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# Content



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# NEWS

## ICRA at climate change COP 27

**ICRA has landed in Sharm El Sheikh for the 27th edition of the UN's Conference of the Parties – better known as COP. The world's leading climate change conference, which opened on 6th November and runs until 18th November, has become an increasingly important event in the cotton cultivation and cotton industries calendar as the industry grapples with its role in the climate crisis.**

**Dr. Mohamed Negm, Chairman of ICRA participated in Cop 27 event which filled with insightful discussions about fashion and environmentalism. The event covered major topics in the sustainable fashion industry including the concerns about contributing to global warming and greenhouse gas emission, Organic cotton, fashion transformation, and more. The sessions aimed to spark debate on ways in which the textile and clothing industry can take a step-change in its approach to sustainability in terms of design, technology and collaborative action. The session title is: How the Textile & Apparel Industry Needs to Coordinate and Align With Brands and Retailers in Order to Lower Its Impact on the Environment Along the Supply Chain.**

# NEWS

**The side event was opened by H.E. Yasmine Fouad, Minister of Environment-Egypt. Egyptian cotton is highly regarded around the world, yet the local cotton industry lacks support in transitioning to sustainable and adaptive practices.**
**This #COP27EnergyAndCivilSociety side event with Hugo Boss explores the fashion industry's participation in the UNIDO-supported 'Better Cotton Initiative'.**

**Filmar Network**

**Heinz Zeller**

**Marie Louis Bishara**

**Mohamed Negm**

**Apparel Export Council of Egypt**

**UNIDO Egypt**

**Khaled Raafat**

COP27
SHARM EL-SHEIKH
EGYPT 2022

# NEWS


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# NEWS

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Research Article

# Evaluation Reactive Groups of Reactive Dyes on Dyeing Egyptian Cotton Fabrics

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## Abstract

***Background*** *Cold reactive dyes were studied for their dye fixation and color strength on cotton fabric. Three Reactive dyes namely: procion Mx, Levafix E, and Drimarine with the reactive functional groups, (Di-chlorotriazine), (Di-chloroquinoxaline), and (Di-fluoro chloropyrimidine) respectively were applied on to extralong stable Egyptian cotton fabric of Giza 94 to explore the role of their functional groups on color strength and fastness properties. Exhaustion-fixation method with different reaction times and temperatures revealed that reactive dyes with different functional groups have different reactivity and affinity to the color strength and fastness properties for the cotton fabric.*

***Results:*** *The results obtained revealed that the reactive dyes exhibited high color strength, and fastness properties at optimum conditions of temperature, and reaction time. Among dyes under investigation, the results obtained showed that Procion Mx dye having the reactive group structure Di-chlorotriazine offer higher reactivity at the optimum condition 30ºC at 60 mins. for exhaustion and 30ºC at 5 min. for fixation followed by Levafix E dye having the reactive group structure Di-chloroquinoxaline and finally Drimarine dye having the reactive group structure Di-fluoro chloropyrimidine).*

***Conclusion:*** *The highest dye fixation (%) was about 85% for all reactive dyes used. The fastness properties of cotton fabric for all reactive dyes used were good to excellent at the optimum dyeing process.*

***Keywords:*** *Cotton fabric, Reactive dyes, functional groups, color components, fastness properties*

## Introduction

Cotton is the most established and the most significant of the material strands. It has been utilized in the East and Middle East for millennia. Cotton is the most generally utilized of the material strands; it has a blend of properties-toughness, minimal expense, simple wash capacity and solace. This one-of-a-kind blend of properties has made cotton a norm for extraordinary masses of the world's kin who live in warm and subtropical environments, (El-Badry et al. 2012, Bledzki et al. (1997). Dyes which are equipped for responding synthetically with a substrate to form a covalent color substrate linkage, is known as reactive dyes, Daria et al. (2020). Many scientists have been concentrated on the coloring of cotton fabrics with reactive dyes. Among the various dyes, reactive dyes were commercially most popular for the last few decades due to their acceptable price, good color value and reasonably good fastness properties, Alam et al. (2008). The reactive dyes comprise the most ordinarily involved class of colors for coloring cellulosic materials, due to their great all-round properties, for example, water solvency, simplicity of use, assortment of utilization techniques, accessibility of various shades, splendor of variety conceals, great to incredible wash and light quickness and moderate cost, David M and Ioan Vo (2007). Reactive dyes might be arranged in different ways based on responsive gathering, based on reactivity, and on the premise dyeing temperature. It is vital to upgrade the coloring conditions to improve the color obsession and variety strength of the cotton textile, Ali et al. (2009). Dyeing of cotton fabric with reactive dyes depend upon various parameters such as electrolyte, alkali, liquor ratio, pH of the dye bath and temperature. The exhaustion of a reactive dye depends upon the amount of electrolyte and reactivity of a dye, Ahsanul (2014). The dyeing with reactive dyes is performed in the presence of an alkali medium of NaCl, $Na_2CO_3$, NaOH, or $Na_2SO_4$. The pH value was very important factor since the ionization of hydroxyl group (OH-) in cellulose fibers is accelerated with an increase in PH. The functional group (nature and number) attached to the structure of reactive dye molecule has distinct influence on dyeing behavior. Reactive dye structures consist of two parts: a conjugated chromosphere and reactive groups, Suwanich and Chutima, (2006). The most common reactive groups are mono-chlorotriazine, dichlorotriazine, and vinyl sulfone. Vinyl sulfone is a sulfuric acid ester of β-hydroxyethyl sulfone and reacts with cellulose at a moderate temperature of 60$^o$C, Burkinshaw P, (2011). Molecular shape and size from the main color components of the reactive dyes, had significant effects on the color strength and fixation properties, Soleimani-Gorgani and J. Taylor, (2006). The dyeing properties depend on the co-planarity of the structures; hence, the positions of different groups greatly affect the formation of a suitable molecular geometry, Xie et al. (2014). The positions of the reactive and soluble groups are very important because the dye will undergo substitution reactions and those positions should remain unhindered, Siddiqua et al. (2017). Dyes containing two or more type of reactive group showed higher fixation efficiency versus dyes containing only one type of reactive, Hunger K. (2017). It is important to optimize the dyeing conditions to enhance the dye fixation and color strength, Umbreen et al. (2008). The low fixation of dyes causes environmental issue since dyes lost in dyeing, and about 15% dyes are lost during dyeing process and have adverse effect on the of environmental safety, Iqbal, (2016**).** The hydrolysis in dyeing bath attributes to the lower dye-fixation and is one of the main drawbacks of continuous dyeing method, Broadbent, (2001). The discharge of dyes in wastewater should be reduced to maximum level to ensure sustainable environmental development, Qureshi et al. (2015). which demands the optimization of process variable along with suitable dyes section. In reactive dyeing, the dyeing process can be broadly divided into two phases, namely exhaustion and fixation. The process is lengthy, because much time is spent on the controlled heating of dye bath and portion wise addition of salt and alkali in order to avoid unlevel dyeing and maximizing the exhaustion and fixation, Iftikhar et al. (2001). The dyeing method, dye type, dye concentration, temperature, reaction time, medium pH and salt amount used during dyeing affect the dye fixation. Moreover, dye structure (number of functional group and their position) is also important in controlling the dye fixation, (Sugimoto T, 1994., Blackburn, 2004). The relationship between temperature and reactivity is that higher temperatures require lower alkalinity; to optimize on hydrolysis. They can be broadly grouped under 'High' 'Medium' and 'Low' categories requiring 40ºC. 60ºC and 80ºC respectively, levels of pH 12.5 for High (cold dyeing), 11.5 for Medium (Warm) and 10 – 11.0 for Low (Hot Dyeing) for the reaction to proceed more favorably towards the substrate. The effect of dyeing temperature has been studied on the color strength and color fastness properties of single jersey cotton knitted fabrics dyed with Novacron Red S-B reactive dye (1%) using conventional exhaust dyeing method, Debasree et al. (2017). The effect of dye concentration, electrolyte concentration, dyeing time and dyeing temperature on dyeing performance of cotton fabric dyed with reactive dyes, viz. Reactive Red 6B and Reactive Yellow RL, has been studied, Md. Shamsul et al, (2008).

In the present investigation, three reactive dyes having different functional group (number and positions) were selected and employed on cotton fabric. The dyeing was performed by exhaustion-fixation method. Various process variables were optimized to enhance to color strength and dyeing fastness properties.

## Materials and Methods

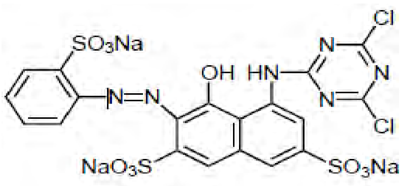
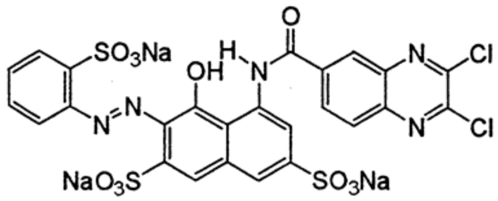
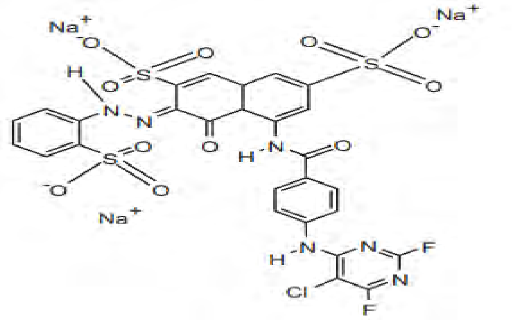
### Materials

Scoured woven plain Egyptian cotton fabrics made from Giza 94 was purchased from Misr-El-Mehala Company for Spinning and Textile, Egypt. The fabrics had the following specification: yarn count: 38 x 40tex; weight: 175 g/m$^2$. Specimens of size of 25 cm x 25 cm were used.

### Chemicals

All chemicals used were of analytical grade using doubly distilled water (18.5 MΏ.cm-1). NaOH was analytical grade (Koch-Light Co.), Sodium chloride (LR grade), the wetting agent was the commercially Ttiton X100 supplied by Merck. The reactive dyes used in this investigation were classified as cold reactive dyes were given in Table 1.

Table 1. Structural formula of the reactive dyes

| Dye No. | Reactive functional group | Dye Structures |
|---|---|---|
| RD1 | Dichlorotriazine |  CI Reactive Red 1 (dichlorotriazine) |
| RD2 | Dichloroquinoxaline |  Reactive Red 41 |
| RD3 | Difluorochloropyrimidine |  Reactive red 124 |

## Methods

### Dyeing bath conditions

### Optimization of Dyeing Conditions

The optimum conditions of dyeing with the mentioned reactive dyes were represented in the Fig. 1.

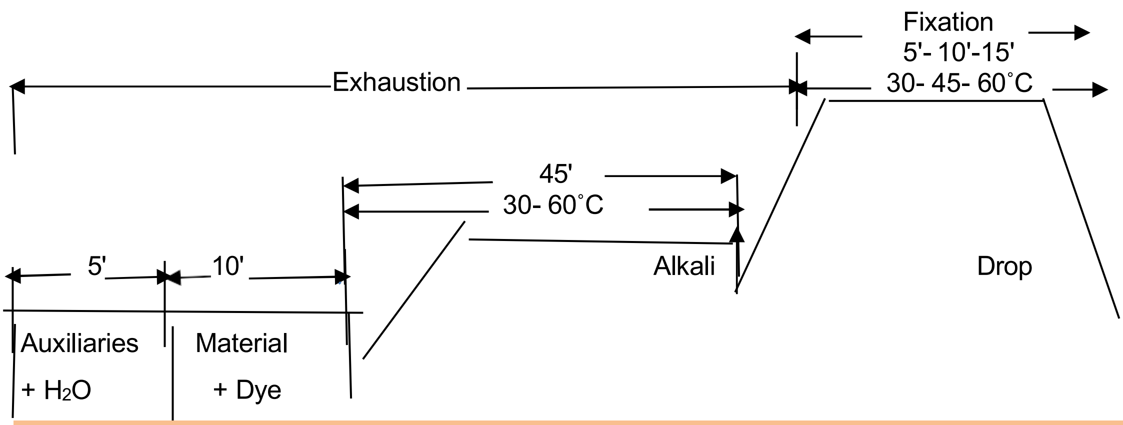



*Fig. 1 Exhaustion thermal fixation dyeing curve*

The exhaustion thermal-fixation dyeing time and temperature was varied accordingly. The exhaustion dye bath was prepared and the samples were dyed for varying 30, 45, and 60˚C at 30 mins. Maintaining the pH at 6-7. At the optimum exhaustion temperature, the dye bath was prepared and the fabrics were dyed for varying exhaustion times 45 and 60 mins maintaining the pH at 6-7. the thermal fixation process was carried out containing NaOH electrolyte 10/l, at 30˚C maintaining the pH at 12.5 and the fixation time were 30, 45, and 60 mins. At the optimum thermal fixation time the fixation process was carried out containing NaOH electrolyte 10/l, maintaining the pH at 12.5 and the fixation temperatures were 45, and 60 ˚C. After dyeing operation is completed the dye samples were put in a bath containing 1% stock solution of acetic acid to neutralizing the fabric. This operation is performed at 60ºC for 10 minutes. The material is then treated with a 1g/L soap solution, which removes the unfixed dye from fabric surface, and makes the surface clean. The material is then treated with a hot water bath and the material is treated with a cold-water bath, as represented in Fig.2. Finally, the material is dried in open air and finally in oven.

