Cotton: Breeding for efficiency

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ABSTRACT

Cotton is a crop that lends itself to breeding for efficiency. It is a bulky commodity from the field and the difference in value between the primary product lint and the secondary product fuzzy seed is usually ten times or more in favour of the former. Capital investment in gins that separate the two products is expensive and the bulky seed cotton often has to be moved vast distances to be processed. It makes sense then that in as many respects as possible the cotton products are as valuable as possible and have the least cost associated with their production. Breeding for efficiency is of paramount importance to the cotton industry under increasing threat from competing man-made and other vegetable and animal fibers, from environmental concerns (especially the effect of pesticides on the environment and the use of scarce water resources to grow the crop) and the often negative impact of cotton production itself directly upon the land in which it is grown. On the positive side, cotton is a totally renewable resource, relying primarily upon human endeavour, rainfall and available nutrients to convert sunshine and heat energy into the lint and seed. Lint is almost totally cellulosic in composition and is therefore totally biodegradable in time. Seed contains significant levels of vegetable oil, proteins and minerals that make it an invaluable source of a huge range of secondary products from unimproved dairy feed to cooking oil, margarine, cattle feedstuff, soap and even explosives. Improving the proportion of the fiber in the seed cotton, the oil and protein content of the seed and increasing the length, strength, maturity, elongation and other parameters of the fiber itself make the products that much more valuable to downstream processors. The breeder can alter all of these characteristics. Being able to guarantee them from season to season is even more valuable still. For the farmers who grow the crop and in many cases rely almost totally upon cotton to give them a chance of improved lifestyles, the breeding efficiency bred into the cultivars available will determine whether or not they can successfully grow cotton in a sustainable manner. All too often improvements in one respect can result in another problem surfacing as the next major threat. Today breeders face the challenge of marrying new technologies such as genetic engineering or highly efficient seed treatments with the best available germplasm for particular environments. For the breeder of the future a compromise between the lure of the new technology and the steadfastness of tried and tested methods will be the greatest challenge of all. There is no doubt that a wide genetic base and its efficient exploitation is essential to the sustainability of cotton's production and to secure its markets. Efficiency built into seed through breeding is the most useful improvement that can be made in the production chain especially when coupled with other technologies that ensure better production practices and output.

Introduction

Crops and animals have been bred for many thousands of years, gradually adapted from wild landraces by men and women who converted from the hunter-gatherer role of our forebears to the settled populations that now dominate the globe. With settlement came the need to secure grain, vegetables, fruit, livestock, building materials and fibers for textiles to clothe, house and manufacture an increasing array of consumer-friendly accoutrements for an ever more demanding public.

Cotton is no different from any other crop in this respect and the modern high yielding, six to seven month old, pip-to-poplin wonder we know today bears almost no resemblance to its increasingly rare, but perennial wild races. Cotton today follows us through life and if our most intimate parts have been kept warm or cool as required we can conceive new-borns. Hopefully one at a time but individual breeding efficiencies determine the actual rate. They will be cosseted in wonderfully absorbent cottons that thwart their most determined efforts to be permanently soggy. This is followed by the same cotton providing protection from the elements for the growing children, often providing the only blanket of security as they enter the confusion of adolescence when they promptly throw out all vestiges of 21st century civilization except their torn cotton jeans, tattered t-shirts and holey underwear and socks if the rebellion is not too severe. It allows them to safely brave the fierce African or Australasian sun, the terrifyingly cold northern winters, the ravages of war, the complacency of peacetime, to work, stumble through parenthood and middle age. They earn money made out of cotton fibers too short too clothe any but the visage of some long dead president or prince, they eat oils and fats that are polyunsaturated and can even eat bread and cookies made out of cotton cake. As they age their cotton clothes shrink with them. Inevitably they die, mourned by relatives and friends dressed in cottons dyed black with sorrow, and are clad once again in a cotton shroud to return to dust once again.

