

The ICAC Recorder

International Cotton Advisory Committee

Cotton Vision 2030 by the ICAC Researcher of the Year Award Winners

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Editorial

What does 'Vision 2030' mean to the cotton world? Well, it would mean a lot if it comes from the best in the business of cotton science, research and development. This edition of the ICAC RECORDER carries the 'Vision 2030 interviews' of the current generation leaders in cotton science. Every year the ICAC recognises an outstanding cotton scientist for the ICAC International Cotton Researcher of the Year Award. Thirteen eminent cotton scientists have been bestowed with the Award so far since 2009. The award winners were asked 10 questions and their responses are documented in this edition. The idea is to provide intellectual leads on the current and the possible future challenges for the younger generation of cotton scientists. Personally, I enjoyed reading the responses and learnt from the wisdom and intellect of the eminent scientists, all of whom have spent almost their entire lives for the advancement of cotton science.

Scientific advancements are blessed with unfathomable, inconceivable and unexpected excitements all the time. The foundation of civilisations is layered with stories of research and development throughout the history of mankind. The excitement is never-ending as the story of science continues to influence our lives in every way possible. It is almost impossible to predict what the future holds for science. The vision for 2030 that we have today is based on the knowledge that has been accrued from science so far. But interestingly, as we have witnessed over the years, a single scientific discovery or invention tomorrow can change the entire trajectory of scientific advancements in all its related fields, and thus the trajectory of our vision. Who would have thought, 70 years ago, that unravelling of the double stranded nucleic acid helical structure of a microscopic thread called DNA would change our world, especially for medical and agricultural technologies? Who would have thought, 40 years ago, that a revolutionary technique called 'polymerase chain reaction (PCR)' would be invented and would change the way biological sciences conduct research? Who would have thought, 30 years ago, that cotton plants expressing bacterial genes would take the world by storm? Who would have thought 20 years ago that a technology called CRISPR-CAS9 would be invented for site-specific gene editing in an absolutely precise manner would open up a myriad of possibilities in medicine and agriculture? All these technologies have dramatically influenced the way science has been carried out since they were invented and discovered. Vision statements documented prior to these inventions would certainly have been very different from what they are today. Nevertheless, our thoughts, views and ideas will be documented now with an idea that these may help the next generation build their science on the edifice that we built.

On the other hand, perhaps that is not how science works. Our generation of scientists might dream of reaching Mars, but soon someone will start dreaming about reaching distant stars. I hope all of us live long enough to enjoy seeing the younger generation discard our visions and replace them with radically different, exciting and thrilling new ideas. I offer my congratulations to our generation and best wishes to the next.

-Keshav R Kranthi



Cotton Vision 2030

Keshav Raj Kranthi, India

ICAC Researcher of the Year 2009



Dr. Keshav Kranthi is Head of the Technical Information Section at the International Cotton Advisory Committee (ICAC), Washington DC. Before joining the ICAC in

March 2017, Dr. Kranthi worked as a cotton scientist from 1991 and was the Director of the Central Institute for Cotton Research (CICR) in Nagpur, India, from 2008 to 2017.

Dr. Kranthi was awarded a gold medal in PhD from the Indian Agricultural Research Institute (IARI) in New Delhi. Dr. Kranthi has a patent granted in South Africa, Mexico, China and Uzbekistan and six patent applications in India. He invented immunological kits to detect *Bt* in GM crops, insecticide-resistant insects and spurious pesticides. He pioneered the development of national strategies for insecticide resistance management, bollworm management, whitefly management and sustainable yield enhancement through high-density planting systems.

He has published 54 peer-reviewed research papers and presented 38 invited papers in 28 countries. He won two international awards and 10 national awards in India. He was the first winner of the ICAC Researcher of the Year Award in 2009. He received the ICAR Award for Leader of Best Team Research

in 2006, Fellow of the National Academy of Agricultural Sciences in 2009, Fellow of the Indian Society of Cotton Improvement in 2017 and the Plant Protection Recognition Award in 2016 by the National Academy of Agricultural Sciences.