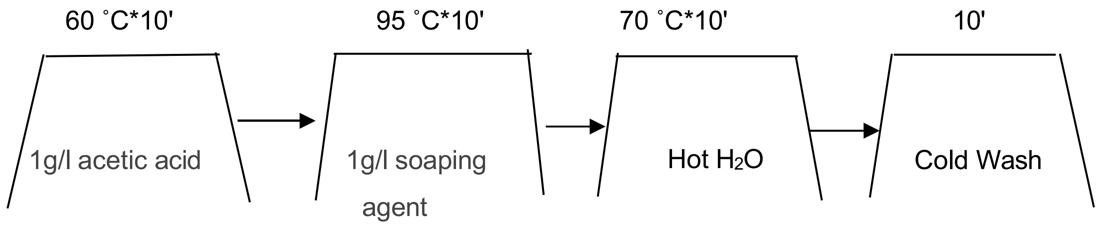



*Fig. 2. Washing off of the dyed samples*

### Evaluation the Properties of the Treated Fabrics

#### Color strength measurements

The color strength (K/S) of the treated samples using the untreated samples as blank was determined using Perkin Elmer Spectrophotometer, Model Lambda 35 equipped with integrated sphere with applying the Kubelka-Munk equation:

$$K/S = [(1-R) 2/ 2R]$$

Where; R is the reflectance, K is the absorption coefficient and S is the scattering coefficient.

#### Dye fixation (%)

The dye percentage fixation ratio was calculated considering K/S values before and after washing of the dyed samples according to the following equation

$$\text{Fixation } \% = \frac{(K/S)_1}{(K/S)_1 - (K/S)_2} * 100$$

where $K/S_1$ and $K/S_2$ were the color strength before and after washing

### Fastness Properties

#### Washing fastness (WF)

Washing fastness of the untreated samples was done according to ISO 105- C01:1998(E). Two single fiber adjacent fabrics complying with the relevant sections of F01 to F08 of ISO 105-F: 1989. One adjacent fabric of cotton and the second of wool.

#### Perspiration fastness (PF)

Fastness to synthetic perspiration was measured according to ISO-E04: 1994. (c)

#### Light fastness (LF)

The dyed cotton fabric was measured according to ISO 105-B01:1994 Textiles- -Tests for color fastness, Part B01: Color fastness to light: Daylight

### Rubbing fastness (RF)

The dyed cotton fabric was measured according to ISO 105-X12:2016(en) Textiles- Tests for color fastness, Part X12: Color fastness to rubbing

### Results and Discussions

Cotton texture contains a hydroxyl bunch (- OH) in the cellulose chain. At the point when the texture is exposed to coloring with responsive colors of various classes by arrangement process, it shows great dyeability. The responsive colors are fit for consolidating with hydroxyl gatherings of cellulose through covalent bond arrangements which differs from one color to another, contingent on the reactivity. The connection of color particles to the cellulosic tie is viewed as through covalent holding as no color atom strips out from the colored example as demonstrated in the accompanying proposed response:

Cell-OH + X-Dye Cell-O-Dye + HX

### Effect of exhaustion temperature on K/S

It has been noted that as the functional groups changed, the temperature sensitivity of dyes also changed, which revealed that functional groups in dyes structure are sensitive to temperature and they may respond differentially under variable temperature values. Fig. 4 exhibits the effect of dyeing temperature on the color strength of cotton fabrics dyed with the three above mentioned dyes. The results obtained revealed that there was variation in the color strength with respect to the reactive functional group of the dye used. The results obtained revealed that K/S value for RD1 showed the maximum at 30ºC, whereas RD2, and. RD3 showed high color strength value at 45ºC. These results may be due to that chlorine imparts medium reactivity, whereas the reactivity of fluorine is the least and its rate hydrolysis is also less. K/S values declined up to 60ºC which mean that this temperature has less impact at the values of dye uptake for fabrics. At 60°C the dye uptake results getting down which may be due to diffusion of dye from the core of the fiber and desorption of already absorbed dye may occur since hydrolytic degradation of dye may occur in aqueous media, Kamel et. al. (2007). Hence, the optimum value of temperature used may be 40°C, which helps in saving water, salt and alkali, Naebe, (2010). In general, RD1 has the highest K/S value followed by RD2, and RD3 respectively.

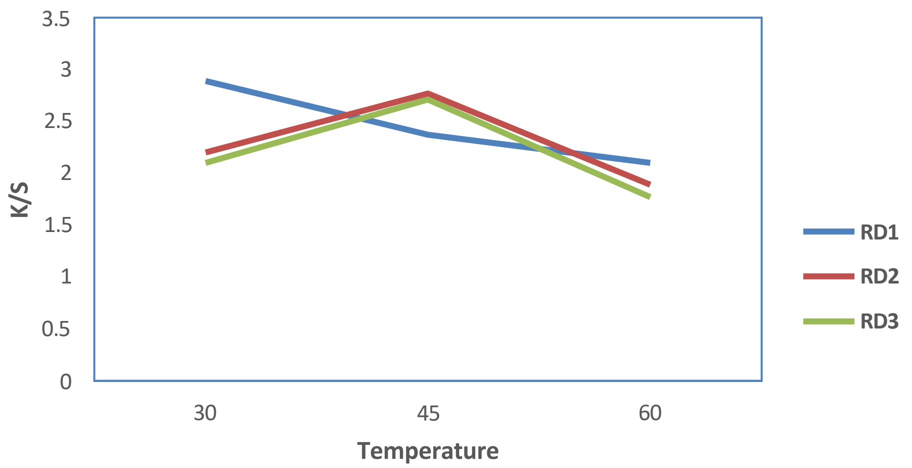



Fig. 4. Effect of exhaustion temperature on K/S

### Effect of exhaustion time on K/S

In dyeing process, surface adsorption, diffusion and dye-fabric fixation of dye is involved, Kamel et. al. (2007). This dyeing process reached at an equilibrium stage for specific reaction time and at that specific time, the sorption and desorption equilibrium are reached. However, prolonged dyeing time at higher temperature would facilitate dye desorption more efficiently, Collins, (2001). The hydrolysis of dye is one of main factors, which desorbs the dye molecule at unfavorable condition. The dyeing behavior of dyes under investigation, as a function of time is shown Fig. 5. The results revealed that 60 minutes dyeing time yielded higher color strength with smooth shade for all the reactive dyes. RD1 showed maximum color strength, while RD3 color strength was least. However, all dyes (RD1 to RD3) furnished color excellent color strength and these findings are in line with reported results of hetero-functional reactive dyes that dyeing time is effective for reactive dyes.

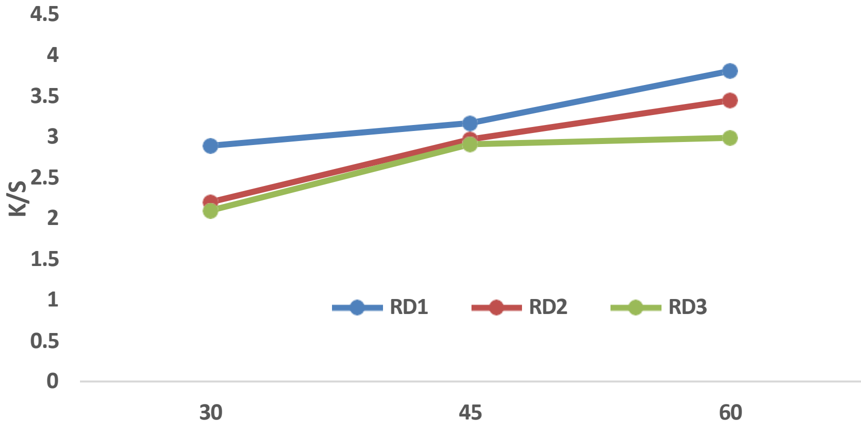



Fig.5. Effect of exhaustion time on K/S

## Effect of time on dye fixation (%)

To compare the dye fixation (%) of the three reactive dyes, the time is taken in x-axis, and the dye fixation% of is plotted in y-axis (Fig. 6). The graph is clearly different from exhaustion graph. Fixation (%) of dye means the reaction of reactive group of dye with terminal –OH group of fiber and thus forming strong covalent bond with the fiber. This is an important phase, which is controlled by maintaining proper pH by adding alkali. The alkali used for this purpose depends on brand of dye and dyeing temperature. In this investigation NaOH is used as alkali depending upon reactivity of dye to create proper pH 12.5 in dye bath and do as the dye-fixing agent. It has been noted that the dye fixation% value for RD1 can be achieved in very short duration (5min), followed by RD2 and then RD3. These results might be due to that RD1 possess such high reactivity that they readily hydrolyze which let it reacts with water. These results were in accordance with the results that the reactive dye fixation can be achieved in very short duration at optimize conditions of temperature and pH, Schmidt, (2003).

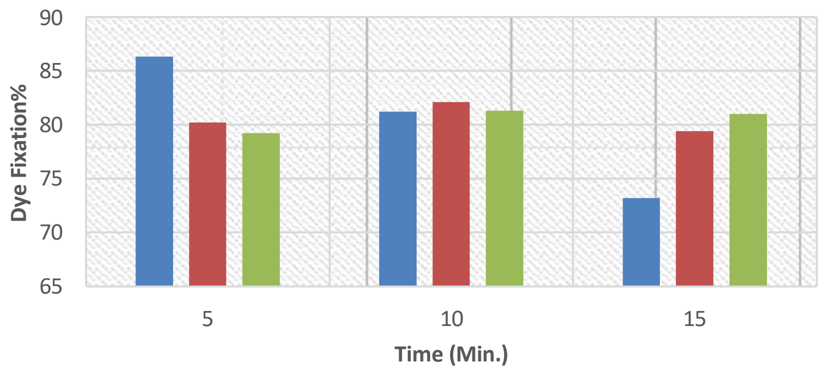



Fig. 6. Effect of time on Dye fixation%

### Effect of temperature on dye fixation (%)

The influence of the dye-fixing temperature on dyeing was investigated and the results are shown in Fig. 7. The dye fixation% values all first increased and then decreased, and the optimum dye fixation% was achieved at 45°C for RD1 and 60°C for RD2 and RD3 respectively. The dye fixation% of RD1 possess such high reactivity that they readily hydrolyze at high temperature; the extent of fixation of these dyes is thus lower. The low dye fixation% at lower temperature was due to aggregation of dye molecule and preclusion of dyes to fix on fiber, Umme et al. (2017). Increasing the dye-fixing temperature can improve the diffusion activation energy and dyeing rate of reactive dyes. Therefore, an appropriate increase in the dye-fixing temperature will improve the K/S. However, the K/S values of the dyed fabric decreased when the dye-fixing temperature exceeded 60°C. Increasing the dye-fixing temperature not only increases the reaction rate of reactive dyes with samples but also increases the hydrolysis rate of the reactive dyes. The increase in the reactive-dye hydrolysis rate might be greater than the increase in the reactive-dye dyeing rate upon increasing the dye-fixing temperature.

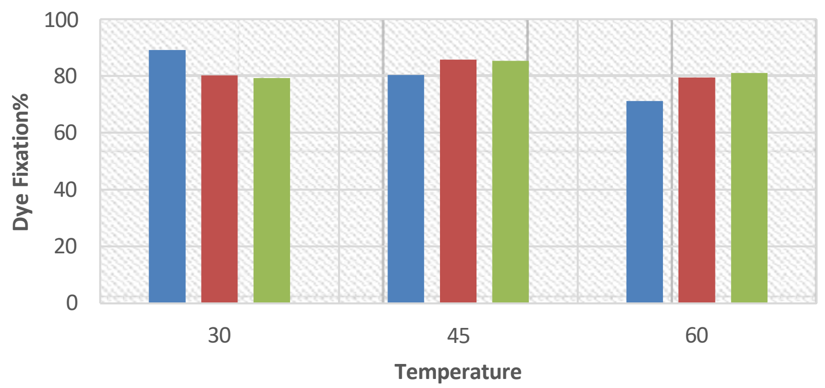


Fig. 7. Effect of temperature on Dye Fixation%

### Fastness properties

### Fastness to Washing (WF)

At the optimum conditions of exhaustion-fixation time and temperatures, the color fastness of dyed cotton fabric has been and the results are given in the Table 2. The wash fastness of cotton fabric with all the dyes is found to be good. However, it is better for RD1, and RD2 than that RD3. The wash fastness depends upon the physical and chemical properties of the fabric, the class of the dyes, their forces of interaction and their interaction with soap solution. The good washing fastness of the reactive dyes may be due to the chemical fixation of the dye molecules, David M Lewis, (2014).

### Fastness to Exposure in Light (LF)

Table 2 showed that the color fastness of cotton fabric to exposure under light decreased and all the dyes is found to be fair. The fastness of a dyed fabric depends upon the dye-fiber interaction and the intensity of light. An intensive oxidation of the fiber occurs due to the capacity of the dye molecule, excited by the light. This oxidation reaction rapidly occurs at the earlier time of light exposure and hence the color of the dyed fiber abruptly changes. Light fastness is the resistance of dyed fiber to fade upon exposure to light. Light fastness of all dyes was fair 3. The explanation of these results may be due to that the strong covalent bond between the dye and cotton fabric seems to have difficult the transfer of energy from the excited dye molecule to the fiber decreasing the stability of the reactive dyes under light exposure, Deepali R et al. (2006).

### Color fastness to rubbing (RF)

Color fastness to rubbing is also considering a crucial parameter. Rubbing fastness evaluates the ratio of color which may transfer from the surface of a colored fabric to an uncolored bleached test cloth during the systematic rubbing practice. All dyes furnished good rubbing fastness. The RD1 to RD3 rubbing fastness values were 4/5 for dry treatment, whereas RD1 and RD2 showed the values in the range of 4 and 3/4 for RD3. Results of the rubbing fastness revealed good penetration and fixation of the dyes

### Fastness to Perspiration (PF)

Perspiration is slightly acidic. Hydrocellulose is produced by the action of dilute acids due to the cleavage of chains by hydrolysis. Hydrolysis lowers the tensile strength of the fabric and breakdown the formation of covalent bonds between the fabric and the Reactive dyes. It is observed from the results that the color fastness of dyed cotton fabric to perspiration is nearly good. The cotton fabric dyed with RD1 and RD2 exhibits better results as compared to RD3 due to its higher affinity to cotton fabric.

