Cotton: (*Gossypium hirsitum* L.) (American Upland cotton)

Breeding desk top study – A short review.

Mathilda van der Westhuizen and Lawrence Malinga.

INTRODUCTION

Cotton is the fifth most important agricultural crop cultivated in South Africa (Areke 1999). In the cotton industry, various role-players have different requirements for cotton cultivars. The commercial farmer prefers a cultivar that is agronomically suitable to his cultural practices and that produces a top yield. Ginners needs a cultivar with a very high lint percentage (GOT), while the spinners main concern is quality. Furthermore, during the past decades, faster spinning technology increased the physical demands placed on cotton fibres and therefore stronger lint is required by the processors while other quality characters, grade and yield, must be maintained.

A cotton breeders main goal is to improve the performance of cotton plants. Therefore, improving its economic value by combining various desirable traits into a single plant. Improved performance is manifested in many ways. Higher yields of cotton plants contribute to more lint fibre production, more profitable agriculture and a lower cost of products for the consumer. Improved plant health increases the yield and quality of the plant and reduces the need for application of protective chemicals. Adapting cotton plants to a wider range of production areas achieves improved yield and vegetative growth. Improved plant uniformity enhances the farmer's ability to mechanically harvest cotton.

One relatively high negative correlation in cotton breeding is between fibre length and lint percentage (GOT). As lint percentage is also negatively correlated to fiber strength it follows that selection for lint percentage will automatically result in selections with shorter and weaker fibres. During the early and middle 1900's breeders in the USA and Africa (Empire Cotton Growing Corporation) did an admirable job in creating a multitude of *G hirsitum* cultivars adapted to varying environmental conditions. It is these cultivars that supply the basis for South Africa's breeding program.

EXECUTIVE SUMMARY

Cotton breeding research in South Africa always had high priority. The ARC-IC delivered much efforts into cotton breeding in South Africa and delivered two Ph.Ds. a MSc, a three-year contract with Arizona breeder Professor Niles, and numerous publications by well-known cotton breeders for example, Cornellison, Greef, Theron and Van Heerden (Table 1). These breeding programmes resulted in a magnitude of information on cotton breeding in South Africa. Cotton lines was bred with tolerance for drought, heat, short season cotton, lines with stronger fibre (Komati), as well as tolerance to nematodes, *Verticilium* and hairy cottons for Jassids. Three researchers from ARC-Vegetable and Ornamental Plants, namely de Ronde, van der Mescht and Cress screened up to six cotton cultivars for drought and heat shock proteins, to be able to identify tolerant cultivars.

Promoted by Professor van Deventer from the University of the Free-State, Dr Thomas Areke submitted a PHd on South African cotton germplasm and concluded as follows: Heterosis values calculated in this study were positive and relatively high and do justify studies on the possibility of a hybrid cotton breeding program. There was relatively high positive useful heterosis for SCYP (Seed cotton yield per plot). This would make hybrid cotton production beneficial and more especially, when the hybrids carry some genes for insect and disease resistance. For some characteristics, the location effects on the genotypes were extremely high indicating the specific adaptation needs of cotton. For the best response it would be worthwhile to split the F_2-germplasm into two groups and run two early generations programs simultaneously, one at Rustenburg and one at Loskop. If such a program is too costly, the breeder can delay the whole process until the breeding material reaches homozygosity before testing it for adaptation at different localities.

Priority should be given to evaluate introduced germplasm, both exotic and local, extensively for good performance and adaptability, and crossed with identified lines having good general combining abilities.

Table 1. Breeding related publications by ARC-IC researchers.