Dr. Kranthi developed and commercialised four *Bt*-detection kits. The kits became popular with sales of US \$1,045,000 within the first five years of commercialisation.

He developed Insecticide Resistance Management Strategies for cotton and facilitated (as team leader of Technology Mini Mission II) their dissemination in 1,500 villages in nine cotton growing districts on about 200,000 ha with 80,000 participating farmers.

Dr. Kranthi developed resistance management strategies to delay the development of resistance in bollworms to *Bt*-cotton and insect resistance to insecticides. The *Bt*-resistance management strategies were developed based on a stochastic model (Kranthi and Kranthi 2004, *Current Science*, 87: 1096-1107).

The Three Big Challenges For The Cotton Sector In The Next Decade

1. Low yields
2. Degradation of soil health
3. Insect pests and diseases

Low Yields

The average cotton yield over the past 15 years (2004 to 2019) was 773 kg lint per hectare (kg/ha) from an average of 33 million hectares. Data show that global yields have been stagnant over the past 15 years with low yields in India and Africa depressing the global figures. Yields have been stagnant in Africa for the past 40 years and in India over the past 15 years. Cotton yields in both Africa and India have been less than half of the yields harvested in rest of the world (yields of the world minus Africa and India). Therefore, low yields in Africa and India are big challenges. Globally, cotton was grown in 34.2 million hectares (in 2019; of which, Africa (13.5%) and India (39.1%)) together occupied more than half of the area but contributed only 30% (7.9 million tonnes) of global production (26.1 million tonnes). The rest of the world contributes 70% (18.2 million tonnes) of production from just 47.4% of the global

acreage with an average of 1116 kg/ha.). Historically, global average yields (763 kg/ha in 2019) are depressed because of low yields in Africa and India. In 2019/20, as in previous years, Africa had the lowest cotton yields (395 kg lint/ha) in the world, followed by India (456 kg/ha).

Table 1. Low Yields in India and Africa

	Area	Production	Yield
	M ha	M Tonnes	Kg Lint/ha
World	34.2	26.1	763
India	13.3	6.1	456
Africa	4.6	1.8	395
Rest of the world	16.3	18.2	1116

Soil Degradation and Poor Soil Health

Land degradation will remain an important global issue for the 21st century because of its adverse impact on agronomic productivity and the environment, as well as its effect on food security and quality of life (Eswaran et al, 2001). Soil health in most cotton-growing regions of the world is a major concern for productivity. Cotton production systems over

several decades have been subjected to excessive tillage and agrochemical applications, thereby leading to soil degradation and poor soil health. Soil degradation is one of the main factors for low productivity in rainfed drylands including Africa and central India.

About 75% of the world's land has been degraded (Xie et al, 2020); 65% of agricultural lands in sub-Saharan Africa (Zingore et al, 2015); more than 40% of China's arable land is degraded (Delang, 2018) and more than 67% of farmlands in India are degraded (Dhruvanarayana and Babu, 1983). In India, soil erosion by water is the most serious threat, affecting 82.57% of the total area, followed by wind erosion (12.40%), acidic soils (17.94%) and other factors (ICAR & NAAS 2010). Soil degradation invariably leads to erosion of biodiversity and loss of soil organic matter (SOM) which in turn results in poor soil fertility and low yields, since SOM is a rich source of mineralisable nitrogen (N), phosphorus (P), sulphur (S) and other nutrients (Baldock and Broos, 2011). Cotton crops grown on soils with poor organic matter, imbalanced nutrients and poor soil health suffer from poor ecosystems, poor health, nutrient stress, water stress and severe pestilence, thus leading to poor productivity and negative socio-economic consequences.

Insect Pests and Diseases

India, China, USA, Pakistan and Brazil together contribute to more than 75% of the global cotton production every year. These top five cotton-producing countries are either battling with a few insect pests and diseases that have been causing yield losses despite intensive pesticide use or are faced with imminent threats of impending pestilence. At least five insect pests and a disease are known for their notoriety, namely the boll weevil, cotton bollworm, pink bollworm, whitefly, thrips and the cotton leaf curl virus. These insect pests and the disease are known to cause heavy economic crop losses and are difficult to manage.

