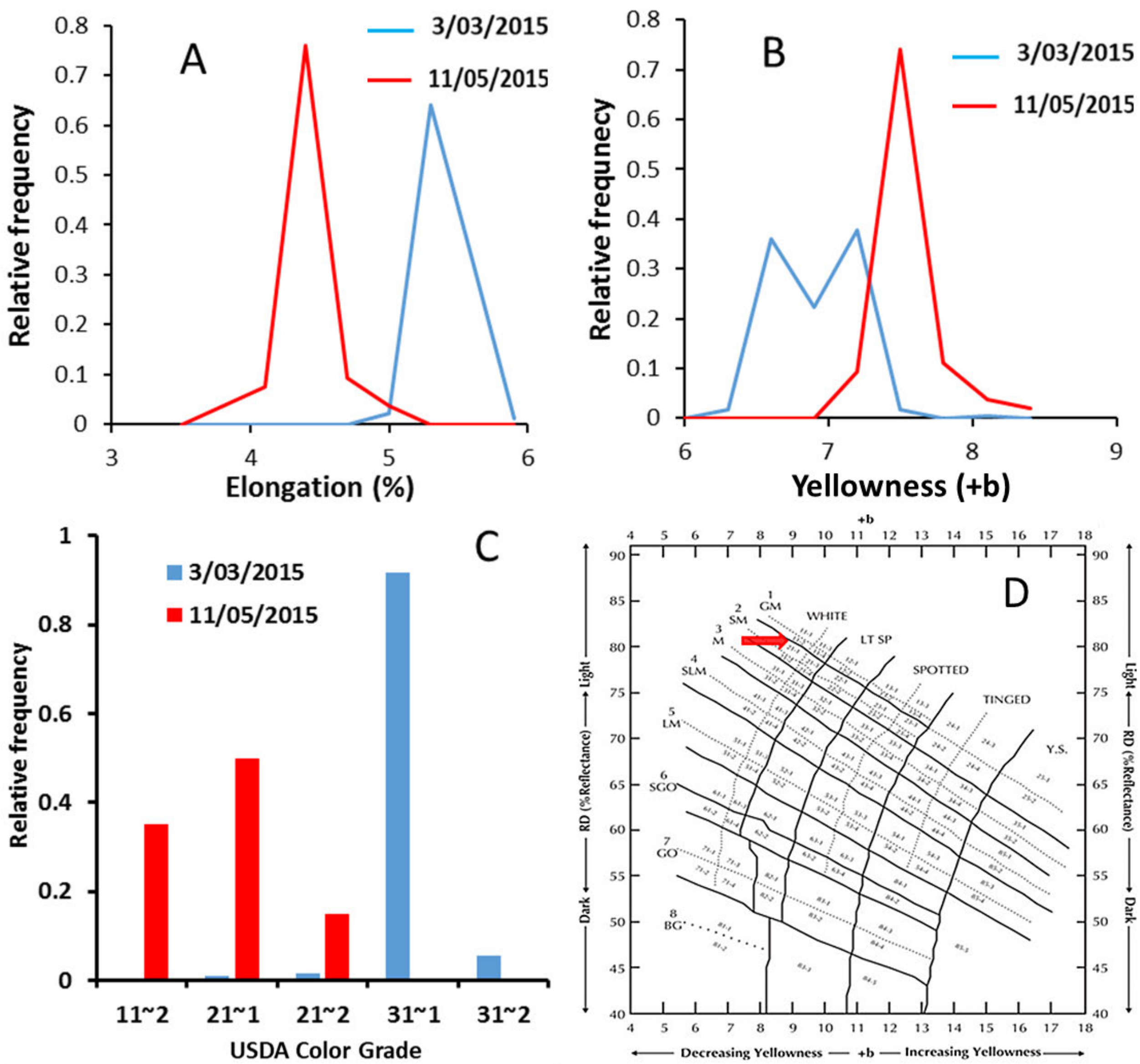


Figure 14. (a) Change in elongation values, (b) yellowness values, (c) USDA colour grade values after two months storage at Emerald QLD in 2015 and (d) the influence of increased +b on USDA colour grade.