Title of publication	**Scientific Journal**	**Authors**
Katoenteling vir die benede Oranje Rivier. Fenotipiese korrelasies.	1975. *Agroplantae* 7,23-24.	C.G. Theron & W.H. van Staden.
The effect of planting date on length of season, seed cotton yields and broad sense heritability estimates of four irrigated cotton cultivars.	1983. *Crop Prod.*7,57-60.	A.I. Greef & J.J. Human.
Genotype and Genotype X Environment Interaction Comparisons in Upland Cotton Cultivar Evaluation.	1986. A PhD Dissertation.	A.I. Greef.
Release of cotton breeding lines (Gossypium hirsutum L.) adapted to South African conditions.	1987. *South African Journal of Plant and Soil*, 4:4, 203-205.	H. G. van Heerden , W. H. van Staden , L. J.B. Rossouw & C. G. Theron
The effect of date of planting on the fibre properties of four cotton cultivars grown under irrigation.	1988. *South African Journal of Plant and Soil*, 5:4, 167 – 172.	A.I Greef & J.J. Human
Comparison of cotton (Gossypium Hirsutum L.) yield and fibre properties over locations and seasons.	1988, *South African Journal of Plant and Soil*, 5:2, 75-78.	H. G. van Heerden , W. H. van Staden , G. Vink & H. van Ark (1988)
The effects of environment on the relationship between cotton fibre properties and yarn characteristics.	1990. *South African Journal of Plant and Soil*, 7:2, 131-135.	H. G. van Heerden , W. H. van Staden & H. van
Registration of cotton (Gossypium Hirsutum L.) cultivars Letaba, NIK2 and OR19.	1991. *South African Journal of Plant and Soil*, 8:2, 108-109.	H. G. van Heerden , W. H. van Staden , G. W. Schoeman , M. E. Stone & G. S.P. Vink
Drought-related protein synthesis in cotton.	1993. *South African Journal of Plant and Soil*, 10:1,50-51.	A van der Mescht & J.A de Ronde.

Heat-shock protein synthesis in cotton is cultivar dependant.	1993. *South African Journal of Plant and Soil*, 10:2,95-97.	J.A. de Ronde, A. van der Mescht & W.A. Cress.
Synthesis of heat-shock proteins in six cotton cultivars at different heat treatments.	1995. *South African Journal of Plant and Soil*, 12:4,177-179.	J.A. de Ronde & W.A Cress
Genotype-Environment interactions in short-season cotton.	1995. MSc Stellenbosch.	Helena de Kock
Genetic variability for yield and quality characteristics in South African Cotton Germplasm.	1999. A PHd Dissertation.	Thomas Areke

Table 2. Information on cultivars used in publications plus summarised recommendations.

Title	**Cultivars evaluated**
Greef & Human, 1988, The effect of date of planting on the fibre properties of four cotton cultivars grown under irrigation.	Albar 70C, Acala 1517-70, Albacala CS-2, DeltaPine 5826 • Strength range from 39.3 – 47.8 g/tex. • Fibre properties least affected when planted between 6 Oct and 3 Nov (Optimum planting time).
Van Heerden 1991. Registration of cotton (Gossypium Hirsutum L.) cultivars Letaba, NIK2 and OR19.	Letaba Nik2 OR19
Van der Mesch & de Ronde. Drought-related protein synthesis in cotton.	Lido, Delta Pine, Acala 1517-70, And OR3, had drought proteins. Selati and Letaba had no protein synthesis.
H De Kock, 1995. Genotype-Environment interactions in short-season cotton.	222-1 x 0125: (Niles), 3133-1-1; (Niles) 811603 (AubM x Ac1517-70) x DPL41; TCRI AET x (NCM x Alma); TCRI, 8163-7-79-2-1; (Niles) CA 3022; TCRI, Stoneville 1014; TCRI, Gamma x 7193; TCRI Gamma x CDP37HH;TCRI, PD 6520 x 77-WW-4;TCRI Molopo; TCRI, 2064-1-1; Niles, E x A4 x 17-18-1-1-1-1; TCRI Nebo x Vlakte 956; TCRI, Acala 1517-70 Standard (American).