Table 2. Insects and disease in the top 5 cotton countries

Insect pest/disease	USA	Brazil	China	India	Pakistan
Boll weevils	**	*****			
Bt-resistant bollworms					
• Pink bollworm		*	**	*****	*****
• Heliothis sp.	**	*	**	***	**
Whiteflies	*	**	**	****	****
Leaf curl virus disease				*****	*****
Thrips	****	**	***	**	**

* The number of asterisks indicates the extent of risk

Boll weevil is a serious problem in South America, where cotton is mainly grown in Brazil and Argentina. Pink bollworm has recently developed high levels of resistance to Bt-cotton thereby emerging as a menace in India and Pakistan. The impending threats of bollworms in India, Brazil, Pakistan, USA and China deserve serious attention. Incidentally, India, China, USA, Brazil and Pakistan are the largest users of insect-resistant biotech cotton technologies and are almost completely

dependent now on biotech traits in their cotton varieties. The dynamics of cotton productivity and production in the world will depend on how well these top five countries combat the threat of these six notorious biotic stress factors.

Novel Production Technologies That Can Break Yield Barriers

Several crop production technologies contribute to high yields and they are now regarded as best practices across the world. Several of these technologies would probably not be as effective in making a big difference in developed countries and much as they could be in increasing yields in India and Africa.

Those technologies include:

- Growth regulators for retention of early formed squares
- High density planting (for Africa and India)
- Regenerative agricultural techniques for soil health management
- Ecological engineering techniques for biotic and abiotic stress management

Several best practices are listed below.

Retention of early formed squares.

Retaining early formed squares is a robust strategy for high yields and pink bollworm management. Why protect early formed squares and bolls? Bolls of the first, second and third fruiting points of a sympodial (fruiting) branch represent bolls from early formed squares. They contribute to the most energy-efficient high yields and better fibre quality in a short time. Square and boll shedding can be prevented by rectifying deficiencies of phosphorus and boron; providing adequate water; reducing shading effects through canopy management; protecting from insect pests and use of ethylene inhibitors. Aim for 70-80% boll retention, especially of bolls at the 1st and 2nd position nodes on sympodial branches. Studies show that these bolls contribute to 60% and 30% of the seed cotton yield, respectively. Bolls on the sympodial branches of the central region contribute to at least 70% of the seed-cotton yield. Proper management of nutrients, water and pests helps to retain fruiting parts, especially bolls. Retaining early formed squares and bolls is critical for high yields in the shortest possible duration of the crop. Protecting early formed squares and bolls from shedding helps improve the management of insect pests and diseases, higher nutrient-use-efficiency, better water-use-efficiency and a higher harvest index. Plants that shed early formed squares and bolls respond by producing extra vegetative growth in efforts to compensate for the fruit losses, thereby resulting in delayed fruiting and maturity. This results in a longer-duration crop that has a longer flowering and fruiting window which makes it more vulnerable to drought stress, nutrient demand and insect pests and diseases. Cotton plants have a predictable growth rate primarily based on heat units. Optimum inputs and the absence of stress allow proper growth. Monitoring plants for their growth rate based on heat units will help to diagnose and rectify problems in a timely

manner to ensure boll retention to an extent of at least 50%-60% to realise high yields.

- On an average, cotton plants produce 1 to 1.5 squares per day starting from the 35th to 40th days after emergence.
- It is extremely important to protect at least 70%-80% of the first 30 formed squares per plant (40-70 days after emergence) and be able to protect at least 70%-80% of the first formed 20 bolls per plant (60-90 days after emergence).
- Retaining about 12 to 15 healthy bolls per plant leads to high yields of 1500 to 2000 kg of lint per hectare at 90x10cm spacing within 150-160 days.
- **Retention of early formed squares/bolls is the most effective strategy to combat the pink bollworm in India & Pakistan. Early formed bolls escape pink bollworm infestation and have a better fibre quality. PBW is a late-season pest in India and primarily affects late formed bolls.**

How to retain early formed squares?