Table 2. Fastness properties of the reactive dyes

| Properties / Samples | WF | LF | RF | | PF | |
|---|---|---|---|---|---|---|
| | | | dry | wet | acid | alkaline |
| RD1 | 4 | 3 | 4/5 | 4 | 4 | 4 |
| RD2 | 4 | 3 | 4/5 | 4 | 4 | 4 |
| RD3 | 3 | 3 | 4/5 | 3/4 | 3/4 | 3 |

Where WF Fastness to Washing, LF Fastness to Exposure in Light, RF fastness to rubbing, and PF Fastness to Perspiration

### Conclusion

Cold reactive dyes were studied for their dye fixation and color strength on cotton fabric. As the functional groups changed, the temperature sensitivity of dyes also changed, which revealed that functional groups in dyes structure are sensitive to temperature and they may respond differentially under variable temperature values. In the present investigation, three reactive dyes having different functional group (number and positions) were selected and employed on cotton fabric. The dyeing was performed by exhaustion-fixation method. Various process variables were optimized to enhance to color strength and dyeing fastness properties. The results obtained revealed that the reactive dyes exhibited high color strength, and fastness properties at optimum conditions of temperature, and reaction time. Among dyes under investigation, the results obtained showed that Procion Mx dye having the reactive group structure Di-chlorotriazine offer higher reactivity followed by Levafix E dye having the reactive group structure Di-chloroquinoxaline and finally Drimarine dye having the reactive group structure Di-fluoro chloropyrimidine.

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Research Article

# Dyeing Performance of Super-Giza 97 Egyptian Cotton Yarns

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## ABSTRACT

***Background and Rationale:*** *This investigation was carried out to evaluate the dyeability of the new Egyptian cotton variety and its effect on yarn mechanical properties during 2020 season. The relationship between various yarn properties and natural and synthetic dye types was investigated. The newest commercial Egyptian cotton variety from the Delta area, G. barbadense namely Super-Giza 97 as long staple (LS) was used.*

***Methods:*** *All tests for this new cultivar to determine the physical, mechanical and chemical fiber properties were done at the Cotton Technology Research Laboratories, Cotton Research Institute, Agricultural Research Center (ARC). Fibers were processed to yarns using ring spinning system, and dyed using different dyestuffs, which are natural dye extracted from outer onion skin, reactive dye named Drimarin K-4BL and basic dye (Methyl violet 2B). Yarn Mechanical Properties as yarn strength and yarn elongation was determined before and after dyeing. Evaluation of color measurements and color strength were measured. Furthermore, the changes in surface morphology of cotton yarns after dyeing were identified by Fourier Transform Infrared Spectroscopy (FTIR) analysis.*

***Results and Conclusions:*** *The results revealed that all characteristics of cotton yarns such as color measurements, color strength, color coordinates, tensile strength and elongation differed according to the dyestuff used. An important advantage of using the natural dye extracted from onion skin is the economical and environmental impact by using an agricultural waste for dying. Also, our study helps in understanding the relation between a new Egyptian cotton yarn and different kinds of dyestuff*

***Keywords****: Egyptian cotton variety, natural dye, reactive dye, basic dye*

## INTRODUCTION

All Egyptian cotton varieties belong to *Gossypium barbadense* species, which plays a great role in economic and social status in the life of Egyptians. Egyptian cotton is one of the most important crops of Egyptian agriculture. Cotton fiber quality is mainly influenced by genotype of the cultivars but agronomic practices and environmental conditions are the secondary factors influencing fiber quality. So, high quality cotton fiber will result in high quality yarn, and high quality final products (Tesema & Hussein, 2015).

Development of this new variety began as promising cross between two cotton genotypes belonging to *Gossypium barbadense L.,* genotype {Giza89xR101)xGiza86} as the female parent characterized by high fiber strength and early maturity with Giza94 as a male parent, which is superior by seed cotton yield and lint percentage in the growing season 2007 at Giza Experimental Station, Cotton Research Institute, Agricultural Research Center, Giza, Egypt during the routine work of Egyptian cotton breeding program followed by the pedigree method of selection (Abdelmoghny *et al.,* 2018).

Now, Super-Giza 97 proudly obtained by Egyptian researchers of the Agricultural Ministry, and commercially approved in 2020, The variety Super-Giza 97 has higher seed cotton yield and higher lint yield than other commercial long staple varieties.

The Egyptian long staple cotton variety (Giza97) had highly significant effects on all cotton fiber properties such as strength, elongation, whiteness and yellowness degrees, as well as spinning constant index, which, significantly differed due to genetic varietal effects (Nassar *et al*., 2019). It is necessary to carefully analyze the structure and the surface properties of cotton fibers in order to enhance the performance of cotton based materials and yarns (El Messirya & Abd-Ellatif, 2013). Egyptian cotton fibers are composed mostly of α-cellulose, the rest is non-cellulosics substances that are located on the outer layers and inside the lumen of the cotton fiber. The chemical composition of cotton fibers varies according to their varieties and growth conditions (Wakelyn *et al*., 2006).

The importance of the relationship between fiber properties and yarn structure has increased due to the need of yarns with best possible quality at optimal cost. The spinning system affects the yarn properties as the tenacity of ring yarns expresses greater value than rotor spun yarns and the elongation of ring yarns has a significantly lower value than that of rotor yarns (Iqbal , 2018).

The skin of onion is not edible and considered as a vegetable waste. Outer onion skin contains a coloring pigment known as “Pelargonidin” which is approximately 2.25% of the weight of the onion (Nurunnesa *et al*., 2018; Chandravanshi & Upadhyay, 2013).

Reactive dyes are among the most popular dyes for dyeing cotton and cellulosic fibers because of their variable color shades and good color fastness properties due to the chemical bonding between the reactive dye and the cellulose (Sharma & Sayed, 2016; Lewis, 2007; Ristić & Ristić, 2012; Bahlool & Saleh, 2020). Reactive dyestuffs can include more than one reactive group and may have more than one type of such groups (Collins, *et al*., 1998). In previous study we used a new technique for evaluating the performance of dyeing cotton fabrics using infrared (IR) heating technique compared to conventional exhaust dyeing method by dyeing Egyptian cotton fabrics made of two Egyptian varieties Giza 90 and Giza 95 using different concentrations of reactive dye using IR laboratory dyeing machine in which the infrared is the source of heating (Bahlool, 2019). Hence, in this study we investigate another reactive dye called Drimarene-K, which is one of the reactive dyestuff suitable for dyeing cotton, linen, rayon and all cellulosic fibers. A unique property of Drimarene-K dye is its stability in water solution (Benkhaya *et al*., 2020; Jamil *et al*., 2019).

Basic dyes are called cationic dyes because the chromophore in basic dye molecules contains a positive charge. Basic dyes are powerful coloring agents. They are applied to wool, silk, cotton and modified acrylic fibers. Usually acetic acid is added to the dye bath to help the take up of the dye onto the fiber because the solubility of these dyes is very good in water, in the presence of glacial acetic acid (https://www.textileblog.com/basic-or-cationic-dye).

FTIR spectroscopy has been one of the useful tools for research development needed for cotton industry**.** Zhongqi and Yongliang, 2021 reviewed the use of FTIR spectroscopy in investigation of cotton fiber and cotton seed components that are impacted by various genetic, cropping, post-harvest processing, and treatments. This was in order to provide a new vision of using FTIR research for the chemistry and quality-evolving mechanisms of cotton and cotton products.

The aim of this study was to investigate the properties of the new Egyptian cotton variety Super-Giza 97 as well as investigate the dyeability of ring spun cotton yarns from this variety using synthetic and natural dyes. We further aimed to study the relation between the cotton and the dyestuff used by FTIR Analysis. And compare the dyeing performance of the Egyptian cotton variety towards reactive, basic and natural dyestuffs.

## MATERIAL AND METHODS

### MATERIALS:

**Cotton Yarn:**

Cotton samples representing Super-Giza 97 Egyptian cotton variety are prepared in order to perform different fiber tests determining their physical properties.

Lint cotton samples were pre conditioned for 24 hours, under the standard conditions of (65 ± 5 %) relative humidity and (20 ± 2 C°) temperature before testing using cotton testing instruments:

All tests of the fibers of this new cultivar to determine the physical, mechanical and chemical fiber properties were performed at the Cotton Technology Research Laboratories, Cotton Research Institute, Agricultural Research Center (ARC), Giza, Egypt. Published in **Cotton research institute annual report season 2020** and summarized in table 1.

Table (1): Egyptian Cotton Fibers' physical, mechanical and chemical properties

| Egyptian Cotton Variety | Color | | | Micronaire | Fiber Length (UHM) mm | Fiber Mechanical Properties | | Image Analyzer ; Fiber Perimeter ( µ) | Chemical Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Color | Bright. (RD%) | Yellow.(+b) | | | Str.(g/tex) | Elong. (%) | | sugar (%) | Wax (%) | Moist. (%) | Ash (%) |
| Super-Giza 97 | White | 74.3 | 9.1 | 4.4 | 33.7 | 46 | 7.5 | 47 | 0.22 | 1.02 | 6.16 | 0.99 |

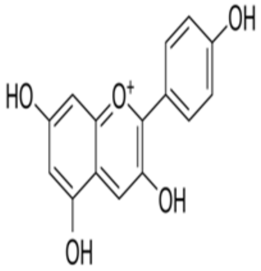
Super-Giza 97 commercial Egyptian cotton varieties representing the long staple category season 2020, were processed to yarns Ne 60 using ring spinning system, at the Cotton Technology Research Laboratories, Cotton Research Institute, Agricultural Research Center, Giza, Egypt

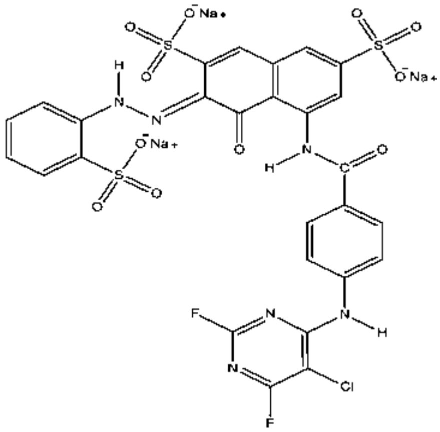
### CHEMICALS AND AUXILIARIES:

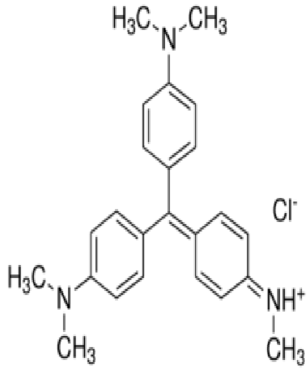
All chemicals used were of analytical grade using doubly distilled water. Glauber salt ($Na_2SO_4 \cdot 10H_2O$) sodium hydroxide (NaOH), sodium chloride (NaCl), sodium carbonate ($Na_2CO_3$), acetic acid ($CH_3COOH$), triton x-100 as wetting agent, and detergent.

**DYE STUFFS**:

Three different dyestuffs have been used and their structure illustrated in **Figures 1, 2, 3 below**







| | | |
|---|---|---|
| Figure 1. Structural Formula of Pelargonidin" Natural dye extracted from Onion skin (Chandravanshi &Upadhyay, 2013) | Figure 2. Structural Formula of Reactive dye (Drimarin K-4BL) Fluorochloropyrimidine (Jamil et al., 2018) | Figure 3. Structural Formula of Methyl Basic Violet Dye |

## METHODS

### (I) Scouring

In order to improve the adhesion of dye to the cotton yarns, an alkaline pre-treatment using sodium hydroxide at concentrations 4.0 % owf with a liquor ratio 1:50 at boiling for 90 minutes. Then yarns were washed with hot water and cold water and air dried at room temperature

### (II) Natural dyes extraction from onion skin

About 100g of onion skin that contains the pigment components were boiled in one liter of distilled water and concentrated to 500ml. The extracted liquor was used as the foundation of the dye.

### (III) Dyeing procedure

Egyptian cotton yarns Ne 60. were scoured and dyed using three different dyestuffs basic, reactive and natural dye in exhaust dyeing method at the temperatures 50°C , 60°C and 90°C, respectively.

Yarn samples were dyed with 3% owf Drimarene Redeactive dye (Drimarin K), 140 g/L glauber salt (electrolyte) , 12 g/L soda ash (Alkali) and Wetting agent 1.0 g/L 1:30 liquor ratio at 60°C.

Cotton yarn was dyed with 3% basic dye (Basic Violet 2), Acetic acid as required to control pH 4.5, Wetting agent 1g/l, M.L 1:30, pH 4.5, Temperature 50c. Salt (20 g/L) used as exhausting agent (Atiqur Rahman., 2020).

Natural dye carried out at a temperature of 90ºC with onion skin natural dye extracted using liquor ratio of 1:30.

After dyeing, subsequently rinsed with water hot and cold then, soaping of the dyed yarns were performed in a bath containing 1 g/l non-ionic detergent 10% at 60ºC for 15 minutes to remove the unfixed dyes present on the yarn surface, and dried at room temperature. The dyeing procedures are as shown in Figure 4

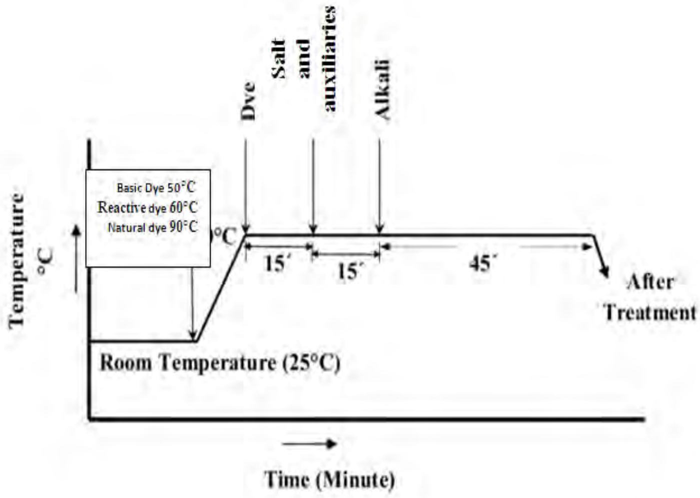



*Figure 4. Dyeing procedures of cotton yarns using basic, reactive and natural dyestuffs*

- **EVALUATION TESTS**

All cotton samples were conditioned for 48hrs at 65% (±5%) relative humidity and 20°C (±2°C) according to ISO: 6359-1971 standard method.