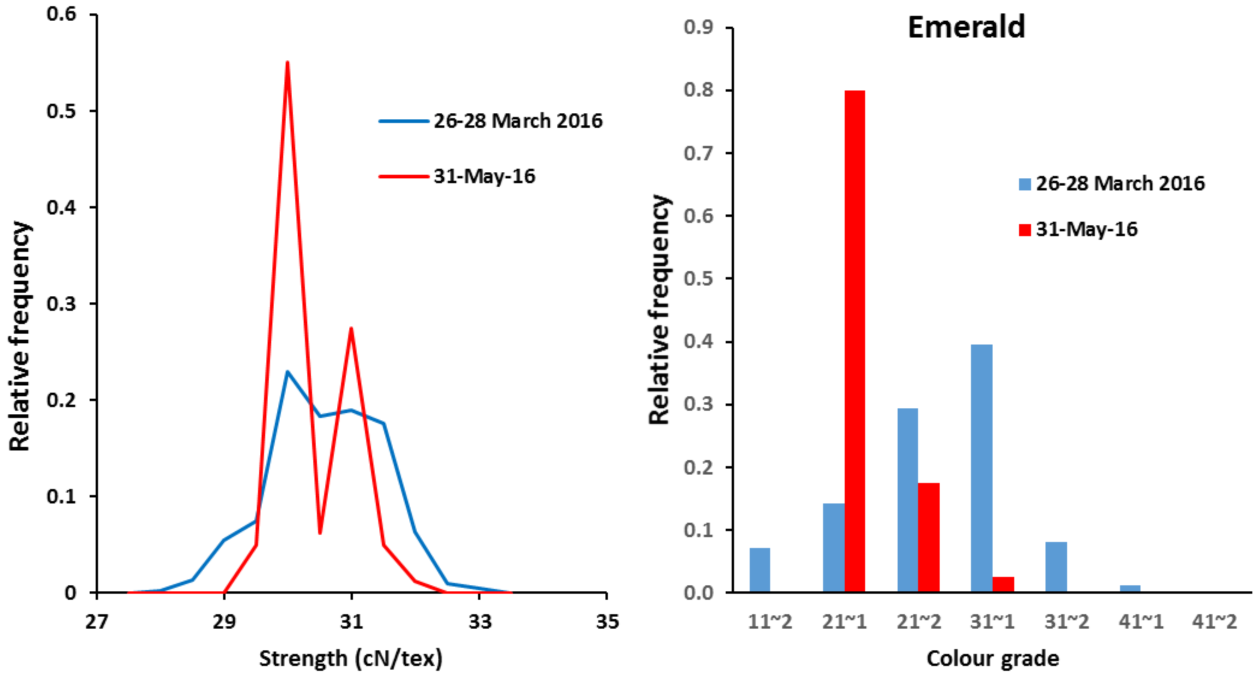


Figure 15. Change in strength values (a) and USDA colour grade values (b) after two months storage at Emerald QLD in 2016.

Table 5. Fibre quality results, Warren NSW season 2013-14

Ginning date		UHML (in.)	SFI (%)	Strength (cN/tex)	Elong. (%)	Rd	+b
26 Aug 2014 (389 bales)	Ave	1.20	7.8	32.8	5.8	77.8	6.8
	SD	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
1 Apr 2015 (74 bales)	Ave	1.17*	9.2*	31.4*	5.0*	77.5*	7.3*
	SD	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