This then is the huge mantle of responsibility that the cotton breeder assumes when he/she steps into a field to make his first sexual assault on the cotton family. The parental lines must be chosen carefully, pedigree is all important, past performance is only just acceptable in some attributes but for most others the demands on the devoted breeder are to make dramatic improvements in output from field yield, to seed size and vigor, tolerance to nutrient imbalances, plant structure, determinacy, fruit retention, drought tolerance, earliness, storm proof but big bolls, locule tenacity (and only five locules will do), pest and disease resistance, pickability, lint out-turn, fiber attachment, fiber length, uniformity, bundle strength, maturity, elongation, fineness, short fiber content, stickiness, yellowness, reflectance, micronaire values, seed coat attachment, spinnability, dye affinity, oil and protein content. You name it, someone, somewhere usually wants something done to the current cultivar that requires painstaking work developing the segregating population, screening it for every ailment imaginable, checking performance of thousands of individual plants for every measure of efficiency and then testing the top performing lines in as wide a range of environmental conditions as possible. And nobody told the fresh new breeder itching to pounce upon and emasculate every second cotton plant that he sees and dust the exposed stigma with pollen gathered from rampant male plants, (that incidentally never breed true to phenotype), that the whole process may take a decade or more! And by the time the new variety is unleashed upon the unsuspecting world a new pest or challenge is top of the agenda.

Which is why breeding for efficiency is the most important activity in the whole cotton industry. A mistake today can take years to clear out of the system. However, careful planning and attention to detail and an on-form crystal ball results in unimaginable efficiencies. Efficiencies that literally spin a better yarn, crush a better oil and make a more nutritious cake.

The production chain

Before dealing with the specifics of breeding for efficiency, I must lay out the ground rules for things to work. The best breeding in the world is not going to make up for poor agronomy, pest management and processing practices. Even worse, bad seed will kill any efficiencies gained elsewhere. Bad seed usually comes when the grower is given it free, there is no properly managed certification system and there is no suitable conditioning and treating system in place.

Unsustainable practices can undo the lifetime work of a breeder in one or two seasons. Unfortunately, when things do not work out in the field, it is always the variety to blame first and foremost. There are always varieties available to other farmers elsewhere in the world that yield much more than the one the farmer is growing. Why can't our breeders get that variety here? Now.

In Zimbabwe, we firmly believe in a production chain that is properly managed from the bottom up. Our growers pay for seed. They get seed of the highest quality and they have the option to have further value added through seed treatments such as Cruiser and Gaucho. Any improvement that can be done through seed is worth pursuing. Which is why the development of genetically engineered traits is so exciting for a cotton industry based upon smallholder farmers.

Seed treatments take some of the guesswork away from the farmer and will free up his time to concentrate on weed control when it is most critical during the early stages of the crop. In Zimbabwe we do not like spraying pesticides with gay abandon over the crop. Scouting, economic thresholds and targeting the pest when most vulnerable are key to using low dosage rates that preclude the development of resistance. Key pesticides are only made available to farmers during the correct windows. Some pesticides are rotated from season to season in different areas.

We take risks with supplying inputs on credit to the farmers, because without credit they would grow cotton in an unsustainable manner. We recover our credit because everything must be done on a sustainable basis.

Good farmers will conserve moisture from one season to the next, rotate crops, plant early, use appropriate fertilizers, mulch and use other techniques to conserve the soil, keep their crops weed-free and harvest the open bolls as they ripen. Above all they do not contaminate their cotton with polypropylene fibers. The best breeding in the world will not help any farmer who wants to self-destruct by giving customers what they don't want.

We believe in a dead season when no cotton is growing. In legislated earliest planting and latest destruction dates. These hygiene practices keep re-infection levels of pests and diseases to minimal levels.

As an industry, we pay for quality and then measure and monitor it all the way through the production chain to supply the customer with exactly what he wants. We gin carefully seed cotton that has been carefully segregated by grade, variety and even quality attributes. Every single bale is individually classed and we use the most modern HVI machinery available.

These are the kinds of farmers and industries that can unlock the potential of varieties that have been efficiently bred.

Germplasm

Efficiencies start with the genetic material to start the whole process, whether simple crosses between complimentary parental lines, to complex three, four or wider combinations, or variable but adapted populations developed with specific objectives in mind. This is probably the biggest single limiting factor in most developing countries in particular. It undoubtedly limits the ability of many enthusiastic breeders from making a technological step up to the next level for some key attributes such as yield and fiber quality. And it is becoming a bigger problem in the first world as seed companies jealously guard their material from predatory competitors. I'll come back to this later.

Today we have techniques that can ensure we know for certain if a variety is resistant to a particular pest or disease, or even to a race of a disease like bacterial blight, once a major scourge of production in Africa in particular. Today there is no excuse for a reputable breeding program to allow a variety to be grown commercially that is susceptible to any of the common races of blight. Inoculant is easily prepared and the techniques for efficient screening and evaluation are well documented, tried and tested.