**(I) Yarn Mechanical Properties:**

Yarn samples were tested using Statimat ME Tester to determine the yarn strength and yarn elongation before and after dyeing.

**(II) Evaluation of Color Strength**

Evaluation of Color Strength: The dyed cotton yarns, which were processed in this study, were characterized by color measurements where the reflection spectra wavelength ranges 400-700nm by using a visible spectrophotometer method CIE-Lab 1976/D65. Color measuring instrument (Optimatch spectrophotometer Datacolor international Spectraflash SF450-UK) determines the K/S value of a given yarn through Kubelka-Munk equation as follows (Broadbent, 2001).

The quantitative value for the color strength was obtained by measuring the percent value of reflectance (% R) at the same wavelength and then converted to K/S value with K/S table assistance by Kubelka-Munk (equation 1).

$$\frac{K}{S} = \frac{(1-R)^2}{2R}$$ **----------------------Equation**

Reflectance value is the reflection of light amount reflected by objects that contain color.
K is the absorption coefficient (absorbed light); S is the spread light coefficient; R is the percent value of the reflectance (λmax). The color coordinates of the CIE-Lab L* a* b* system and their position in the color space show the color difference values.

## Fourier Transform Infrared Spectroscopy (FTIR)

Cotton yarn samples have been crushed and examined using Fourier Transform Infrared Spectroscopy (FTIR 6300) instrument from Jasco Inc., Japan, and the measurements were carried out using an attenuated total reflectance (ATR) technique. All the spectra recorded in the range 4000-400 cm−1 were averaged over multiple scans at a resolution of 4 cm−1. All the recorded data was processed with Spectra Manager II software from Jasco Inc., Japan.

## RESULTS AND DISCUSSION

Mechanical properties of cotton yarns before and after dyeing were detailed in Table 2 and Figure 5. We noticed that dyeing has a slight positive effect on the tensile strength of yarns and almost no effect on the elongation percentage

The tensile strength of yarn increases after scouring from 25.5 to 26.8 CN/Tex this increase in strength after scouring possibly is due to fiber swelling and removal of un-cellulosic components, such as wax during wet processing and alkali treatment, which was in agreement with Shrikant *et al*., 2005.

Table 2: Mechanical Properties of cotton Yarns before and after dyeing

| Egyptian Cotton Variety G97 | Yarn Mechanical Properties | |
|---|---|---|
| Treatment | Strength (CN/tex) | Elongation (%) |
| Raw Cotton Yarn | 25.5 | 5.3 |
| Scoured/ undyed | 26.78 | 5.4 |
| Dyed with Natural dye | 26.25 | 5.3 |
| Dyed with Reactive dye | 27.66 | 5.3 |
| Dyed with Basic dye | 26.9 | 5.4 |

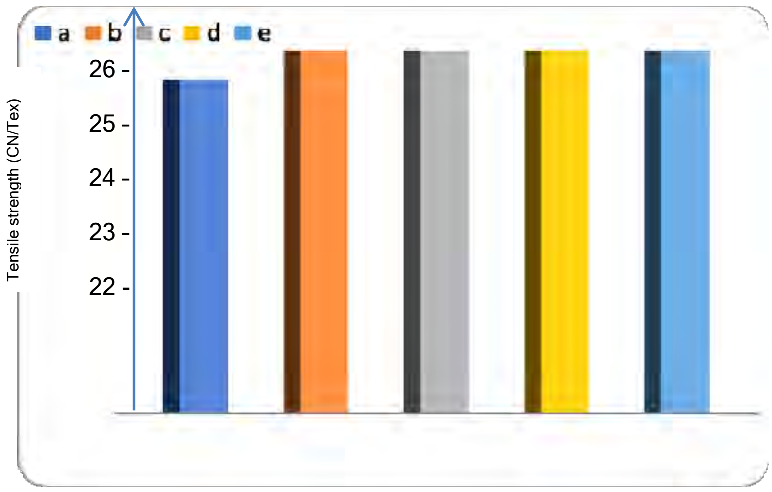



*Figure 5. Tensile strength (CN/Tex) of cotton yarns: (a) Raw cotton yarns; (b) scoured cotton yarns; (c) dyed with natural dye; (d) dyed with reactive dyes ; (e) dyed with basic dyes*

Figure 6 showed the color strength K/S spectra in the wavelength range 400-700nm of cotton yarns by using a visible spectrophotometer, where the color depth of the dyed yarns was analyzed by measuring the K/S values of samples. The higher the value of K/S, the more the amount of dye absorbed into the cotton yarn.

The Outer onion skin contains a coloring pigment called “Pelargonidin” (3, 5, 7, 4 tetrahydroxyantocy anidol) and is used to dye cellulosic fibers (Chandravanshi & Upadhyay 2013).

The increase in the reactivity of this kind of basic dyes was made by the substitution of chlorines by fluorine. The bond formed with the textile fiber has been more stable in an acidic medium. The ideal temperature for a good fixation of this type of dye is between 40 °C and 50°C (Benkhaya *et al*., 2020; Jamil *et al*., 2019; Atiqur Rahman & Foisal, 2016). Bi-functional reactive dyes are known for their better exhaustion and fixation properties as they have higher probability to be attracted to the fiber due to double reactive groups.

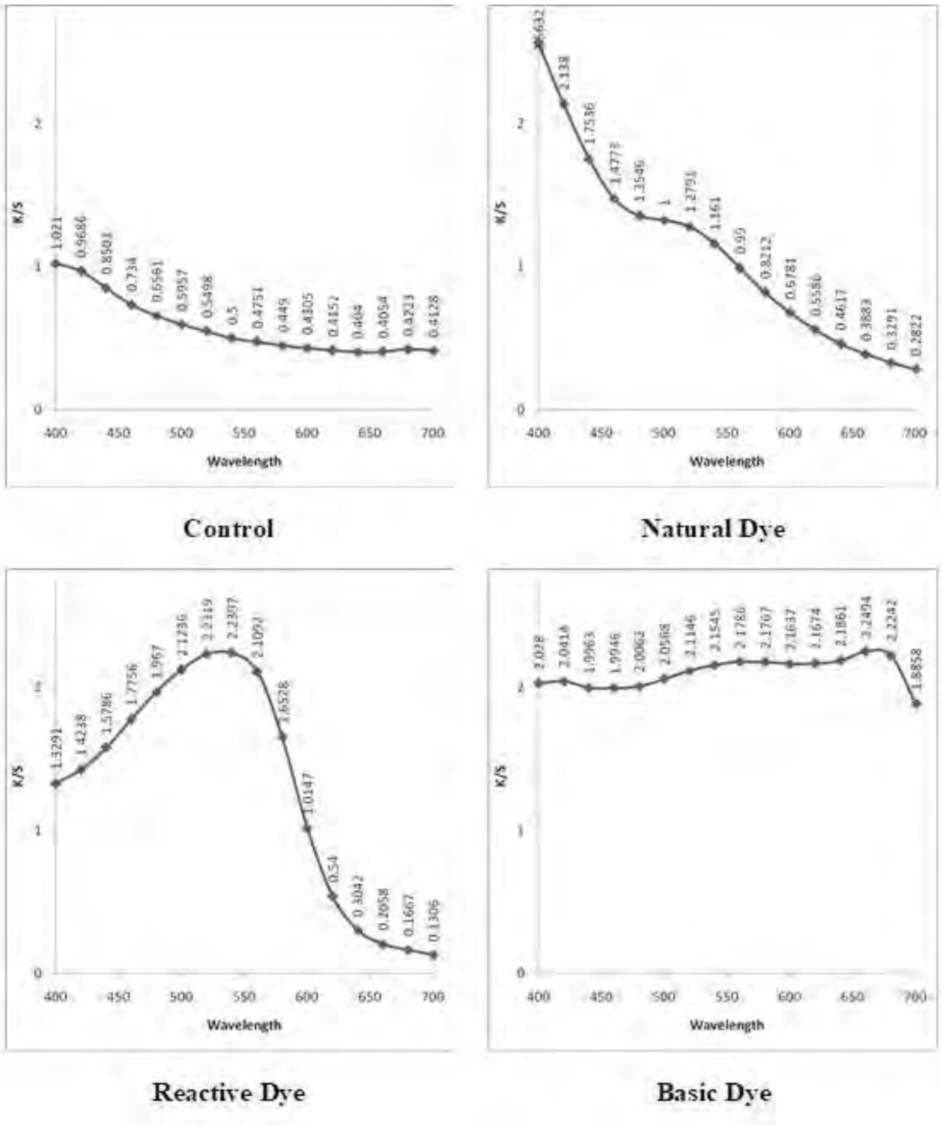



*Figure 6. Color strength k/s spectra wavelength range 400-700nm of cotton yarns:(a) scoured cotton yarns(control); (b) dyed with natural dye; (c) dyed with reactive dyes ; (d) dyed with basic dyes*

The K/S values measured at each wavelength, from λ = 400 to λ = 700 nm as Illustrated in figure 6. The color strength was measured at maximum intensity wavelength λmax = 400nm, 400nm, 540nm, 655nm for Natural dye, Reactive dye and Basic dye respectively.

The variation of K/S values is highest at λ = 655 nm and is equal to 2.25 when dyeing with basic dye and at λ = 540 nm and is equal to 2.39 when dyeing with reactive dye, λ = 400 nm and is equal to 2.56 when dyeing with natural dye and at λ = 400 nm and is equal to 1.02 for undyed yarns

Table 3 Color strength k/s values of undyed and dyed cotton yarns

| Dye | K/S | Color Obtained | Color Name |
|---|---|---|---|
| Undyed | 1.02 |  | White |
| Natural dye | 2.56 | | Light Brown |
| Reactive Dye | 2.39 | | Red |
| Basic Dye | 2.25 | | Dark violet |

Table 4 showed that CIELAB color spaces lightness, values were different as colorant compound is different also by using different light: daylight, artificial light and fluorescent light. The color coordinate values L* for color brightness (brightness, 100 = white, 0 = black), redness (+a*), greenness (-a*), yellowness (+b*), and blueness (-b *)

Table 4. The color coordinate values L*, a* and b* of dyed cotton yarns

| Dye | | L* | a* | b* |
|---|---|---|---|---|
| Natural dye | D | 68.76 | 09.12 | 16.73 |
| | A | 70.79 | 10.95 | 15.50 |
| | F | 68.55 | 08.78 | 15.55 |
| Reactive dye | D | 52.21 | 22.09 | 2.04 |
| | A | 55.04 | 24.49 | 7.62 |
| | F | 52.12 | 15.99 | 1.38 |
| Basic dye | D | 47.46 | -0.06 | -1.61 |
| | A | 47.33 | -0.28 | -1.83 |
| | F | 47.34 | 0.10 | -1.84 |

*D; daylight, A; artificial light, F; fluorescent light*

**FTIR spectroscopic analysis**

FTIR spectroscopic analysis is used to determine characteristic peaks of functional groups (4,000:400 $cm^{-1}$) region measured by transmission mode.

From Figure 7, the peak at 3754 cm is attributed to H- bonded and broader band between 3400 and 3300 $cm^{-1}$ is attributed to OH- stretching vibration forming hydrogen bonds between the cellulose molecule located at 3300 and 3334 cm-1cm-1 attributed to intermolecular and intra-molecular hydrogen bonds

The peaks observed at 2917 and 2920cm-1is attributed to –CH2 asymmetric vibrations. We can observe broad peak at 3000-2800 $cm^{-1}$ region for C– H stretching.

Although cellulose has –CH2– groups in their structure, the peaks corresponding to the symmetric and asymmetric stretching modes have never been separated as sharp peaks (Chunga *et al.,* 2004).

Other common bands appearing in different intensities in the spectra showed a peaks 1630 and 1633 cm-1 which is the characteristics of –CH2-symmetrical bending, the spectra showed a peaks 1420 and 1430 cm-1 which is the characteristics of CH2-scissoring. Peaks at 1372 cm are attributed to CH- bonding deformation stretch. Then we observed peak attributed to C-OH stretching at 1200 cm

1160 and 1170$cm^{-1}$ which is the characteristics of symmetric bridge -C-O-C- , peak attributed to C-O stretching at 1000 cm and 1157 $cm^{-1}$. Also, Peaks at 1160 and 1170$cm^{-1}$ which are the characteristics of symmetric bridge -C-O-C, Peaks at 850 cm and 900$cm^{-1}$ are attributed to β glucosidic linkage. The C-O stretch corresponds to the peak at 1,162 $cm^{-1}$, whereas the peaks at 600 and 700 cm-1 represent the symmetric bending of the benzene ring.

The characteristic absorption peaks of cellulose backbone at 3347, 2900, 1160, and 1030 $cm^{-1}$ were assigned to the stretching vibrations of O-H, C-H, C-C, and C-O bonds, respectively, in all samples, which indicated that the cellulose backbone chains of cotton did not change after modification by dyeing. However, the spectrum of dyed yarn showed mild changes in intensity of the peaks.

The results of our study are supported by other researches such as Chunga *et al*., 2004 and Kumar *et al*., 2011who investigate the ATR-FTIR spectral features of cotton plant parts and their functional group assignments. Adapted from Shrikant *et al*., 2005 and Chunga *et al*, 2004 who compared the FTIR spectra of the raw and scoured cotton fabrics.