*** Significantly different, tested using t-test of unpaired means (two-tailed P value) P<0.001**

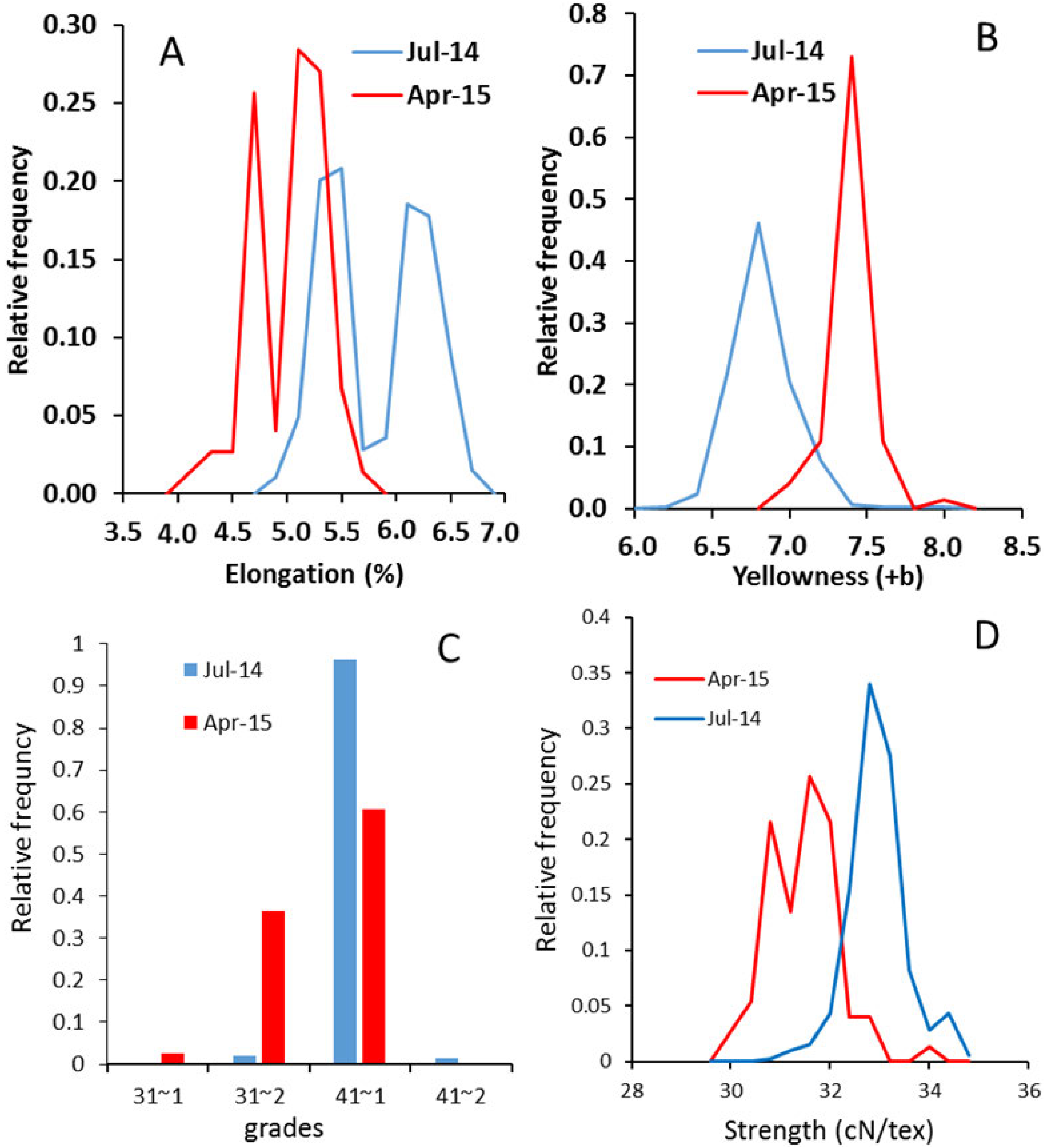


Figure 16. (a) Change in elongation values, (b) yellowness values, (c) USDA colour grade values and (d) the change in strength values after >9 months storage at Warren NSW.

As a result of rain during this period, many of the stored modules were flooded with the bottom lip of the plastic module wrapping retaining water after rain events. The position of the bottom sensors in these modules was about 20 cm above the ground but as per the traces in Figures 8(a) to (d), the measured conditions in the modules were not affected, with conditions in the bottom (at 20 cm) closely matching conditions in the core of the module. The cotton submerged in the water, contained within the lip of the module wrapper, became very wet and was affected by fungal and microbial growth, although only superficially. Visual assessment showed the microbial growth penetrated no more than 10 cm from the surface into the module (see Figure 17) and was removed prior to ginning.

Figure 17. Water damage on round module.