	Overall, the trials have identified, Genotype 3133-1-1, ExA4x17-18-1-1-1-1 and 2064-1-1 as high yielding genotypes over all three localities and planting dates. Acala 1517-70 (standard) did intermediate. Another cultivar that performed in the LOG yield is CA3022 (TCRI) and 2064-1-1; (Niles).
T.E.E Areke, 1999. Genetic variability for yield and quality characteristics in South African Cotton Germplasm.	PHd research at Loskop and Rustenburg, 1997/1998 and 1998/1999. Parental lines 2131-2-5 and Palala had the highest mean lint yield. F1 Crosses that ranked the highest regarding lint yield were 2131-2-5xlR and 2131-2-5xPalala Palala and Sicala proved to be the best yielders at Rustenburg, while Irco yielded the best at Loskop. OR27 proved to be the best combiner for yield and most of the yield components at both Rustenburg and Loskop. Sicala proved to be the best general combiner for fibre length, and OR 27 the best for fibre strength and fibre uniformity at both localities. Other parents evaluated in the study were Irco, OR27, DPAc90, Sicala and 15 Crosses.
Cornelissen, APF. 2002.	Selection and breeding of cotton cultivars for the resourcepoor farmers. CottonSA. A journal to the cotton industry, Vol 5, p 24.
De Ronde & van der Mescht. Drought-related protein synthesis in cotton.	Lido, Selati, Letaba, DeltaPine, Acala 1517-79 and OR3. Selati and Letaba did not deliver drought related proteins.
Heat-shock protein synthesis in cotton is cultivar dependant.	Selati, NIK2, Letaba, Delta Pine Acala 90, Acala 1517-70, Acala OR3
De Ronde & van der Mesch. 1995. Synthesis of heat-shock proteins in six cotton cultivars at different heat treatments.	Selati unstable under different heat treatments. More stable were NIK2, Letaba, Delta Pine Acala 90.

TOBACCO AND COTTON RESEARCH INSTITUTE (TCRI). BREEDING PROJECTS.

Marthie Botha, Daleen du Plessis and Rudi van der Westhuizen

Nematode resistance and Short-Season cultivars. Long term objective of the nematode resistant breeding programme: The establishment of suitable cotton cultivars adopted according to agronomical requirements for specific cotton production areas. Due to tremendous population densities of Meloidogyne spp prevalent in the Vaalharts irrigation scheme. Forty hybrids were made using resistant sources and quality parents such as Tetra, OR26, OR27, Lambright x OR3 synthesis and Kariega. The F1 progeny has been planted at Rustenburg for self-pollination and seed multiplication.

Daleen du Plessis and Rudi van der Westhuizen: Progress in short-season cotton breeding. Short season cotton has many advantages:

1) Reduced cropping inputs
2) Early harvesting and residual disposal
3) Evasion of late-season inclement weather
4) *More uniform and favorable weather conditions during boll and fiber maturation
5) And more effective use of harvesting equipment and gins.

Helena de Kock, Dr van Heerden and Professor G.A. Niles (Short season expert from Arizona, US). A short season breeding program was started in 1986/87 at TCRI. The aim of the program was to develop early-maturing cultivars especially adapted to areas of South Africa where temperatures and/or moisture conditions shorten the effective growing season. This had to be achieved without loss of yield, GOT and fibre qualities. The breeding objective was early fruiting, early maturity, high fruiting efficiency, and acceptable yield, GOT and fibre qualities. To breed short season cotton, the pedigree method was used. That is suitable parents are crossed and single plant selections are made in the F2 to the F5 generations. The F6+ generations were genetically stable and were planted in in replicated trials at 5 localities. A line 2131-2-5, with a growing season of 120-125 days was developed. This line is much shorter than conventional cotton (growing season of 160 days from the time of planting to 60 % boll burst). 2131-2-5 also matures faster than Tetra which has a growing season of 150 days from the time of planting to 60% boll burst. This line, and others with acceptable short growing seasons, yields and fibre qualities will be used for new crosses. Selection criteria will become even more refined to include other characteristics such as nematode resistance.

Antoon Cornelissen and Letty Masemola

Jassid resistance. Selecting plants from a registered cultivar shortened the time required to stabilize the genome, so that cultivar status can be attained and a new cultivar registered for the farmers in a shorter time span. He started a breeding program to transfer the red-leaf, Okra-leaf, Frego-bract and hairiness traits into a new cultivar at Rustenburg. Ten selected hairy lines were hybridized with a high-GOT-line in order to form a new base with this trait. Sabie – drought tolerant. – Selecting for drought tolerance remains a very sensitive procedure which must be undertaken very cautiously.