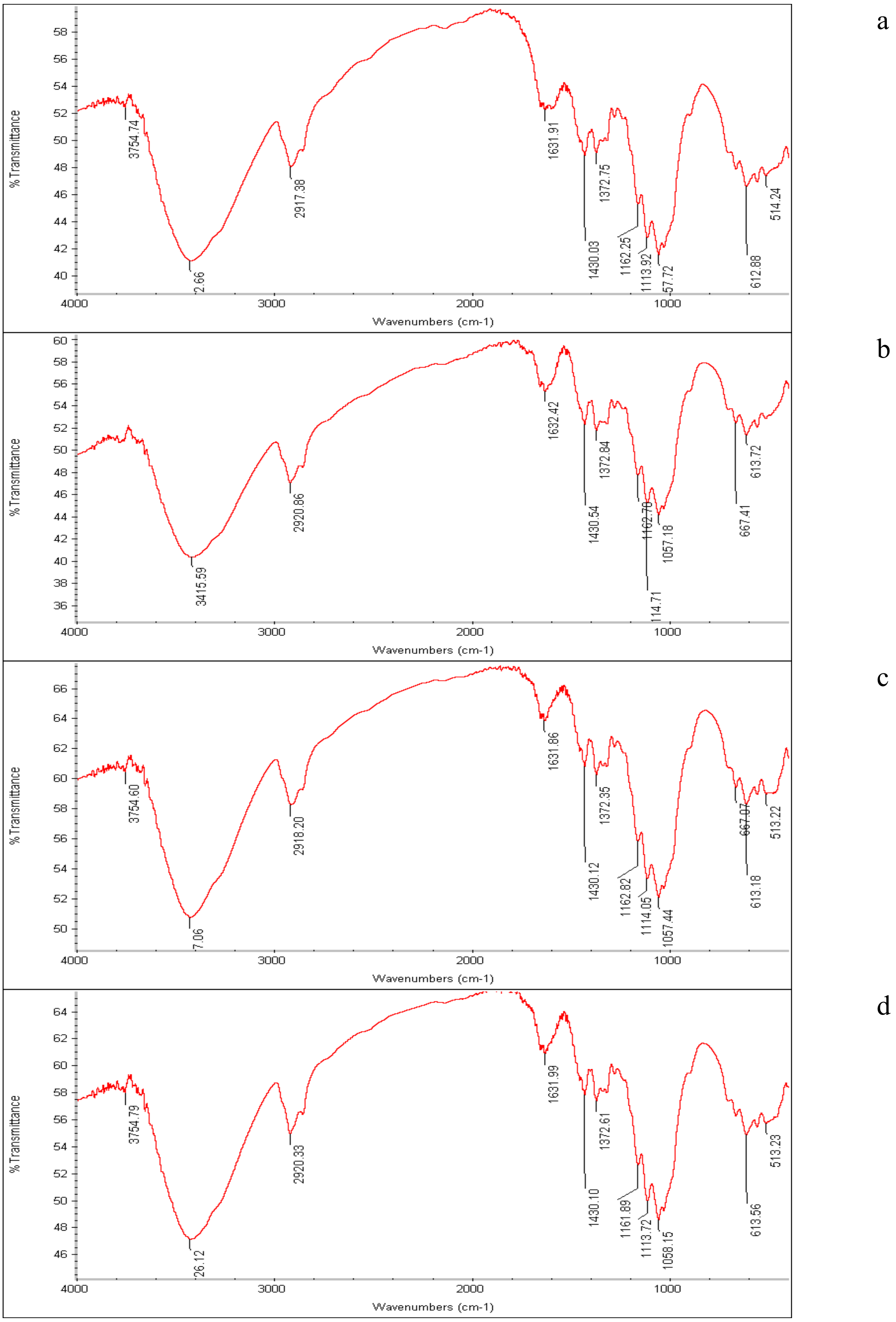



*Figure 7. FTIR spectrogram of :(a) scoured cotton yarns(control); (b) dyed with natural dye; (c) dyed with reactive dyes ; (d) dyed with basic dyes*

## CONCLUSION

The dyeing performance of Egyptian cotton yarn made of Super-Giza 97 variety using reactive, basic and natural dyes has been investigated.

Due to eco-friendliness of natural dyes and the awareness among people regarding the environmental and health hazards associated with the use of synthetic dyes, needing for materials dyed with natural dye is increasing. In the present study the onion outer skin was taken as dye material for the dyeing of cotton yarns as onion is an available and cheap agriculture waste, it will be convenient to produce naturally dyed cotton yarns and eco-friendly fashionable cotton cloths.

Yarns dyed with synthetic dyes, whether reactive or basic showed higher depth of shade than the natural dyed yarns. However, the eco-friendly property of natural dyes especially when extracted from waste materials and applied to a new Egyptian cotton variety is desirable due to the economic and environmental qualities of such treatment.

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# Field evaluations of site-specific overhead irrigation of cotton using adaptive control

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## Introduction

Variable-rate irrigation (VRI) technology has been demonstrated to improve spatial management of crop water requirements through reduced water use. Existing commercial and research VRI prescription map development focusses on filling the soil-water profile with spatial crop water requirements; however, filling the soil-water profile may not maximise yield because of the variations in crop response and water requirements with crop stage. For example, cotton crops produce optimal yield under slight water stress during squaring stage. An irrigation strategy 'Model Predictive Control' (MPC) has been developed that uses biophysical models to identify spatially varied irrigation depths that maximise predicted yield with minimum water. MPC has been implemented in the software 'VARIwise' (McCarthy et al., 2010, 2014) to automatically and iteratively execute the biophysical crop model APSIM once parameterised with local soil and weather information, for different irrigation depths, to identify which combination maximises yield with the minimum depth of water application. MPC has been demonstrated in simulations to outperform soil-water based strategies for cotton irrigation. This research reports the field performance of MPC for irrigation of cotton.

## Materials and method

Four irrigation control strategies were selected for evaluation in a supplementary irrigated commercial cotton field. The irrigation strategies were implemented on the days the grower was irrigating, as detailed below:

- Uniform – Flat irrigation rate with no sprinkler flowrate alterations.
- VRI from fixed map – Fixed variable-rate irrigation map developed based on apparent electrical conductivity or elevation maps (Figure 1).
- VRI from soil-water (SW) sensors – Apply irrigation depths to replenish the soil-water profile as sensed using soil-water sensors, and pre-determined field capacity.
- VRI from MPC maximising yield – The MPC strategy of McCarthy et al. (2014) was implemented to maximise predicted final yield. The model was parameterised from on-site weather data, soil properties and management information to predict yield obtained from irrigation depths at increments of 5 mm between 0 mm and the base application depth (30 mm). The

irrigation depth applied was that which produced the highest predicted lint yield. If two irrigation depths produced the same predicted yield, the lower irrigation depth was chosen in these comparisons.

The trial site selected was a seven-span centre pivot irrigating cotton crops over four irrigation seasons near Yargullen, Queensland, Australia. The VRI hardware was Valley VRI-iS which enabled individual sprinkler control. AgSense was installed on the machine to enable remote control of the machines and the remote upload of regularly updated VRI prescription maps.

The variability in soil types was assessed in each field to select four locations for replicates of treatments across the fields. The cotton fields were surveyed using a DUALEM-1S that records electromagnetic responses to 50 cm and 150 cm depths. Soil cores were collected in the sampling locations and analysed to characterise parameters required for APSIM (bulk density, drained upper limit, lower limit, saturated water content).

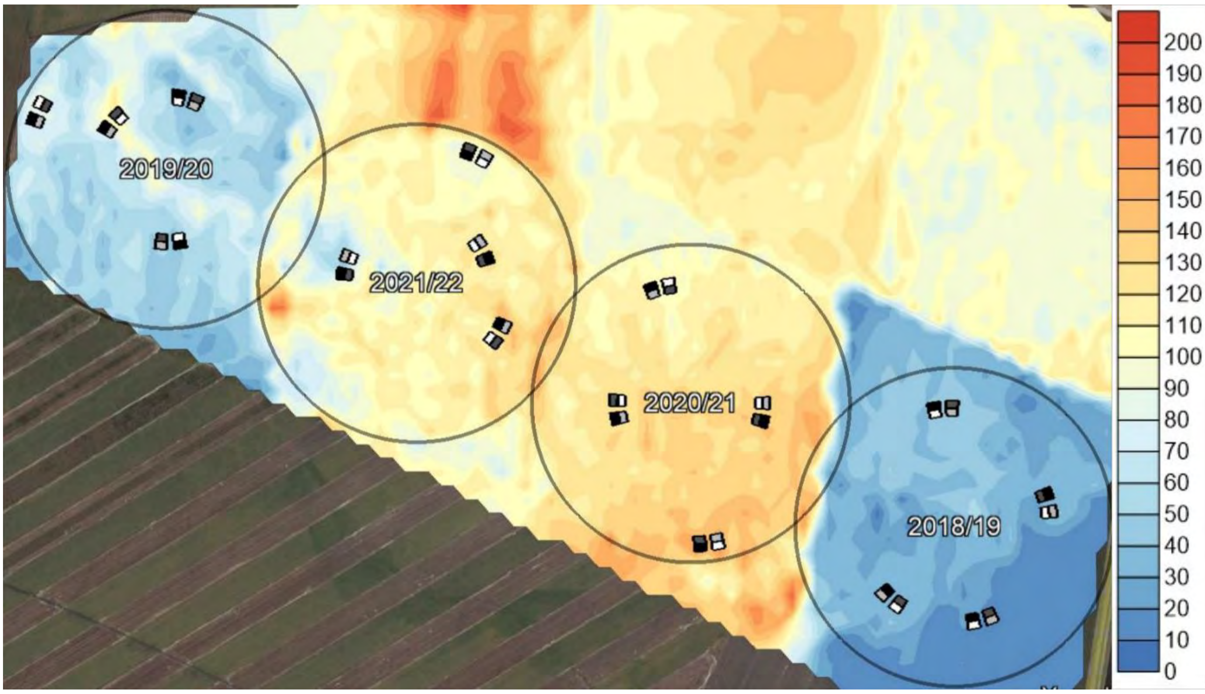


**Figure 1**. Field variability maps for cotton field sites in 2018/19, 2019/20, 2020/21 and 2021/22 where the legend is for vertical apparent electrical conductivity, $EC_a$ (dS/m). The dark grey circles outline the field boundaries for the404 m long centre pivot irrigation machine. The plots where the Uniform strategy were imposed are white, the VRI-Fixed plots are light grey, the VRI-SW plots are dark grey, and the VRI-MPC plots are black.

Weather data was collected from an on-site automatic weather station (Environdata Weathermaster 2000) each season to provide minimum and maximum daily temperature, rainfall and solar radiation for APSIM simulations. Soil moisture was monitored at the centre of the VRI-SW plots using soil-water sensors. ICT International MP406 standing wave sensors were installed at depths of

30, 60 and 90 cm. All plots were monitored weekly to compare in-season crop growth patterns between irrigation strategies using a DJI Phantom 4 UAV to assess canopy cover and open bolls. Yield was assessed at harvest from measured lint weight, and and expected average cotton gin turnout percentage of 40%.

The irrigation strategies were initiated from approximately 40 days after sowing during each season. The irrigation strategies were evaluated from measured end-of-season yield, total irrigation applied, irrigation water use index (IWUI), gross production water use index (GPWUI), and weekly crop growth features. The percentage differences in these parameters were compared with the Uniform and various VRI irrigation strategies. Variations between plots over fields are reported using standard deviations.

**Results and discussion**

Table 2 compares the performance of the Uniform irrigation and VRI strategies in field trials for cotton. During the 2018/19 season, the irrigation machine had insufficient system capacity to deliver the crop's water requirements due to higher than usual temperatures, historically low in-crop rainfall, and a supplementary irrigation approach for the season. This led to the Uniform irrigation strategy producing the highest yield in 2018/19. During the 2021/22 season, the crop yield was significantly lower because of two flood events and cooler temperatures, leading to similar performance across all strategies.

From Table 2, compared with the VRI-Fixed strategy, the VRI-MPC strategy produced 0.8% more yield with 7.4% less water, VRI-SW produced the same yield with 2.9% more water, and the Uniform irrigation strategy produced 1.8% less yield with 6.4% more water. Compared with the Uniform irrigation strategy, VRI-MPC produced 0.3% more yield with 11.7% less water, VRI-SW produced 1.5% more yield with 6.0% less water, and VRI-Fixed produced 5.8% less yield with 5.6% less water.

Table 2. Average and standard deviation of yield of cotton, total irrigation applied, irrigation water use index (IWUI), and gross production water use index (GPWUI) for the four irrigation strategies over each season are detailed. The average and standard deviation of these values over the four replicates are shown. The effective rainfall was 196, 229, 228 and 396 mm for the 2018/19, 2019/20, 2020/21 and 2021/22 seasons, respectively.

| Strategy | Season | Yield (kg/ha) | Irrigation applied (ML/ha) | IWUI (bales/ ML) | GPWUI (bales/ ML) |
|---|---|---|---|---|---|
| | 2018/19 | 1958.3 ± 74.9 | 3.3 ± 0.0 | 2.6 ± 0.1 | 1.8 ± 0.1 |
| | 2019/20 | 2969.2 ± 139.3 | 3.7 ± 0.1 | 3.6 ± 0.2 | 2.3 ± 0.1 |
| | 2020/21 | 1977.6 ± 60.5 | 2.9 ± 0.1 | 3.0 ± 0.2 | 1.5 ± 0.1 |
| | 2021/22 | 1640.8 ± 35.2 | 2.2 ± 0.1 | 3.3 ± 0.1 | 1 ± 0 |
| **Uniform** | **Average** | **2136.5 ± 77.5** | **3.0 ± 0.1** | **3.1 ± 0.1** | **1.6 ± 0.1** |
| **VRI-** | 2018/19 | 1457.2 ± 88.5 | 3.2 ± 0.0 | 2.0 ± 0.1 | 1.3 ± 0.1 |

| Strategy | Season | Yield (kg/ha) | Irrigation applied (ML/ha) | IWUI (bales/ ML) | GPWUI (bales/ ML) |
|---|---|---|---|---|---|
| **Fixed** | 2019/20 | 3043.7 ± 127.2 | 3.5 ± 0.1 | 3.9 ± 0.1 | 2.4 ± 0.1 |
| | 2020/21 | 2005.2 ± 65.2 | 2.7 ± 0.1 | 3.3 ± 0.2 | 1.6 ± 0.1 |
| | 2021/22 | 1615.0 ± 65.4 | 2.1 ± 0.1 | 3.4 ± 0.1 | 1 ± 0 |
| | **Average** | **2030.3 ± 86.6** | **2.9 ± 0.1** | **3.2 ± 0.1** | **1.6 ± 0.1** |
| | 2018/19 | 1962.1 ± 68.4 | 3.4 ± 0.0 | 2.5 ± 0.1 | 1.8 ± 0.1 |
| | 2019/20 | 3020.7 ± 146 | 3.6 ± 0.1 | 3.7 ± 0.2 | 2.3 ± 0.2 |
| | 2020/21 | 2010.3 ± 13.4 | 2.8 ± 0.1 | 3.2 ± 0.1 | 1.6 ± 0 |
| | 2021/22 | 1672.3 ± 60.9 | 1.8 ± 0.1 | 4.1 ± 0.3 | 1.1 ± 0.1 |
| **VRI-SW** | **Average** | **2165.4 ± 73.8** | **2.9 ± 0.1** | **3.4 ± 0.2** | **1.7 ± 0.1** |
| | 2018/19 | 1803.5 ± 73.4 | 3.2 ± 0.1 | 2.5 ± 0.1 | 1.7 ± 0.1 |
| | 2019/20 | 3023.3 ± 159.3 | 3.3 ± 0.1 | 4.1 ± 0.2 | 2.5 ± 0.1 |
| | 2020/21 | 2055.5 ± 105.4 | 2.5 ± 0.1 | 3.7 ± 0.3 | 1.7 ± 0.1 |
| **VRI-** | 2021/22 | 1684.8 ± 56.0 | 1.8 ± 0.1 | 4.1 ± 0.4 | 1.1 ± 0.1 |
| **MPC** | **Average** | **2141.8 ± 98.5** | **2.7 ± 0.1** | **3.6 ± 0.2** | **1.7 ± 0.1** |

In all seasons, similar irrigation depths were applied by all strategies until flowering. In the 2020/21 and 2021/22 seasons, irrigation applications were reduced after 80-100 days after sowing which was after peak bloom. Water stress during peak bloom to open bolls can cause young boll shedding but has less impact on yield than loss of early season bolls. In the 2018/19 and 2019/20 seasons, the VRI-MPC strategy also reduced irrigation applications at approximately 120 days after sowing, which coincides with boll opening. Less water applied during peak boll opening may hasten boll maturity, improving defoliation and reducing regrowth that may lead to increased yield and improved fibre quality.