Hay location. A similar storage period as Warren NSW was observed in Hay NSW in the following year. Fibre properties were checked after 66 days storage in September 2015 at the end of the Hay ginning season and again after 288 days in April 2016. Fibre properties after each storage period are shown in Table 6.

Contrary to expectations, there were no recorded changes in fibre length and improvements in strength and SFI. There were however changes in elongation, Rd and +b that were very similar to other survey locations. Elongation and +b deteriorated substantially in practical terms by -19% and +22% respectively over the 288 days at Hay. Figures 18 (a) to (d) show the distributions of fibre strength, elongation, +b and USDA colour grade values across the three gin runs during storage. The overall USDA colour grade changed similarly to other locations showing an improvement in value at the end of the storage period as a result of increased yellowness (+b) values.

The rate of deterioration in elongation through the storage period was constant, whilst the rate of yellowing increased after the first 66 days (Figure 19). The dashed yellow line in Figure 19 represents the predicted deterioration in yellowness according to a linear function fitted through the first two data points, the rate of change by this function being similar to the rate of change in yellowness at Warren, the previous year, under similar conditions. Given the similarity in conditions, the increased rate of yellowing is difficult to attribute, as is the deterioration in elongation. Further work is required to understand the influence of the fibre and seed chemistry and/or the cellulolytic fungi and bacteria present under these storage conditions.

The survey of the 2014/15 carryover modules in Hay was followed by a shorter (three month) within-season survey of modules harvested in the 2015/16 season and stored between May and August 2016. This period was particularly wet for this area. Bureau of Meteorology data shows the Hay area received a cumulative rainfall of 132.8 mm during the period (Figure 13). Conditions at different positions inside the modules during this period are illustrated in the graphs presented in Figure 12. The conditions inside the modules corresponding to the cooler, wetter ambient conditions.

Table 6. Fibre quality results, Hay NSW season 2014-15

Ginning date		UHML (in.)	SFI (%)	Strength (cN/tex)	Elong. (%)	Rd	+b
Stage 1 9 Jul 2015 (77 bales)	Ave	1.20	9.2	30.5	7.2	81.8	6.8
	SD	0.02	0.85	0.87	0.28	0.31	0.09
	Min	1.16	7.8	28.5	6.7	80.8	6.5
	Max	1.23	11.1	32.0	7.7	82.6	7.1
Stage 2 12 Sep 2015 (93 bales)	Ave	1.20	8.2*	30.7*	6.9*	81.3*	7.0*
	SD	0.01	0.64	0.52	0.30	0.39	0.12
	Min	1.18	7.1	28.9	6.4	79.9	6.7
	Max	1.23	10.2	32.6	7.6	82.5	7.6
Stage 3 15 Apr 2016 (86 bales)	Ave	1.20	8.6*	30.9*	5.9*	81.1*	8.7*
	SD	0.01	0.60	0.53	0.44	0.35	0.15
	Min	1.18	7.4	29.4	5.4	79.9	8.3
	Max	1.23	10.5	32.4	6.6	82.3	9.0