Table 3. Lines bred by ARC-IC plus some USA and Australian commercial cultivars used as standards.

Line	Selected from	Trait + info
Letaba	Pedigree selection from the cross DC/Br100//AET/G2.1-17-904/3/Reba B50. 1988. (A dryland cultivar).	DC/ Br100 as a line, as well as AET, was supplied in 1970 by G.A. Niles, Texas A & M University, U.S.A. The two other parents, G2.1-17-904 and Reba B50, were both African introductions. DC/Br100 was combined with AET/G2.1-17-904 when the latter combination was in the fifth generation. The combination DC/Br100//AET/G2.1-17-904 was subjected to pedigree selection and in the fifth generation crossed to Reba B50. The latter parent was used in an attempt to simultaneously improve fibre tenacity and yield. Subsequent selection of progenies out of this cross was aimed at maintaining and purifying two distinct plant types, each with its own characteristics.
Selati	Was registered in 1985 (van Heerden, van Staden, Rossouw &Theron 1987.	The differences between Selati and Letaba include a shorter plant type in the case of Letaba with a higher fiber tenacity and a lower lint percentage**. Letaba's main advantage is its ability to produce above average yields over a wide**

		range of environmental conditions. Conditions range from arid regions in the Western Cape to those of the cloudy summer rainfall area in the east of the country.
Acala 1517-70	American cultivar developed in New-Mexico.	Generally, the standard used to compare local cultivars. Letaba is shorter in height than Acala 1517-70 with an equal boll size and larger leaves. Letaba produces fiber superior in length and lower in tenacity than that of Acala 1517-70. Letaba produces slightly finer fiber than Acala 1517-70. Acala 1517-70 requires a season of medium length, is fairly determinate in growth habit and has good medium staple fibre, and it is known for its exceptional fiber strength.
NIK 2	Cross between AET/G2.1-17-904// Reba B50. The combination AET/G2.1-17-904 was registered as cultivar Nebo in 1983	Nebo gave excellent yields combined with good fiber length, but it lacked fiber tenacity. Combining Nebo with Reba 50, followed by pedigree selection, increased fiber tenacity but in the process lint percentage was reduced significantly. NIK 2 showed increased yield and fibre length under irrigation compared to Acala 1517-70 but NIK2 is lower in lint percentage and fiber tenacity. Plant height and boll size are comparable than those of Acala 1517-70 and it shows a tendency to shed its leaves at maturity which benefits harvesting.
OR-19	Lines developed out of Acala SJ-l/Cape Acala//Del Cerro and Acala 4-42/3/Cape Acala/Albar//SJ-1 were crossed and further developed through pedigree selection. 1988	In the 1960's local selections from New Mexico material, such as Cape Acala, were grown at Upington and the breeding approach centered on combinations of New Mexico introductions and African types like the Albars. These combinations failed to break certain negative associations amongst yield and fibre properties (Theron & van Staden 1975) or to solve the ever-increasing problems with Verticillium dahliae. The red leaf disorder presented a problem which also could not be solved with these combinations.
OR-3	A selection from California Acala SJ-1.1976	OR3 was released for commercial production in 1976 in the Upington area and materials from California became the