Monitor the crop for square and boll retention for 50 days starting from square initiation on a 40-day-old crop. Examine squares to diagnose the causal factor responsible for shedding and initiate control measures to prevent square shedding. Square shedding could occur due to nutrient deficiencies, insect damage, drought, water logging, cloudy conditions or inter-plant shading effects. If square shedding is noticed, diagnose the causal factor and initiate immediate control measures. Square shedding can be prevented by using any of the following strategies:

- ^a Nutrients such as nitrogen, phosphorus and boron
- ^a Growth regulators such as Mepiquat Chloride or Paclobutrazol for canopy management to prevent shading effects
- ^a Ethylene inhibitors such as Aminoethoxy vinyl glycine or 1-Methyl cycloprene
- ^a Plant hormones such as 1-Napthalene Acetic Acid to reduce square shedding
- ^a Eco-friendly insecticides such as Bt, NPV, Pyriproxyfen, Buprofezin, Indoxacarb, Chlorantraniliprole, etc., to control mirid bugs or bollworms

Aim for 70%-80% square/boll retention. Retaining about 12 to 15 healthy bolls per plant leads to high yields of 1500 to 2000 kg of lint per hectare at 90x10 spacing within 150-160 days.

High-Density Planting

High yields are obtained across the world at both low and high plant densities. However, high yields are obtained in less time and in a more efficient manner from higher density crops compared to crops with low density plant populations. High yields can also be obtained with low density fields planted at spacings of 90x60cm, 90x90cm etc., but it takes a longer time to protect and retain a larger number of squares/bolls per plant for high yields which also makes the late formed bolls vulnerable to pink bollworm, water stress and nutrient stress. Cotton in India and Africa is normally planted at a spacing of 90x60cm

which results in a field population of 18,518 plants per hectare. To obtain the world average lint yield of 800 kg/ha in such fields, each plant needs to retain on an average 29 bolls (1.5g lint per boll). The average yield of India is 500 kg/ha which indicates a retention of 18 bolls per plant on an average. The average yield of Africa is 350 kg/ha which indicates a retention of 13 bolls per plant on an average. Cotton is planted at a spacing of 90x10cm in Australia, Brazil, China, Mexico, Spain, Greece and USA, to get a field population of 111,111 plants per hectare. To obtain a world average lint yield of 800 kg/ha in such fields, each plant needs to retain on an average 5 bolls/plant (1.5g lint per boll). These countries harvest 950 to 2000 kg lint per hectare, which indicates retention of six to 12 bolls per plant respectively. On average, cotton plants produce one square per day starting at about 35-40 days of age. In order to obtain a yield of 800 kg lint per hectare, it is relatively efficient and easier to monitor and protect 10 early formed squares per plant at a plant population of 111,111 plants/ha, — which could result in the final retention of about 5 bolls per plant — as compared to the protection of 60 early formed squares at a plant population of 18,518 plants/ha., which could result in the final retention of 29-30 bolls per plant. There are several advantages of a higher density planting. Dense planting at 8-10 plants per meter row with rows spaced at 80-100 cm reduces the physiological load on individual plants. Dense planting reduces the duration of the critical window of boll formation to facilitate efficient water and nitrogen management. It reduces the number of monopodial branches to increase harvest index. Dense planting also reduces the number of poor-quality bolls on upper terminal region of the plant and beyond the third node on longer sympodial branches.

Soil health management

Soil health holds the key to achieving higher efficiency of water-use and nutrient-use in agriculture. Soils that are rich in organic matter, soil microbes and soil organisms enable better retention and translocation of air, water and nutrients. Healthy soils enable uptake of the essential macro and micronutrients to produce a healthy crop that has a better capacity to combat biotic and abiotic stress.