*** Significantly different, tested using t-test of unpaired means (two-tailed P value) P<0.001**

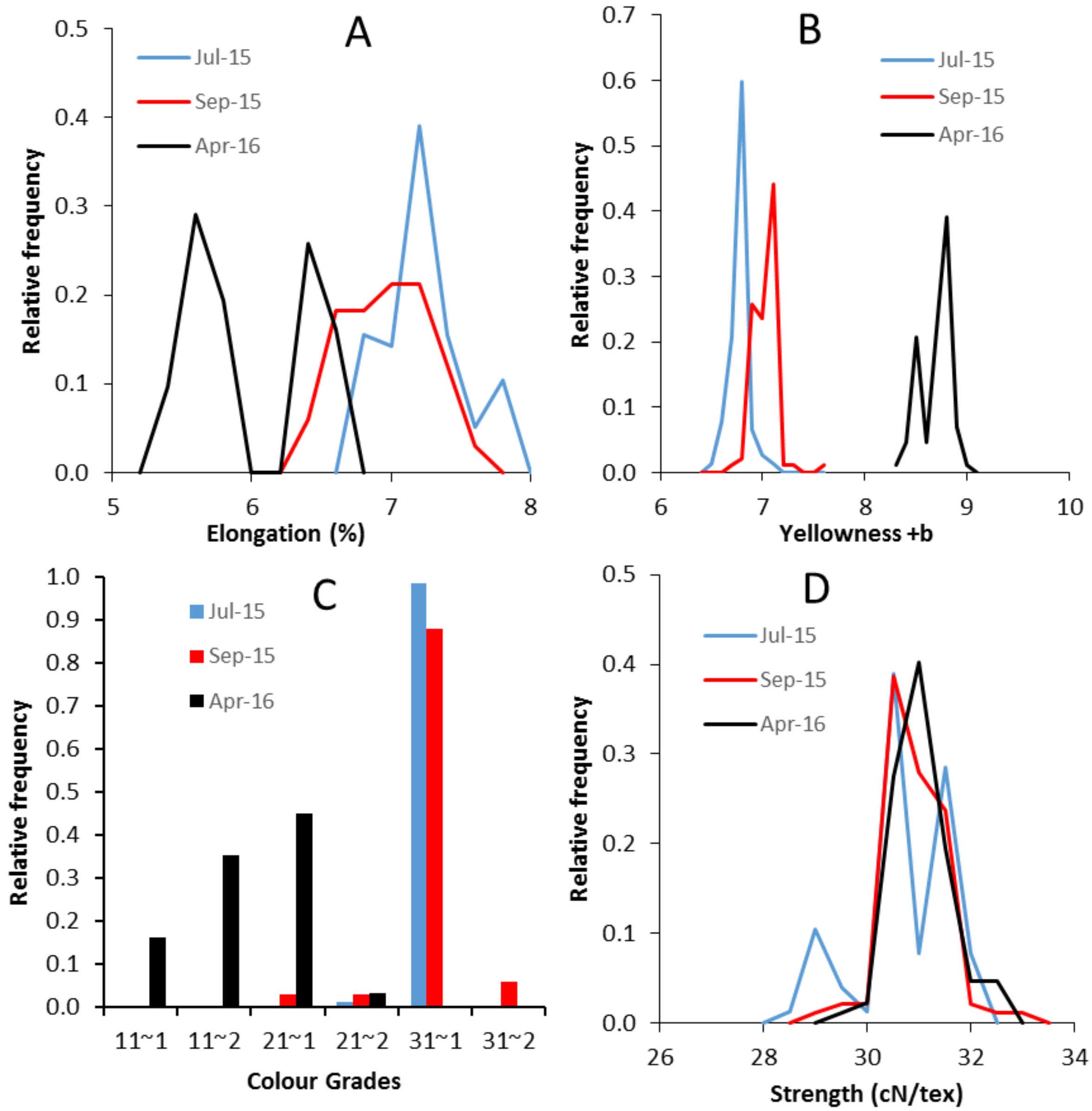


Figure 18. Change in (a) elongation, (b) yellowness, (c) USDA colour grade and (d) strength after 288 days of storage at Hay NSW.

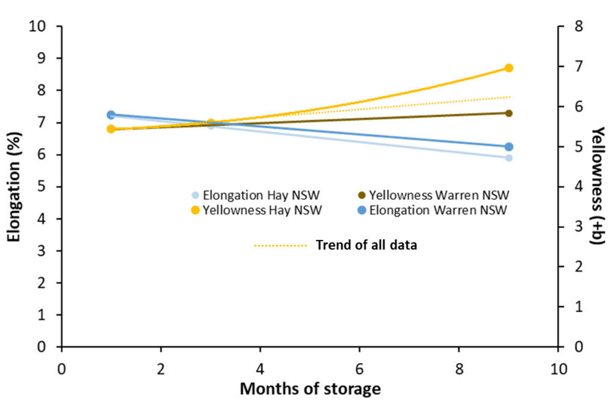


Figure 19. Progressive changes in yellowness and elongation over a nine-month storage period at Hay NSW. Months storage: Warren –August 2014 to April 2015; Hay - July 2015 to April 2016.