## Conclusions

Field trials have been conducted over four seasons to evaluate the accuracy of the yield prediction of the biophysical model and compare field performance of irrigation strategies including Uniform and VRI using MPC. In this commercial cotton field irrigated under a supplementary irrigation management regime, the VRI strategies generally had a larger impact on irrigation amount applied rather than yield, with the VRI-MPC strategy successfully maintaining yield with 7.4% less water. Water savings occurred through reduced irrigation applications at squaring and/or open-boll physiological stages. Further work includes expanding the research trials to other cotton regions with a fully irrigated management requirement, for greater variability of in-field soil characteristics, using a VRI equipped machine where initiation/timing of irrigation can also be completely controlled by the VARIwise MPC strategy.

**Acknowledgements**

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# Preparing the Australian cotton industry for genes of biosecurity concern

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When we think about 'biosecurity', newly invading species are often seen as the key threat, but the genetic traits of organisms are just as likely to have impact. These are knowns as 'genes of biosecurity concern': the species may already be in a country, but if new genetics arrive then the impacts of those species may be much greater.
One of these concerns for the Australian cotton industry is that new Bt resistant genes in the key target pest *Helicoverpa armigera* could arrive (Table 1). This would especially be a concern should they come from Asia which has documented several types of dominant resistance to Cry1Ac in this pest which may evolve more quickly than the recessive forms isolated to-date in Australia.

***Table 1.*** *Threat identification and pest risk assessment for* Helicoverpa armigera *(carrying Bt resistance alleles) as extracted from Table 5 'Cotton industry high priority plant pest threat list' in 'Biosecurity Plan for the Cotton Industry Version 3.0 August 2015'.*

| Hosts | Plant part affected | Entry potential | Establishment potential | Spread potential | Economic impact | Overall rating |
|---|---|---|---|---|---|---|
| Wide host range including: cotton, maize, chickpea, lucerne, soybean, peanuts | Above ground plant parts | MEDIUM | HIGH | HIGH | HIGH | HIGH |

Beyond assessing the threat and likelihood that such an incursion may occur, we also need to consider how the best response to it aligns with current industry risk management practices. We compared the Bt Resistance Management Plans (RMP's) adopted in Australia and China, and gained insights through computer simulation models, to provide preliminary recommendations on how to prepare for an incursion in Australia of *H. armigera* that carry dominant Cry1Ac resistance genes.

**What did the models tell us?**

We applied a simulation model to the Australian situation and compared the trends with those developed for China.

The model is initialised with several user-specified parameters:

| Population initialization parameters | Genetics initialization parameters |
|---|---|
| Adult population (equal male-female), currently introduced on the first day of the simulation only | The dominance of resistant alleles for each of the two genes (h) |
| Planting and harvest dates of crops (as well as a specified landscape file and selected year to run the model) | The survival of the susceptible genes (ss) for each of the Bt toxins |
| Directionality of movement and perception distance (the latter is different for males and females) | The frequency (freq) of initial r allele for each gene (NB a frequency of 0.1: rr freq = 0.01, rs freq = 0.18, ss freq = 0.81) |

We found that the single gene Bt technology currently in China is likely to be much less effective in managing the spread of dominant resistance genes than the pyramided traits in Australia. This is particularly the case if we were to simply rely only on the 5% mandated refuges in the landscape as per the Resistance Management Plan (RMP) in Australia.

The Australian cotton industry can have somewhere between 25% and 75% of some of our cotton landscapes like the Darling Downs acting as an effective or 'natural' refuge (sorghum crops in particular), in addition to the mandated refuge (Fig. 1). When this habitat is considered, the concern of resistance evolving is far less, regardless of whether the gene is dominant or recessive, even if part of our current pyramid technology were to be overcome (Table 2). This is not currently accounted for in the RMP in Australia because the composition of landscapes can be highly variable based on rainfall and difficult to predict among seasons (Maelzer & Zalucki, *1999*, Bulletin of Entomological Research 89, 455-463).

Fitness costs (i.e., increased pest mortality) due to carrying dominant resistant genes do not seem to impede the rate of resistance evolution in the models (Table 2).


***Fig. 1:*** *Three landscapes on the Darling Downs, Qld, over five years (spring/summer cropping season) showing Bt Cotton, mandated refuges of conventional cotton/pigeon pea, and 'natural refuges' of sorghum.*

***Table 2:*** *CSIRO model scenario results for a single landscape/year on the Darling Downs showing the percentage of resistant individuals after a year (3 generations) with varying dominance of resistance (h), in comparison with the results of Jin et al. (2015, Nature Biotechnology 33(2), 169-174) in Northern China.*

| | | **Resistant individuals (%) after 1 year (3 generations)** | | |
|---|---|---|---|---|
| | **Dominance (h)** | **0.0** | **0.5** | **1.0** |
| **Northern China (Jin et al. 2015, Fig. 1)** | 2% effective refuge | 95.9 | 68.2 | 86.4 |
| | 56% effective refuge | 1.1 | 1.6 | 2.4 |
| **Nandi 2011-12 - single gene scenario*** | Mandated refuge only (4%) | 20.0 | 22.0 | 21.4 |
| | Mandated and effective refuge (54.1%) | 1.4 | 3.1 | 2.8 |
| **Nandi 2011-12 - two gene scenario*** | Mandated refuge only (4%) | 0.0 | 0.0 | 0.0 |
| | Mandated and effective refuge (54.1%) | 0.0 | 0.0 | 0.7 |
| **Nandi 2011-12 - single gene scenario with resistance fitness cost of 50% in non-Bt crops*** | Mandated refuge only (4%) | 16.6 | 27.0 | 13.6 |
| | Mandated and effective refuge (54.1%) | 4.3 | 4.8 | 4.7 |

*Preliminary results only from single simulation runs.

It is worth noting that much of the model scenario analysis was based only on within-season dynamics: we are yet to explore complex processes of diapause and overwintering which may impact resistance evolution as well as best practice for management.

**What are the key recommendations?**

We used insights from the models along with the comparison of RMP's for Bt crops in Australia and China to develop some key guidance for the Australian situation.

(1) *Monitoring should be continued* for the evolution of resistance alleles over space and time – this is the best way for early detection of any genes of biosecurity concern (see Fig. 2).

(2) *Current RMP strategies in Australia should be maintained*, noting that refuge strategies are likely to be equally effective if resistance is dominant rather than recessive. The interaction of refuges with a pyramid makes them much more effective, including when resistance is dominant. The suppression effect of un-mandated 'natural' refuges is important to consider.

(3) *Fitness costs cannot be assumed for dominant resistance* and may not be present or slow down the spread of the resistance gene throughout the landscape.

(4) *It is critical to understand existing cross-resistances and multiple-resistances* upon any new genes of biosecurity concerns being detected.

(5) *We need to estimate the between-season survivorship* of *H. armigera* in China and Australia, to inform the potential value of planting windows and pupae busting which are currently elements of the RMP that could be strengthened if required.

(6) *IPM compatible non-Bt control tactics should be considered* as control options for *Helicoverpa* spp. for managing any resistances to Bts.

# Early season bud retention and high yielding Bollgard® 3 cultivars in Australia

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Artificially-induced early season plant damage (leaf and flower bud removal) was studied by numerous researchers in the 1990s and early 2000s (Brook *et al.* 1992; Sadras and Fitt 1997; Lei and Gaff 2003; Wilson *et al.* 2003), who demonstrated full yield recovery with occasional minor delays for crop maturity. Since this research, cotton production in Australia has become reliant on Bt cultivars, which have virtually eliminated bud loss caused by *Helicoverpa* spp. larvae feeding but are ineffective on the mirid sucking pest *Creontiades dilutus*, that can frequent crops during squaring and flowering.

Australian yields have continued to increase with a recent with a 5 year average of 2483 kg ha$^{-1}$ for irrigated crops (Conaty and Constable 2020), with new cultivars and improved management accelerating yield gains threefold since the mid-1990s (Liu *et al.* 2013). The rapid fruit accumulation cycle of Bollgard II® cultivars enabled cotton production to prosper in shorter season, cooler environments and has been a significant factor in the industry expansion and ginnery construction in southern NSW over the past 15 years (Knight *et al.* 2021).

Previously many producers were willing to sustain 40-50% square loss during the earlier growth stages, however continuing industry expansion into climatically diverse regions coupled with increasing yield has led crop managers to question whether these guidelines informed by earlier research remain applicable.

We have been conducting simulated bud loss experiments to study growth, maturity, lint yield and quality impacts for high-yielding irrigated Bollgard® 3 cultivars grown under commercial conditions across multiple seasons and locations spanning subtropical central Queensland to cool temperate southern NSW.

Treatments have included damaging all buds from the first five sympodial (fruiting) branches prior to flowering, all buds from sympodia 6-10 just after first flower and an extreme treatment that incorporates both. Small pliers were used to bruise the buds and initiate a shedding response. Each experiment was located within large commercial cotton fields with no adjustments made to agronomic management.

Preliminary results suggest that the compensation ability of high yielding Bollgard® 3 varieties remains largely consistent with earlier studies, with little impact on yield, lint quality and crop maturity. Post-damage yield recovery primarily occurred via additional bolls borne in close proximity to the damaged reproductive positions.

When complete this work will be used to update industry pest management guidelines to assist crop managers to better target insecticide inputs for pests such as mirids and importantly avoid unnecessary early season usage, which is a key component of the integrated pest management of secondary pests such as mealybug, mites and whiteflies in Australia.

**Pliers used to 'pinch' the buds and initiate a shedding response.**

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# Benchmarking water productivity of Australian irrigated cotton – the latest results

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**Summary**

Improving water productivity is a high priority for Australian agriculture, especially given increased pressure on available water supplies. The water productivity indicator, the Gross Production Water Use Index (GPWUI), of Australian cotton has increased from an average of 0.60 bales/ML in 1997 to 1.22 bales/ML in 2021. The average GPWUI in 2021 was 30% higher than the maximum achieved in 1997, with the top 20% of growers achieving ≥1.41 bales/ML. The annual rate of GPWUI improvement was 9% between 1997 and 2007, however it has slowed to 0.6% since 2007.

The long-term average (2001—2021) water productivity of Australian cotton is 1.08 bales/ML. This is 2.25 times the 2011 global average of 0.48 bales/ML.

Australian cotton water sustainability indicators have improved significantly. The water used to produce one bale of cotton in 2021 was less than half the water used in 1997. The long-term average (2001—2021) water consumption in Australia was 0.93 ML/bale, which is less than half the global average of 2.07 ML/bale reported in 2011. Improvements in Australian water productivity are the result of increased yield, reduced water inputs and increased irrigation efficiency, during a period when rainfall is declining. There is potential for most growers to increase water productivity through improved water management and increased yield.

## Introduction

Demands for global freshwater are increasing to meet the growing need for food and fibre. Improving water productivity is a necessity, to reduce pressure on the limited freshwater resources. This is a high priority for Australian agriculture industries.

New South Wales (NSW) Department Primary Industries (DPI) is working with the Australian cotton industry to improve the productive and sustainable use of irrigation water. DPI, in partnership with the Cotton Research and Development Corporation has been assessing the water productivity of irrigated cotton since the 1990s. GPWUI is used as the benchmark, and the industry has a target of achieving an average GPWUI of 1.32 bales/ML by 2023.

**Methods**

DPI assessed the water productivity and irrigation use efficiency of Australian cotton farms for the 2019 and 2021[1] seasons. For 2021, we surveyed 31 irrigated cotton farms from across Australia's major cotton growing areas in Queensland and NSW. Collectively these farms produced 138,156 bales of cotton from an area of 11,748 ha, which represents 5.5% of the irrigated cotton produced in Australia in 2021.

Water productivity was assessed using the GPWUI which is the established method used in the Australian cotton industry. We have continued to use the average GPWUI as the industry benchmark to ensure a valid and consistent presentation of the long-term trends (Tennakoon and Milroy 2003; Williams and Montgomery 2008; Montgomery and Bray 2010; Roth *et al.* 2013; Montgomery *et al.* 2014).

We used grower records of water use to estimate the water balance for each farm, capturing all water inputs and outputs. This data was used to calculate water productivity and water sustainability indices, and irrigation efficiency metrics, as well as to assess sources and quantity of water loss. Details are provided below.