Technologies such as cover crops, improved fallow, minimum tillage, manures, bio-fertilisers and recycling crop residues enhance soil health. In rainfed regions, water conservation methods such as water harvesting, ridge planting, mulching, conservation tillage, organic enrichment, drainage, drip and sprinklers, draining excess water, cover crops, etc., are very important to conserve and provide adequate soil moisture to the crop, especially during its critical stage of boll formation. Regenerative agricultural practices such as reduced tillage minimise soil degradation and increase water and nutrient use efficiency. Legume cover crops are used for management of soil moisture, weeds and nitrogen. Crop rotation and intercropping with shallow rooted crops or legume crops also help in reducing soil erosion. Technologies for improved fallow with legume crops helps immensely in the improvement of nitrogen and organic matter.

The cotton crop is hungriest and thirstiest during boll formation. Ensure that the plant gets 70%-80% of its requirement of nitrogen and water during the critical window of green boll formation. While regenerative agricultural practices are used to enhance soil organic matter and soil health, agronomic practices must be adjusted to reduce the duration of the critical window of plants by developing high density planting systems. Nutrients such as potassium, phosphorus, boron and zinc play a crucial role in yields, as does soil pH. Under rainfed conditions key considerations are sowing time, monsoon window, planting density and nutrient management to ensure that the green boll development gets optimum inputs for good growth and yields. Precision nutrient management technologies will help to avoid excess nitrogen and rectify nutrient deficiencies.

Ecological Engineering for Biotic and Abiotic Stress Management

Cotton suffers from biotic and abiotic stress. Biotic stress factors include insect pests, diseases and weeds. Abiotic stress factors include drought, water logging, salinity, high rainfall and extreme temperatures. Amongst the biotic stress factors, insect pests cause maximum yield losses in cotton. A few bacterial, fungal and viral diseases also damage the crop and reduce yields but to variable extents in different parts of the world. Generally, farmers prefer chemical control of insect pests, diseases and weeds because of the quick action. However chemical pesticides have negative side effects on ecology and the environment. Most insecticides cause pest resurgence which necessitates repeated use of insecticides and their mixtures, which in turn leads to insecticide resistance in target insect pests, poor pest control and crop losses.

Ecological engineering relies on the use of cropping systems and cultural methods for habitat manipulation that are unfavourable for pests but enhance the survival and growth of naturally occurring biological control. Ecological engineering improves performance of biological controls and reduces the need for chemical insecticides. Several integrated ecological practices such as cover crops, inter-crops, trap crops, biofertilisers, biopesticides, organic mulching, manure, compost application, etc., have the least disruptive effects on naturally occurring biological control. Simple strategies such as choice of 'sucking pest resistant cultivars', 'timely sowing', 'avoiding excessive nitrogenous fertilisers', 'growing intercrops that shelter beneficial insects', 'use of bio-pesticides, biological control and selective insecticides at economic threshold levels of insect pests' can help in effective pest management with minimum chemical intervention and with the least disruptive effects on the ecosystem.

Promising Recent Advances in The Science of Genomics, Genetics and Plant Breeding

The science of cotton genome sequencing has advanced tremendously over the past eight years. The draft sequences of major diploid and tetraploid genomes have revealed valuable

information on the association of genes and traits. Draft genomes of *G. raimondii* (Wang et al, 2012) and *G. arboreum* (Li et al, 2014) were reported in 2012 and 2014 respectively; for *G. hirsutum* (Li et al, 2015; Zhang et al, 2015) and *G. barbadense* (Liu et al, 2015; Yuan et al, 2015) in 2015 and for *Gossypium turneri* (Udall et al, 2019) and *Gossypium australe* (Cai et al, 2019) in 2019. Based on the available information, several research groups have initiated genomic breeding strategies to improve fibre yield, fibre qualities and climate resilience (Yang et al, 2020).