Table 7 shows the progression of fibre properties during the shorter, cooler and wetter storage period. Interestingly, elongation, Rd and +b deteriorated in a similar manner compared to other locations even though the rate of deterioration was diminished; elongation and +b deteriorated up to 4% over the three months, whilst Rd deteriorated <1%. Fibre length and strength did not change significantly. The slower rate of change in these properties is reflected in Figure 20, which shows the distribution of strength, elongation, +b and colour grade values for the bales from each storage period. The strength and elongation distributions did not shift significantly, although movement of values from higher to lower values can be seen. 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 was consistent with the USDA colour grade changes found in all the other trials.

Table 7. Fibre quality results, Hay NSW season 2015-16

Ginning date		UHML (in.)	SFI (%)	Elong. (%)	Strength (cN/tex)	Rd	+b
Stage 1 25 May 2016 (282 bales)	Ave	1.21	8.6	5.8	31.8	81.8	7.3
	SD	0.01	0.72	0.69	0.65	0.37	0.14
	Min	1.18	7.1	4.9	30.0	80.4	6.7
	Max	1.25	11.2	8.0	33.7	82.8	7.9
Stage 2 14 Jun 2016 (169 bales)	Ave	1.22	8.9	5.9	32.0	81.7	7.5
	SD	0.01	0.65	0.60	0.66	0.56	0.19
	Min	1.18	7.6	4.9	30.1	78.5	6.6
	Max	1.26	10.8	7.0	34.0	82.8	8.5
Stage 3 25 Aug 2016 (104 bales)	Ave	1.22	8.4	5.6*	32.0	81.3	7.6*
	SD	0.01	0.59	0.70	0.62	0.68	0.20
	Min	1.18	7.0	5.0	30.2	76.0	6.3
	Max	1.25	9.7	7.3	33.9	82.4	8.0