Similarly, the ravages of the devastating jassid sucking pest (Empoasca devastans) can be easily avoided by screening for sufficient under-leaf hair to provide a physical barrier to the pest's somewhat mechanical mouthparts. In Zimbabwe, we are very proud of the techniques we have developed to efficiently screen all our breeding material for resistance to the jassid. It involves growing the desired material in amongst check rows of highly susceptible smooth leaf cottons and/or of the cowpea, an alternative, but very juicy host. The screening plots are planted late, after the commencement of the rains, when populations of jassids have had the chance to develop on their numerous wild hosts. Once the jassid is well established on the cowpeas they are uprooted and the highly mobile pests migrate onto the cotton and dramatic damage takes place on all susceptible, smooth-leafed plants. Scoring is easy and 100% effective. Those of you who have bred the hairiness out of cotton to meet the needs of mechanical harvesters have switched one form of efficiency for another. However you are betraying the very name of our crop, for where would *Gossypium* be without *hirsutum*? A family without honor I am afraid.

In our own country the benefits annually of utilizing jassid resistant cultivars is huge. At least two sprays of the environmentally unfriendly organophosphate pesticide are saved. Spraying for one pest invariably brings on another problem so the knock-on effect of not spraying at all will be even greater. It keeps the road to truly integrated pest management wide open instead of closing it permanently shut.

Fiber attributes

The same screening efficiencies apply to many of the quality attributes associated with desirable cottons. Fortunately, there is also a wide range of suitable parental material available suited to most environments where simple breeding techniques can dramatically improve the characteristics of the cotton crops grown. By using mini-gins, scales, and HVI and individual fiber testing technologies, large numbers of single plant selections and early generation strains and lines, grown over a wide range of environments, can be screened for directly marketable attributes. Again there is no excuse for a variety to be released that does not meet certain minimum criteria for important attributes such as boll mass, seed size, lint out-turn and a range of fiber quality characteristics. These translate directly into picking, planting, processing and end-use efficiencies respectively. However too often, new cultivars are released that fall short of the mark for one reason or another. Ruthless screening at the single plant stage is at least part of the answer.

In Zimbabwe, a commitment to improve the lint out turn over the last twenty years has seen commercial gin results improve from 35% to the current average of about 41%. On a 300 000 ton seed cotton crop this translates into an increased annual lint output of 18 000 tonnes. This is worth nearly US$24 million each year to an economy hard-pressed to generate foreign exchange. Similar success stories in processing efficiency are common throughout Francophone Africa where the efforts of CIRAD working with local breeding programs have resulted in a stream of higher-yielding, improved lint out-turn and better quality varieties.

To truly measure the consumer friendliness of cotton's primary product I am afraid that the future calls for investment in micro-spinning testing technology so that the end use performance of the fiber can be measured and evaluated before a country or a company takes the step of releasing a variety that falls short in mill performance. Customers are just not prepared to put up with sub standard performance and the world of custom built man made fibers of frightening uniformity looms threateningly over our industry.

Which raises the question exactly what do customers want and what can breeders provide? The breeder can certainly give the farmer cultivars that are adapted to a range of environmental conditions, pest and disease resistance and fiber quality ranges. This can be done in plants that have normal or okra leaves, which can be smooth or hairy, normal or frego bracts, small or large bolls, tall and indeterminate growth or short, early and very determinate ones and many other things besides. But, we cannot give the farmer what he really wants from cotton- a plant that has a single huge boll like a maize cob or a sunflower head that he can combine harvest wet or dry and that grows on a crop that takes only four months to maturity and ripens the week after the rain stops and always gets the top grade. But maybe the biotechnologist can and will and if they do the breeders had better have done their homework.

The breeder can give the ginner a variety that has higher fiber content on smaller seeds more often than not but rarely on larger ones. Fibre attachment is a big unknown however and I believe there is merit in examining this aspect from the viewpoint: If cotton only had slick seeds with virtually no fiber attachment tenacity, could ginning be done easier, with less aggressive technology that does not tear and tangle up this wonderful fiber? Would ginneries have been developed at all or might we have seen cotton fibers teased off the seed with gentle air blast technologies to give products better suited to the end-user? Would cotton not then automatically be more attractive than it is today compared to its most feared competitors? The ginner would also like cotton that is not tangled up with leaf trash and that does not have any seed coat tip or chalazal cap that comes off with the fiber. The cotton must not develop neps during the aggressive ginning process and yet its ability to twist and intertwine and its tenacity in doing so will be its main selling point to the end-user!