Table 3. Cotton genome sequencing

Species	Reference
<i>Gossypium raimondii</i>	Wang et al, 2012
<i>Gossypium arboreum</i>	Li et al, 2014
<i>Gossypium hirsutum</i>	Li et al, 2015; Zhang et al, 2015
<i>Gossypium barbadense</i>	Liu et al, 2015; Yuan et al, 2015
<i>Gossypium turneri</i>	Udall et al, 2019
<i>Gossypium australe</i>	Cai et al, 2019

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

Genomic research has enabled the identification of genes related to high boll numbers per plant, high yields and also genes that are involved in fibre development and can play a major role in fibre quality such as length and strength. Genome wide association studies (GWAS) were used to examine millions of genetic variants to unravel the genetics of fibre quality and yield. The genes, *GhFL1*, *GhFL2*, and *GhXIK* were found to be involved in fibre cell elongation, *Gh_A07G1769* was shown to be related to fibre strength; *GhLYI-A02* and *GhLYI-D08* were found to pleiotropically increase lint yield and boll number per plant (Fang et al, 2017). Genes such as *GhACT_L11* for fibre development (Thyssen, et al, 2017), *GoPGF* for glandless phenotype (Ma et al, 2016), *GhLMI1-D1b* for leaf shape (Andres et al, 2017), *GoSP* for branching (Si et al, 2018), and *GhLMMD* for necrotic leaf damage (Chai et al, 2015) have been cloned. Availability of genetic markers and genome sequence data can improve targeted approaches to assign gene action for specific fibre quality traits at the molecular level to facilitate marker assisted selection and marker assisted breeding.

How Can Cotton Combat Climate Change?

Cotton farming is both a contributor to climate change as well as a victim of climate change. Interestingly the cotton crop offers solutions to climate change by sequestering more carbon that it emits. The passages below describe three aspects of cotton related to climate change.

- Impact of cotton farming on climate change
- Impact of climate change on cotton farming
- Technologies to combat climate change effects

Impact of cotton farming on climate change

The factors related to cotton farming that mostly impact climate change are deforestation, use of electricity and petroleum products in irrigation, farm operations and the transport and use of chemicals, such as fertilizers and pesticides, in cotton farming, textile manufacture, and use. Fossil fuel and natural gas products such as electricity, petroleum, polyester, nylon, acrylic, chemical dyes, etc., are used in textile manufacture and use that also contribute to climate change. However, many studies point out that cotton farming has the least impact on climate change and if anything, it helps in reducing atmospheric CO₂ levels significantly better than most other crops. Like other C3 crops, cotton not only contributes significantly by sequestering high levels of CO₂, but also captures extra CO₂ by sequestering it in its fibres. Studies show that per every kg of fibre that it produces, the crop sequesters about 0.5 kg more greenhouse gases than it emits.

Impact of climate change on cotton

Climate change can have both positive and negative effects on cotton production. Scientific reports have shown that increased levels of atmospheric CO₂ improve radiation use efficiency, reduce leaf transpiration, increase photosynthetic rates and increase carbohydrate pools thereby enhancing plant growth and root growth as well as increasing the number of bolls, thus resulting in high yields. However, higher temperatures have been reported to cause enhanced insect pest problems, reduced water-use-efficiency, poor pollination, reduced seed-set, lower boll numbers with reduced weight and poor boll retention thereby leading to yield losses and deterioration in fibre quality, in addition to having the potential to prolong the duration of the crop. A longer growing season under uncertain climatic changes would lead to greater complexities in management of crop health, soil health, water, nutrients, weeds, insect pests and diseases. Extreme weather vagaries such as heat waves, drought and excessive rainfall will enhance risks to cotton production systems. Heat stress often accompanies drought to complicate risks further. Shifts in rainfall patterns, especially in the 54% of rainfed regions, will result in a mismatch between the 'crop water critical requirement window' and the monsoon, thereby resulting in stress and yield reduction.