		main donors to the breeding program at Upington. OR 19 is one of several lines developed as possible alternatives to OR3. OR19 has the same level as resistance to Verticilium Wilt as OR3 and is more tolerant to the red leaf disorder. OR19 is more stable in yield than OR3. OR19 is shorter in plant height with smaller bolls than OR3. Leaves are cupped, smaller and more pilose than those of OR3.
Sabie	A complex cross between Carolina Queen, Loco B5160, Acala SJ-1 and NM Acala 30. 1996.	Tolerance of Verticilium wilt in Marble hall and Lower Orange River: Good drought tolerance. Lonrho held license
Komati	A complex cross between AET, G2.1/17/904. Loco B5160 and Acala SK-1. 1997	Best adapted to the Northern Cape areas, of Vaalharts and Rietrivier. Exceptionally strong fibre.
OR-25	An even more complex cross between Deltapine Acala 90, Del. Cerro 169, BR100, AET, G2.1/17/904 and Reba B50. 1997	Best adapted to the Northern Cape areas of Vaalharts and Rietrivier.
OR27	Elite line	Fairly or normal hairy line with big bolls.
Palala	A cross between Acala OR3, Del Cerro, Caroline Queen, Loco B5160 and Acala SJ-1.	Hairy insect resistant cultivar for small scale farmers in Makhathini. Large round bolls. Harvest by hand. Fibre does not drop out easily. Is susceptible to Verticillium dahliae and bacterial boll rot. Palala is moderately tolerant of angular leaf spot. Areke, 1999, summarized Palala as having the same pedigree than Marico, but differ in the level of hairiness. Marico was developed as a smooth variety, but Palala was developed from a single plant for its hairiness, giving Palala an added genetic advantage over Marico, for resistance to

		Jassids. Palala is comparatively a high yielder with satisfactory fibre characteristics.
Gamka	1997/98.	Planted at Weipe, Yielded 4488 kg/ha micronaire 4.5.
Irco		This accession was obtained from West Africa. It is very hairy and was used in the crossing program aimed at improving resistance of other breeding lines to Jassids. This accession is also supposed to have a high ginning out turn.
Gariep Vertol 1 and 2	1995/96.	*Jassid resitance* *Hairy trait*
2131-2-5	Elite Line.	Short season (120 – 125 days). Areke summarized this line in 1999 as developed for short rain season areas. Normal hairy line with reasonably good yield and fibre quality characters.
Marico	TCRI	Smooth cotton breeding line
Sicala	Commercial variety.	Developed by Australia, Clark Cotton. Smooth variety and produces good yields and good quality characteristics.
DPAc90 Deltapine 5826	Old commercial cultivar.	Developed in USA and released for excellent fibre strength and yield potential. Short-statured plants with relatively small bolls. GOT is high. Smooth type. DeltaPine 5826 was an American cultivar used by Dr Greef in his PhD study, but had lower fibre strengths than the other cultivars.
Beta, Gamma and Tetra	Bred at Oudestad Research Station.	Beta weaker fibre thab Acala 1517-70. Gamma had the best fibre of all cultivars. Tetra – medium staple category
Vlakte	Bred by Department of Agriculture.	Requires long growing season and has medium staple fibre.

Table 4. Research (2019/2020) and recommendations for the 2020/2021 season.

2019 Research	Lines	Proposed 2020/2021 Research
Six lines were planted in a **glasshouse trial** at ARC-IC in December 2019, initially to test nematode tolerance, and proved to be drought tolerant.	OR20 OR27 Line 1018 Line 1072 Line 1710 Tetra	100 gram of seed of nematode tolerant cultivars should be send to a Douglas farmer to plant in his heavily nematode infested soils, as these lines were identified by breeders as Nematode tolerant.
Seven cultivars were planted in a small **field** block, unfortunately at the border of a field with a Potassium deficiency that resulted in weak fibres. See fibre qualities in Table 5.	Sicot 74 OR20 OR27 Line 1018 Line 1072 Line 1710 Tetra	Plant a germplasm screening trial at Loskop and Rustenburg with eleven cultivars namely, Sabie and Letaba (bred for Drought tolerance), Sicot 74 as standard, Komati (Strong fibre), Line 2131/5/2 (Short season) and Lines with potential drought tolerance (OR27, 1072, 1710, and Tetra, Gariep 1 and Gariep 2).