**Gross Production Water Use Index** (GPWUI) measures how productively water is used. It is the ratio of cotton yield (bales/ha) to all water potentially available for cotton crops (ML/ha) and is expressed as bales/ML (Equation 1). A bale is 227 kg of cotton lint.

**Equation 1.** $$GPWUI = \frac{cotton\ yield}{irrigation\ water + rainfall + soil\ moisture\ change}$$

[1] All years refer to the year the cotton was picked.

**Whole Farm Irrigation Efficiency** (WFIE) is a measure of how efficiently irrigation water is used (Tennakoon and Milroy 2003). WFIE reflects the proportion of irrigation water used by the crop relative to the total irrigation water on farm (Equation 2).

**Equation 2.** $$WFIE = \frac{crop\ water\ use\ - effective\ incrop\ rain - soil\ moisture\ change}{total\ irrigation\ water\ used\ on\ farm} \times 100$$

**The Water Sustainability Index** (WSI) indicates how much water is used per unit of product. For cotton it is expressed as ML/bale. A smaller index demonstrates more sustainable water use. This index has become increasingly important to cotton buyers and consumers seeking to ensure the product they are purchasing has been produced efficiently (CRDC and CA 2020a,b).

**Equation 3.** $$WSI = \frac{irrigation\ water + rainfall\ - \ soil\ moisture\ change}{cotton\ yield}$$

To enable comparisons with international data, we have excluded the soil water component in total water inputs in our Australian calculations.

**Results and Discussion**

**The average GPWUI of irrigated cotton has increased by 98% since 1997**

The average GPWUI of Australian cotton has increased from 0.60 bales/ML in 1997 to 1.19 bales/ML in 2018. It further increased to 1.22 bales/ML in 2021 (Figure 1), and is progressing towards the industry's 2023 target of 1.32 bales/ML. In 2021, GPWUI ranged from 0.79 to 1.61 bales/ML with the top 20% of growers achieving ≥1.41 bales/ML. This suggests that there is a potential for most Australian cotton growers to improve productivity by increasing yields and better water management

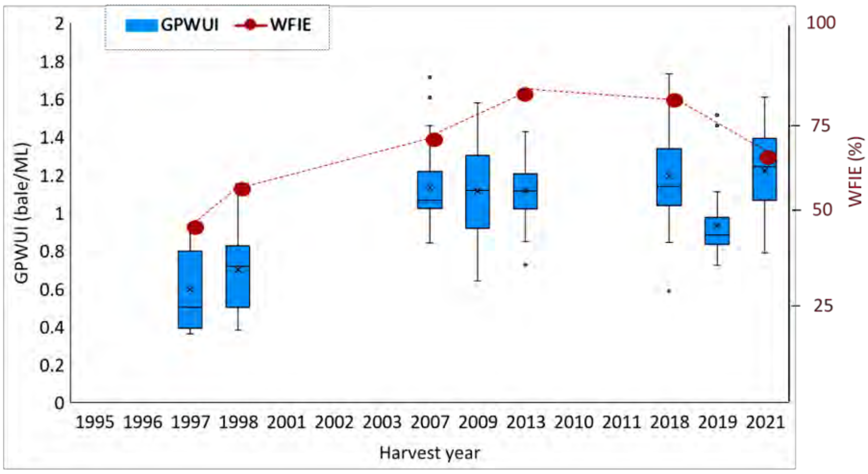


***Figure** 1. GPWUI and WFIE from 1997 to 2021 benchmarking: The blue boxes represent the distribution of GPWUI values in the harvest year the benchmarking occurred. The x in the centre of each blue box is the average GPWUI, the top of the blue box represents the water productivity obtained by the top 25% of growers. The red circles represent WFIE. Data prior to 2019 are redrawn from previous benchmarking[1].*

The annual rate of productivity improvement from 1997 to 2007 was 9% but has slowed since 2007 to less than 0.6%. The average GPWUI in 2021 was 30% higher than the maximum productivity achieved in 1997. These improvements in Australian cotton water productivity are the result of increased yield, reduced water inputs and increased irrigation efficiency during a period when rainfall is declining (Figure 2).

The water productivity achieved by the Australian cotton industry consistently exceeds the global average published in 2011[2]. The average GPWUI of Australian cotton for 2001 to 2010 was 0.97 bales/ML and for the 2011 to 2021 period it was 1.17 bales/ML. The average GPWUI for the whole 2001—2021 period is 1.08 bales/ML or 2.25 times the global average of 0.48 bales/ML equivalent (Mekonnen and Hoekstra 2011).

[2] The most recent publicly available global data on cotton lint water consumption was reported in 2011 (Mekonnen and Hoekstra 2011).

The average GPWUI dropped from 1.20 bales/ML in 2018 to 0.93 bales/ML in 2019 due to severe drought, greater irrigation water inputs and reduced yields (Figure 2). These drought conditions have affected the rate of long-term improvement in GPWUI, which shows the vulnerability of irrigated cotton to climate change.

**Irrigation efficiency (WFIE) has improved significantly but can decline in periods of high rainfall**

WFIE increased from 45% in 1997 to 81% in 2018 (Figure 1). However, 2021, which was a very wet year following severe drought, it fell back to 59%, due to increased evaporation and drainage losses that are inherent after prolonged dry periods (Figure 3).

Improved irrigation efficiency from 1997 to 2018 is attributed to reduced losses from storages and seepage (Figure 3), and improvement in irrigation infrastructure and management. WFIE declined from 81% in 2018 to 59% in 2021 which was associated with doubling of the seepage losses from 10% in 2011 to 20% (Figure 3) during the wetter than normal season of 2021 (Figure 2). Greater losses are probably the result of water being stored longer in dams and channels while growers capitalise on rainfall and soils are wetter for longer periods.

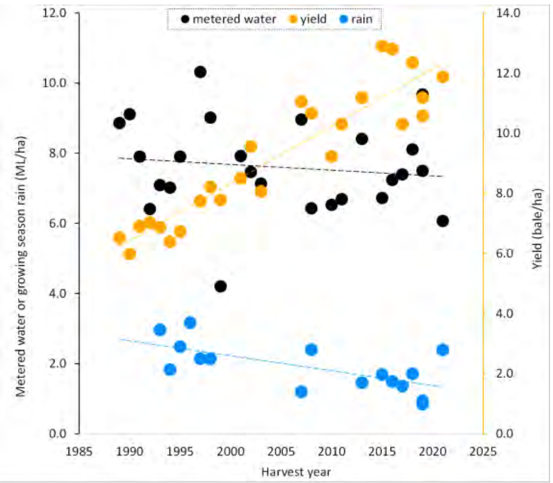


*Figure 2. Cotton yield, rainfall and irrigation water trends: The trend of rising cotton yields since the 1990s (the yellow dots) has occurred while total growing season rainfall (blue dots) and irrigation water use on farm (black dots) has been trending downwards. Data prior to 2019 are redrawn from previous benchmarking*[2]

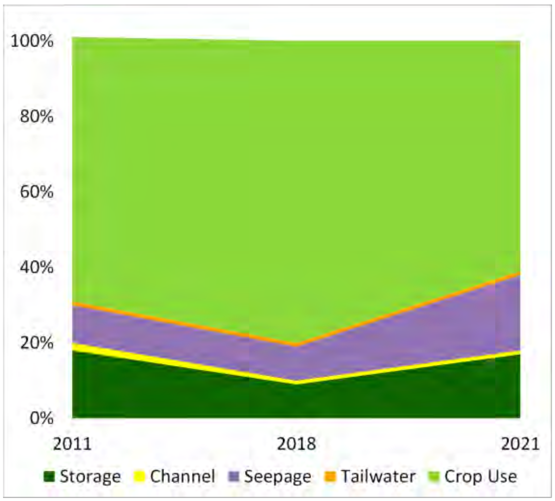


*Figure 3. The partitioning of irrigation water into crop use and various on farm losses from 2011, 2018 and in 2021: The proportion of seepage and storage losses doubled from 10% in 2018 to 20% in 2021. Data prior to 2019 are redrawn from previous benchmarking*[2]

**The Australian cotton industry demonstrates improvement in the sustainable water use indicator by consuming less water to produce each bale of cotton from 1997 to 2021**

The cotton water sustainability indicator for Australian cotton has improved significantly over the last 24 years. In 1997,1.54 ML of water was used to produce a bale of cotton, in 2021 this had fallen by 53% to 0.72 ML (Figure 4). Long-term water consumption in the Australian cotton industry averaged 0.93 ML/bale between 2002 and 2021, which is less than half the global average of 2.07 ML/bale (Mekonnen and Hoekstra 2011)[3].

Conclusion and future directions

The average water productivity for the Australian cotton industry for 2021 is 1.22 bales/ML, and it is approaching the 2023 industry target. Improvements in Australian water productivity and water sustainability indicators are the result of increased yield, reduced water inputs and increased irrigation efficiency, during a period when rainfall has generally declined.

Increasing water productivity continues to be a high priority for the Australian cotton industry and potential for improvement exists for most Australian cotton growers. DPI and CRDC will continue to benchmark cotton water productivity, including the benchmarking of water productivity in rain fed cotton systems.

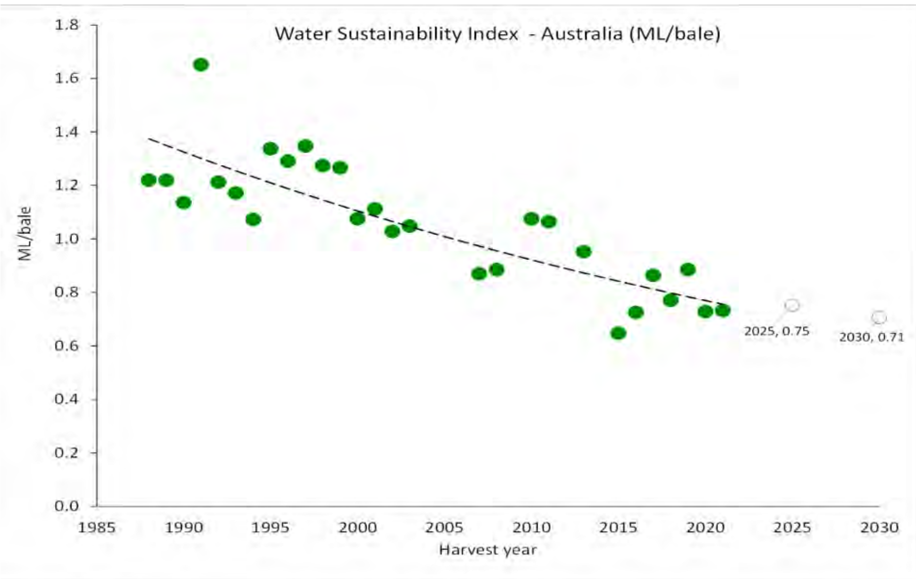


*Figure 4. Change in cotton water sustainability indicator in Australia 1985 to 2021: Data prior to 2019 are redrawn from previous benchmarking[2].Projected values for 2025 and 2030 are based on continuation of the current trend.*

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# Pesticide sustainability indicators for the Australian Cotton Industry

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## 1. Introduction

Sustainability targets are being proposed worldwide as a means for agricultural industries to reduce potential negative impacts of agricultural practice at regional to global scales (Smith et al., 2019). Many of the proposed sustainability targets quantify crop yields relative to off-site impacts including water use, land use or habitat destruction, fertilizer use or eutrophication potential, greenhouse gas emissions and human resources (Smith et al., 2019; Greer et al., 2020). At times pesticide mass is also used as an indicator (e.g., Devkota et al., 2019), but fewer sustainability targets include goals to reduce ecological and human health risks associated with pesticide use (Lynch et al, 2019). This is important because, unlike single target units such as water, N, P, $CO_2$-e, or energy, there is a huge diversity of pesticides in use across different agricultural industries. Because pesticides differ significantly in chemical and biological properties, reductions in pesticide mass do not necessarily equate to lower ecological or human risk and a collective appraisal of their sustainable use is therefore challenging.

Pesticide sustainability indicators are generally comprised of two factors representing pesticide exposure and toxicity. Some indicators also explicitly use additional measures of pesticide fate (e.g., leaching potential, bioaccumulation potential) as endpoints in their own right, or incorporated into the exposure factor. Depending on how these exposure and toxicity factors are formulated, the resulting indicators can be broadly classified into score-based indicators or exposure-toxicity ratio (ETR)-based indicators, hereafter referred to as ratio-based indicators.

In this work, we compared the widely-used, score-based indicator 'Environmental Impact Quotient' (EIQ; Kovach et al., 1992) to a ratio-based indicator called the Environmental Toxic Load (ETL) indicator (de Blécourt et al., 2010) for assessing the sustainability of pesticide use in the Australian cotton industry over the last two decades. Both methods have previously been used to determine the impacts of agronomic practice change on the hazards associated with pesticide use in the Australian Cotton Industry (Knox et al., 2006; de Blécourt et al., 2010). The EIQ can be compiled into a single score; but for the ETL, values are given for four different environmental compartments (terrestrial invertebrates, aquatic invertebrates, aquatic vertebrates, and aquatic plants) based on pesticide toxicity to bees, *Daphnia*, fish and algae, respectively.

## 2. Methods

Data on pesticide applications across the Australian cotton industry were obtained from Crop Consultants Australia (CCA), Australia. This data is obtained annually through a survey of cotton consultants, with a coverage of between 32-58% of the cotton area grown in Australia. Information on the volume/mass of each pesticide used was converted from the applied commercial formulation to the active ingredient. Note that this data did not include information on pesticides applied as seed treatments, for example, neonicotinoid insecticides.

EIQ values for individual pesticides were downloaded from the most recently updated database provided by Cornell University (via https://nysipm.cornell.edu/eiq/list-pesticide-active-ingredient-eiq-values/). In the case where EIQ values were not directly available for certain pesticide actives, these were calculated according to the method of Kovach et al. (1992). An industry-wide EIQ value (per ha) was then calculated for each year by multiplying the average industry-wide application rate for each active ingredient by its EIQ score, then summing the mass-weighted EIQ score for each active ingredient.