For the spinner, breeding can do many things but in all honesty, I do not think that we will deliver, from pure breeding alone, a cotton plant that has seeds with fibers all perfectly matched in length, strength and other attributes. It is a tempting thought though. Incremental improvements in overall length, in uniformity ratios and reduction in short fiber content will all work to make cotton more marketable. We may not meet the spinner's expectations with regard to fiber strength, elasticity, fineness and maturity, but for sure, any improvements in these will strengthen our hand. Once again, the primary germplasm pool into which we delve in search of improvements is the key here. The message to the spinner of course should be to clearly identify what attributes you really want and then pay premiums for cottons that have them discount mediocrity but reward excellence.

Seed attributes

I come from a country where at least 75% of the vegetable oil requirements of the nation will be supplied from the secondary product of the ginning process, fuzzy cottonseed. In thirty years of working in this industry at the end where we could make a difference to the composition of cotton seed, it still amazes me that I have never had a single approach from an oil expressor nor from a cattle feedstuff manufacturer to see whether improvements could be made to the oil percentage or protein content. So they remain much as they were thirty years ago. A lasting tribute to industrial inefficiency in a sellers market where all oil and all protein will be sold.

Farmers like big seeds, so we have given them big seeded varieties. Ginners like high fiber out-turns which usually come associated with small seeds. Small seeds are a problem to ginners because they go through the ribs and get mixed up with the fiber and this really annoys the spinner. With breeding we have given ginners big seeds but with high out-turns. This is breeding efficiency at its very best.

Regional germplasm pools

It is unfortunate that cotton does not enjoy on a global scale the resources that are available to grains and other crops through organizations such as CIMMYT and ICRISAT. Great work has been and continues to be done by organisations such as CIRAD, universities and state-run institutions in many parts of the world. Many are extremely generous with access to their germplasm and we thank all breeders from all corners of the world who have shared even a single pip with another breeder. Certainly here in Africa we would be much poorer without the work done and coordinated by CIRAD over many years.

However, I think the time has come for the world cotton community to band together and develop pools of diversity that anticipate future needs, particularly with regard to quality, pest and disease resistance attributes and then let breeders select within these broad populations for the gene combinations to marry those that contribute to overall quality, adaptability and field performance in specific environments.

This type of primary population development lends itself to a systematic exploitation of all the wild species of cotton available. Similarly, it will permit comprehensive variety collections to be held in perpetuity, before they are lost forever. And in time when the biotechnologists have reached the level of maturity that breeders have had for a long time, the incorporation of new genes can be done into broader, even segregating, populations rather than into only specific varieties with all the attendant risks of narrowing the germplasm pool of cotton in commercial production. Breeders can then select within these broader pools for specific adaptability to local environments and the gains in efficiencies will be immense.

The use of genetic markers and genetic fingerprinting will I am sure make the patenting of individual traits that much easier to do and administer as time moves on.

I am sure that germplasm development can be done relatively inexpensively, but the benefits will be there for generations to come and may even halt the currently inexorable slide of cotton's market share. We have common funds that are available for cotton and improving the genetic pool available to breeders worldwide would be one of the best ways to utilize these to benefit all.

Conclusion

There have been dramatic improvements in efficiency generated through breeding in cotton. For the future, however, success hinges as much upon individual countries, companies and individuals getting the whole production chain right as it does on preparing broad based populations with as wide a range of material as it is humanly possible to gather. Investment in research is essential in the environment in which the crops are to be grown. There is scope to utilize the lower cost environments of southern hemisphere countries with the technological advances of the northern ones to dramatically improve the efficiency of breeding. Breeding remains a numbers game.

Table 1. *Zimbabwe: smallholder cotton yields, national rainfall and hectares grown 1970 to 2002.*

Year	Three Year Moving Averages		Hectares 000's
	3-Year Yields	3-Year Rainfall	
1972	886	641	21
1973	761	585	25
1974	762	727	39
1975	709	732	47
1976	809	853	50
1977	726	768	41
1978	731	822	37
1979	714	766	32
1980	686	730	30
1981	801	690	36
1982	760	647	46
1983	812	568	58
1984	742	436	72
1985	892	538	98
1986	940	635	115
1987	843	621	128
1988	759	621	138
1989	743	591	151
1990	767	658	156
1991	725	577	168
1992	511	487	178
1993	512	489	193
1994	482	495	188
1995	541	523	187
1996	639	546	193
1997	681	642	222
1998	824	680	241
1999	777	706	260
2000	835	731	280
2001	829	830	326
2002	718	570	358

Figure 1. *Zimbabwe: Increased lint outturn extra earnings 1990 vs. 2002 in millions of USD.*