Table 5. Fibre properties of seven cultivars at Rustenburg ARC-IC, 2019/2020

Line	GOT %	Length	Uniformity	Strength	SFI	Micronaire	SCI
1018	38,5	1,01	81,3	25,6	8,9	5,2	98
1072	40,0	1	83,8	25,8	5,7	5	115
1710	36,1	1,05	84	25,9	6,1	4,7	119
OR20	39,0	0,99	81,8	26,6	8,3	5	106
OR27	41,0	1,05	82,7	27,1	5,7	5,2	111
Sicot 74	48,6	1,07	81,6	24	9,1	4,9	101
TETRA	39,6	1,02	82,4	26,6	6,8	4,8	112

INTERNATIONAL COTTON BREEDING

AUSTRALIA

Bange *et al* 2016, reports on genetic improvement and cotton physiology and found that cultivar choice is a strong component of realizing both target yield and fibre quality levels. A delicate balance needs to be resolved between yield, fibre quality, price and other important considerations such as disease, insect and herbicide resistance. For cotton breeders, delivering commercially available high-yielding cultivars to cotton growers remains a necessity, such that cotton systems remain economically viable. High selection pressure on yield remains a successful means to capture tolerance to both abiotic and biotic stress. Amongst records of improving yields across region there is also evidence that this approach has been successful in generating tolerance in high-yielding cotton cultivars for abiotic for abiotic stress. Specific tolerances for heat (Constable *et al*., 2001; Bibi *et al*., 2008; Cottee *et al*., 2010) and water stress in rain fed environments (Stiller *et al*., 2005) have been recorded despite no specific selection pressure on these stresses. Genetic of transpiration responses to vapour pressure deficits (VPD) have been established for soybean (Glycine max (L.) Merr.) (Sadok and Sinclair, 2009) and it was found that a particular genotype could limit transpiration rate at high VPD and approach wilting point slowly, when under water stress. This warrants more attention in cotton systems that are water limited (Bange *et al*., 2016?)

The Australian Cotton Breeding Program can serve as a very good example of breeding for local South African conditions. In the early 1960's only American-bred cultivars were planted in Australia. After the Australians have established a local breeding program at the demand and with the full support of their cotton industry, Australian-bred cultivars probably comprise more than 95% of the market share. These well- adapted locally bred cultivars probably contribute tremendously to the fact that Australia prides itself on the highest average cotton yields in the world. Problems with low micronaires: Micronaire value is a combined measurement of fibre fineness and maturity: The real problem is not the micronaire value as such but the maturity, which results in weak fibres. In this respect, a cultivar like Komati, with an exceptionally strong fibre, will have a definite advantage (Chris Theron).

USA

Zeng *et al*., 2018 summarized that in the last century, cotton breeders in the US have mainly focused on selecting for high yield and early maturity under the impact of the boll weevil (*Anthonomus grandis* Boh.). Selection for high fibre quality was once a less important objective in cotton breeding. With the transition of the US cotton industry from a domestic consumer to a major exporter of raw fibres into the global market and the technology advancements in the textile industry since the 1990s, the need for high fibre quality cotton has increased. In recent years, genetic improvement in cultivars for insect resistance, disease resistance, and abiotic stress tolerance has become important for maintaining cotton yield. Under strong competition from other major crops, increasing profit in cotton production has become an urgent task for cotton breeders and increasing economic potential in cottonseed and other economic traits can help promote profits for cotton growers.

Progress that US obtained (Zheng *et al*., 2018) is the reduction of negative associations between yield and fibre quality, Meredith (1977) has shown that the negative association between lint yield and fibre strength can be reduced through introgression of exotic germplasm into Upland cotton.

CHINA

YU *et al*., 2016, reported that cotton is an important economic crop in China with 20 million farmers producing cotton. Yield is the most important trait on the premise of the comprehensive development of other traits, so high yield is the most important goal of cotton planting. From 1950 to 2015, the cotton yield per unit area in China was increased by more than 9 times, and the introduction and improvement of varieties have made a great contribution to the increase of cotton yield. In recent years, the improvement of cotton yield per unit area was slow because of the narrow genetic diversity, seriously hindering the development of cotton industry. Cotton yield per unit area contains four major components, stock number per unit area, boll number per plant, single boll weight and lint percentage. Boll number per plant and lint percentage are more important for the cotton yield breeding, but the improvement of cotton yield is a complex progress which need every trait coordinated properly. Germplasm introduction has played an important role in raising cotton yield and replaced the Gossypium arboreum varieties of lower productivity and poor quality in China, and promoting the development of cotton breeding in China.

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