*** Significantly different, tested using t-test of unpaired means (two-tailed P value) P<0.001**

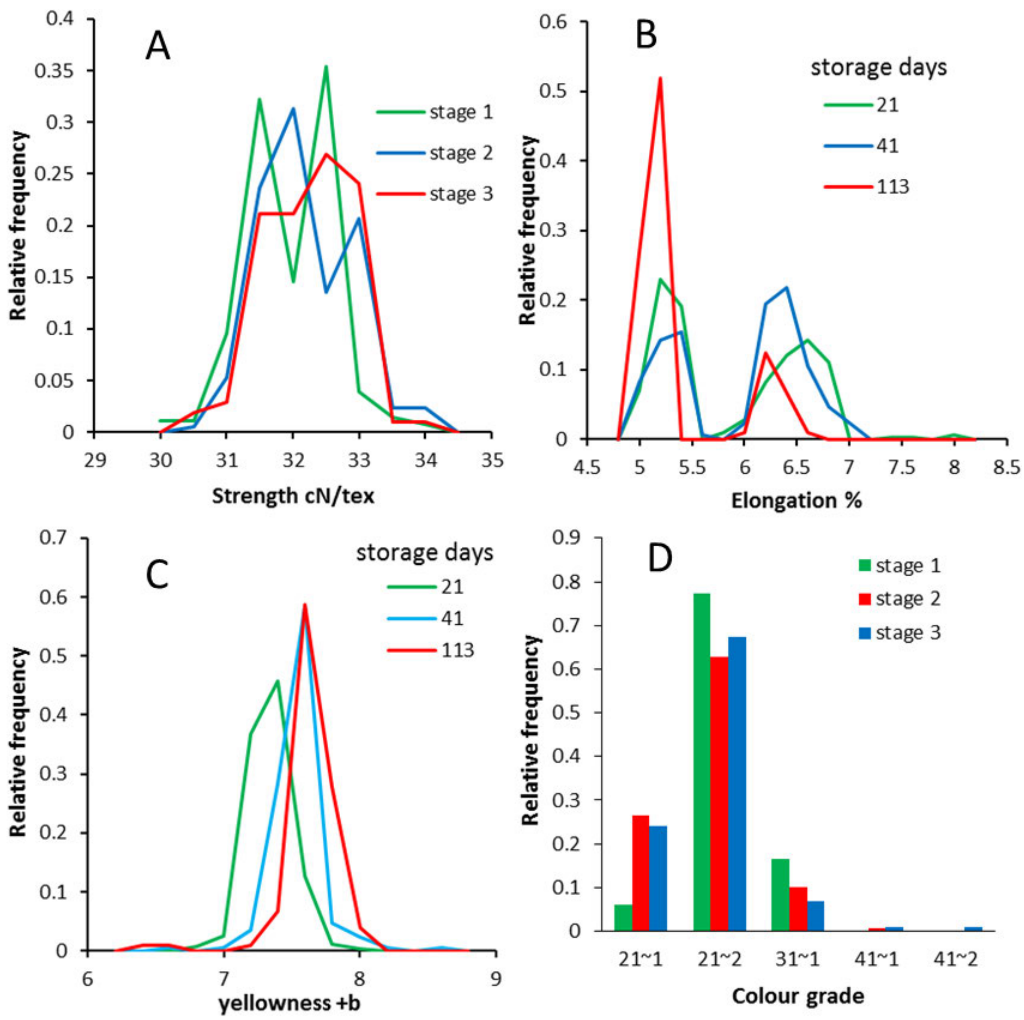


Figure 20. Influence of module storage on cotton quality after ginning. Hay, 2015-16.

CONCLUSIONS

In this project, we studied round modules of seed cotton harvested and stored according to industry guidelines (moisture content <12%) for different storage periods at three geographical locations in Australia representing a range of climatic conditions. Temperature and RH changes inside the core of the modules, under all climatic conditions, lagged behind ambient conditions. Changes in conditions at the top of the modules were more variable and followed more closely with the variation in ambient conditions. The demonstrated stability of the seed cotton allows us to conclude that current guidelines on cotton harvesting and storage based on experience from traditional square modules are adequate and applicable to round modules.

We did however observe some consistent trends in fibre quality as a result of storage periods that were two months or longer. Yellowness (+b) increased and fibre elongation decreased after storage in all locations. The scale and rate of deterioration in both parameters did not follow a consistent relationship with initial temperature or moisture of the seed cotton, nor with the ambient conditions under which the modules were stored. The degree of deterioration tended to be greater over the longer storage periods. Further work is required to understand the reason for these changes.

For the bulk of Australian cotton, the increase in yellowness resulted in a positive impact on the USDA cotton colour grade. With only small, negligible changes in Rd, the increased yellowness allowed some cotton bales to be classed into a higher grade. This improvement extended to round modules stored for up to ten months.

ACKNOWLEDGEMENTS

We would like to acknowledge the support of Cotton Research and Development Corporation project CMSE1501, Auscott Limited, Louis Dreyfus Company and CSIRO during this project.

REFERENCES

Anthony, W.S., and W.D. Mayfield (eds.). 1994. Cotton Ginners Handbook. USDA ARS Publication No. 503.

Anthony, W.S. 2004. Moisture management practices at gins. *In:* Proceed. Cotton Incorporated Engineered Fiber Selection Conference. Greenville, SC, USA.

Anthony, W.S. 2006. The harvesting and ginning of cotton. p 176-201. *In:* Cotton: Science and Technology. Gordon, S.G. and Hsieh, Y.L. (eds.). Woodhead Publishing, Cambridge, UK.

Lalor, W.F., M.H. Willcutt, and R.G. Curley. 1994. p 16-25. Seed cotton storage and handling, *In:* Cotton Ginners Handbook. Anthony, W.S. and Mayfield, W.D. (eds.). USDA ARS Publication No. 503.

Mayfield, W., W. Lalor, and G. Huitink. 1998. Harvesting: Spindle pickers and cotton quality. Cotton Incorporated Bulletin, Raleigh, NC, USA.

Sorensen, J.W. Jr., and L.H. Wilkes. 1973. Seed quality and moisture relationships in harvesting and storing seed cotton. *In:* Proceedings Seed Cotton Storage and Handling Seminar, Cotton Incorporated. Pub. Phoenix, AZ, USA.

van der Sluijs, M.H.J. and R.L. Long. 2016. The effect of seed cotton moisture during harvesting - part 1 - fiber quality. Textile Res. J. 86(18):1925-1934.