For ETL calculation, toxicity data were extracted directly from the previous ETL assessment document (de Blécourt et al., 2010) without modification. In most cases, the original source of these data was the Pesticide Properties Database (PPDB, University of Hertfordshire, UK; Lewis et al., 2016). Toxicity data that was not present in the original reference, including those for herbicides, defoliants and fungicides, was compiled directly from the PPDB (Lewis et al., 2016). The ETL indicator for each compartment was calculated separately as per methods provided in de Blécourt et al. (2010). The ETL is based on the total applied pesticide active ingredient (a.i.) amount per year (AIweight, kg per year), the active ingredient toxicity (T, i.e., L(E)C50 for algae, Daphnia or fish and the LD50 for bees), and the total cotton area (CottonArea, ha):

$$ETL = \sum_{AI} \frac{(AIweight/T)}{CottonArea}$$

## 3. Results and Discussion

Total insecticide use in the cotton industry declined from a 5-year average of 3740 g/ha during 2000-2004 to 352 g/ha during 2016-2020, representing a reduction of over 90% (Figure 3.1.3). Most of this (80%) occurred during the period 2000-2010. By contrast, herbicide use increased by 18% from 2850 g/ha during 2000-2004, to 3370 g/ha during 2016-2020. Accounting for both insecticides and herbicides, there was a total reduction of pesticide used (in kg/ha) during this period of 46%.

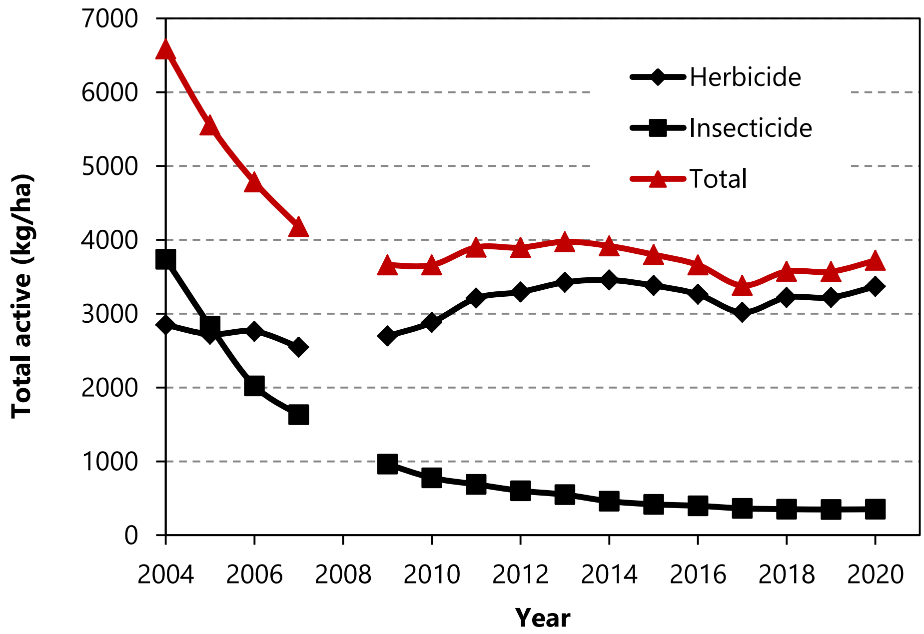


**Figure 1**. Mass of herbicide and insecticide used per ha in the Australian cotton industry from 2000-2020. Values are rolling averages for the previous 5 years (e.g., 2004 represents average use from 2000-2004). Total pesticide use is the sum of herbicide plus insecticide.

The total EIQ score for the Australian cotton industry was 61% lower in 2020 than in 2000 (Figure 2). This was mainly a result of decreasing EIQ scores for insecticides, which were 93% lower in 2020 than in 2000. The EIQ contribution from herbicides has remained reasonably static over this time period, with an 9% increase in herbicide EIQ over the period 2000-2021.

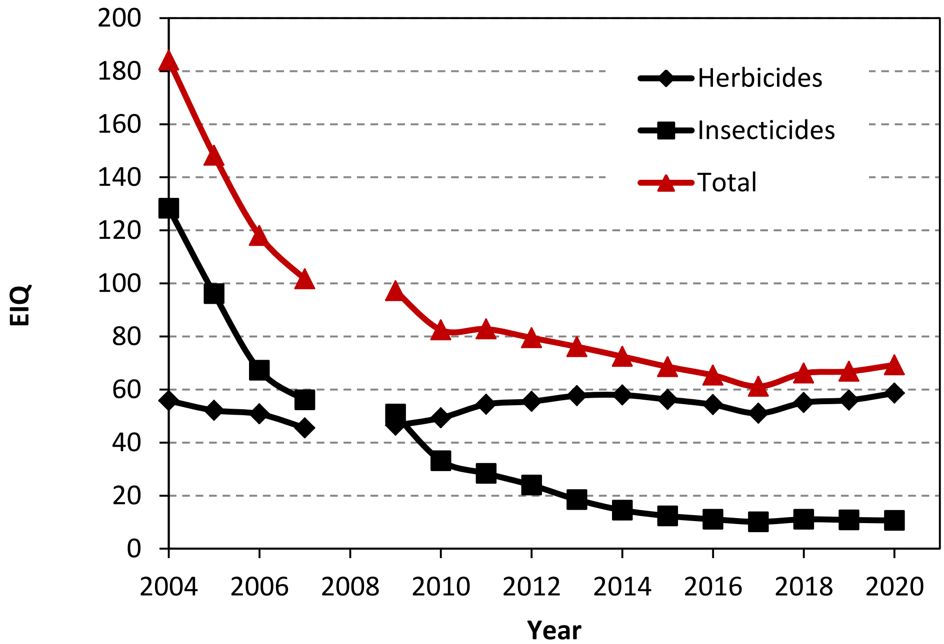


**Figure 2**. Change in EIQ for pesticide hazard in the Australian cotton industry from 2000-2020. Values are rolling averages for the previous 5 years (e.g., 2004 represents average use from 2000-2004).

In contrast, ETL scores in 2020 were < 70% of the 2020 scores, for compartments (Figure 3). Indeed, the ETL scores for bees, Daphnia and fish in 2020 were all < 90% of 2020 scores. The higher ETL scores for algae reflect the fact that the mass of herbicide actives in use in 2020 is not significantly lower than 2000 – but the relative toxicity of the herbicide being used towards algae has declined.

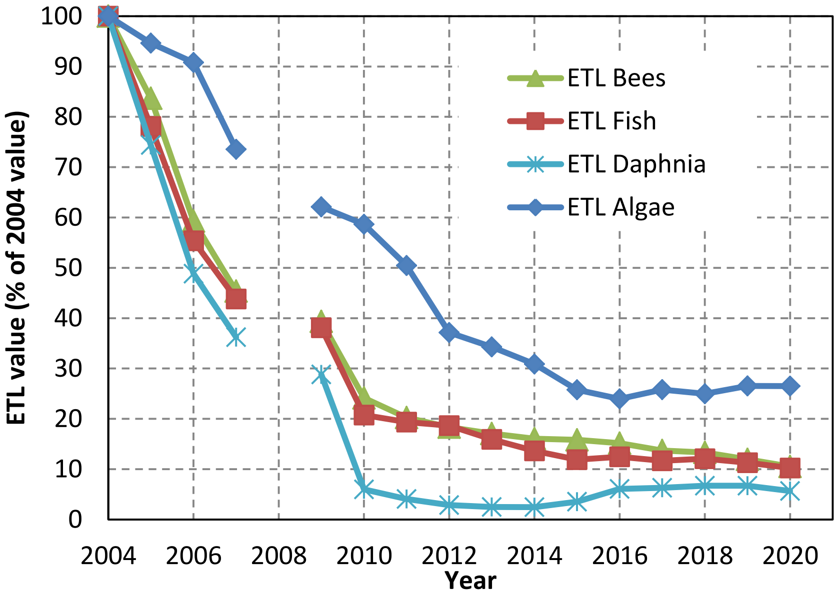


**Figure 3**. Change in ETL values for pesticide hazard in the Australian cotton industry from 2000-2020. Values are rolling averages for the previous 5 years (e.g., 2004 represents average use from 2000-2004).

## 4. Conclusions

The current analysis shows that over the 20 years prior to the 2020 cotton season, the total intensity of pesticide use (kg/ha) in the Australian cotton industry has dropped by ~46%. Concomitantly, the ecological hazard posed by pesticides used in the Australian Cotton Industry as measured by both score- and ETR-based indicators has markedly declined. That the EIQ and ETL indicators declined by 60-95% over this period indicates not only a reduction in total mass of pesticide in use, but also a shift away from pesticides with a higher non-target toxicity and/or exposure potential. The ETR-based indicators suggest an even greater reduction of specific hazard to fish, and aquatic and terrestrial invertebrates, by 75% or more. Overall, these sustainability indicators give complementary information about the magnitude and reason for changes in pesticide hazard over time. Continued monitoring is needed to ensure improvements in the sustainability of pesticide use are documented and maintained into the future.

## 5. Acknowledgements

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# Cotton Smallholders in Sudan Locally Innovate in Certified Seed Propagation: Taiyiba Agribusiness Success Story in the Gezira Scheme

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**Historical:**

Taiyiba was the first evolutionary step in the huge undertaking of the Gezira Scheme (now about 0.9m ha of irrigated land, in central Sudan and under single management): "Small pumping schemes were started at Taiyiba (1911-1912) and Barakat (1914-1915). On these experimental work, trial rotations, and the training of tenants (many of whom had come from Zeidab in Northern Sudan) was undertaken for a number of years. These experimental areas proved that cotton could be grown successfully in the Gezira and formed the nuclei for future expansion" (Tothill, 1948). This history dates back to the Anglo-Egyptian rule of Sudan, the very name of the Society, "Taiyiba" reveals an Egyptian connection and an early exposure of farmers to modernized farming methods is indicated here. Therefore, Taiyiba farmers are assumed more advantageous than in other parts of the Scheme in terms of civilization and a central location in the country.

**Gezira Scheme Act, 2005:**

The year 2005 witnessed in the Gezira Scheme a *new*, till now controversial act. Farmers were relieved of growing cotton compulsorily in the rotation, most of infrastructure were commercialized or sold including the famous Gezira Scheme's Seed Propagation Department: "The high quality of Sudanese cotton in earlier years was to a large extent the result of high quality seed. Maintenance, propagation and certification remained the joint responsibility of Sudan Gezira Board (SGB) and The Agricultural Research Corporation (ARC). Organizational changes in the Agricultural Administration of the SGB have resulted in the Seed propagation Department working on a commercial basis. The SGB can obviously not certify its own production" (WB, 2000).

Thus farmers in the Gezira resorted to Companies and commercial dealers (contract farming) to satisfy their demands from certified seeds. Cotton varieties grown in the Gezira include GM: Brazilian RR, Chinese 1 and an Indian hygiene etc. High risk was involved in this process. In one season a cheat dealer had sold seeds to a farmer as Indian Hygiene, but they did not grow. In this case the poor farmer had been compensated only for the seeds' cost! A farmers' leader said. In another case, a professional farmer claimed that Brazilian

RR seeds could not be grown by farmers in Sudan because of property rights of the owner! And the performance of these is known to be very high under *glyphosate*. Amidst such circumstances, given the stock of Indigenous Technical Knowledge (ITK) Taiyiba Society (at Block level: the Block was the administrative unit in the Gezira Scheme) had to locally innovate in seed propagation and certification. As had been said creativity was born of need!

**Methodology:**

This small case study was mainly based on social research methods, capitalizes on *field visits* for qualitative form of data tapped from *local leaders* (LL), *key informants* and used instruments:

- Personal interviews
- Established rapport
- Participant observation (PO)
- Social media: WhatsApp and SMS

**2018/2019 cotton season:**

In an interview (on 8.2.2020) with El tayeb Shopaly, a farmer leader said that the Taiyiba Society at Block Level was composed of 23 basic societies, at village level. The number of farmers in Taiyiba Society was1500. Of these 300 were cotton growers in season 2018/2019 and the area was 934.25 acres. In season 2019/2020 that area was halved for 150 farmers. The following table depicts the production cycle, propagation, certification and distribution of this locally innovated seed technology:

| Season | 2018/2019 |
|---|---|
| **Item** | Foundation Seed "Chinese 1" |
| **Source** | Chinese Factory, El-Rahad Scheme |
| **Area** | 830.5 Acres |
| **No. of farmers** | 300 |
| **Block** | Taiyiba |
| **Activities/Docs** | Seed Propagation Administration in the Federal Ministry of Agriculture: for rouging and cleaning |
| **GINNING** | |
| **Ginning type** | Rotary Ging |
| **Quantity** | 100 Tons |
| **Place** | Bagair |
| **Activities/Docs** | Chemical, physical and dusting by the Seeds Unit of Sudan Cotton Company in Maringan<br>National Biosafety Council |
| **Distribution** | Season 2019/2020 |
| **Places** | Taiyiba, Estrihna, Rahad Scheme |
| **Quantity** | 47 Tons |
| **Area** | 8131.5 Acres |
| **Distributer** | Fadase Society |

**Lessons learned:**

As a Sudanese saying goes: "He who forgets his past is lost" many lessons would be learned from this success story of Taiyiba Society. El Sheikh Mohamed El Tayeb Hamdoon (Key informant, 7.2.2020) says: "Wad Ballal (part of Taiyiba) Agribusiness Society membership is composed of all people in the village and their close relatives, brothers-in-law etc. The shares were collected for all and from all without exception of the poor by our younger generation in Khartoum". This reflected the existence of a unique social fabric in the villages on which to capitalize for formation of a farmer organization and a full-fledged agricultural cooperative society. This innovative organization is important for an operative and active agricultural extension system. Further, the earlier research activities by the British in Taiyiba for the expansion of the Scheme could be resumed for vertical expansion in cotton, given the locational advantage of Taiyiba in proximity of the Gezira Research Station and the University of Gezira and for a cooperative extension system. These experiences could be replicated elsewhere in the Gezira. Technical assistance from ICAC/ICRA is of paramount importance.

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