Technologies to combat climate change effects:

The three most important strategies that could reduce the impact of climate change on cotton farming are as follows:

1) Breeding heat-tolerant cultivars

Since high temperatures have the most detrimental effects on germination, fruit setting and boll retention, it would be prudent to focus efforts on developing heat tolerant cultivars that can produce fertile pollen and fruit setting under higher night temperatures of more than 27° C and retain bolls under higher temperature regimens. While the main focus is to develop heat-tolerant cultivars, additional traits of enhanced water-use-efficiency, high nutrient-use-efficiency, and

the potential to adapt and withstand unpredictable drought, changes in heat, water logging, insect pests and diseases would enable extra resilience to biotic and abiotic vagaries. Cultivars with indeterminate growth habit have been reported to show a better resilience to climate effects. Similarly, cultivars with relatively slow fruit setting — but a higher final fruit number — were found to produce higher yields.

2) Enhancing soil health

Healthy soils not only supply adequate macro- and micronutrients but also facilitate better nutrient utilisation by crops. Soils rich in organic matter capture rainwater more efficiently and provide soil moisture over a longer period to enable the crop to endure drought conditions. Therefore, production practices must be developed to enhance soil health by using crop-residue recycling, green manuring, cover crops, bio-fertilizers, farmyard manure, compost, biochar, slow-release urea, crop rotation, crop diversification and ecological engineering so as to mitigate the effects of climate change on cotton production.

3) Reducing dependence on chemical inputs

Conventional cotton farming systems have become increasingly dependent on chemical inputs for high yields. Increased chemical use has been found to adversely impact soil health. The soil organic carbon content has been deteriorating in many countries thereby leading to poor factor productivity of fertilisers. Under such conditions, low yields are obtained despite more use of fertilisers. Reducing dependence on electricity, petroleum products, chemical fertilisers and pesticides helps in reducing the carbon footprint and thereby reducing the impact on climate change. Strategies such as ecological engineering and regenerative agriculture can strengthen soil health and biodiversity that help in reducing the need for chemical usage in agriculture. A few technologies such as starch coated urea or neem coated urea have been reported to improve nitrogen use efficiency.

Novel Technologies to Fight Insect Pests, Weeds and Diseases

Thus far, the role of transgenic cotton was confined to bollworm resistance and herbicide tolerance. In a recent development, transgenic cotton plants 'MON 88702' incorporated with the Bt gene *Cry51Aa2* were found to be effective in combating thrips (Huseth et al, 2020).

Yin et al (2019) expressed Cas9 and dual gRNAs to simultaneously target multiple regions of the cotton leaf curl virus to demonstrate that it was possible to engineer plants with complete resistance to the leaf curl disease. In a recent report, Khan et al (2020) showed that CRISPR CAS9 systems using two guide RNAs, one targeting the Replication associated protein (Rep) gene and the other targeted the βC1 gene of the Beta-satellite, could be used as a multiplex strategy to reduce infectivity of the cotton leaf curl virus.

Cotton plants expressing a bacterial phosphite dehydrogenase *ptxD* gene showed capabilities of utilising phosphite fertilizer which was toxic to weeds. Thus, selective fertilisation with

phosphite allowed unhindered growth of the transgenic cotton plants while suppressing weeds (Pandeya et al, 2018). The authors claim that '*ptxD*/phosphite system represents one of the most promising technologies of recent times with potential to solve many of the agricultural and environmental problems that we encounter currently'.

Cotton Transgenic Technologies and the Way Forward

Commercial transgenic technologies in cotton have thus far been confined only to two traits — insect resistance and herbicide tolerance (HT) — across the world. Transgenic cotton technologies were commercialised in 1996 and ever since have been instrumental in changing the crop protection scenario in global cotton production systems. Over the past 24 years, the majority of developed countries adopted the transgenic Bt-cotton and HT-cotton for bollworm management and weed management, respectively. Transgenic cotton has been approved in 19 countries and was grown on 24.9 million hectares in 2018, occupying 76.0% of the global cotton area. The transgenic cotton grown in India, USA, Pakistan, China and Brazil represents 94% of the total transgenic global cotton acreage.

Though herbicide tolerant cotton has been developed for tolerance against six herbicides — glyphosate, glufosinate, dicamba, 2,4-D, isoxaflutole and bromoxynil (HT not in use) — only five of the products are currently in use. Similarly, though bollworm resistant Bt-cotton transgenic cotton varieties were developed incorporating seven Bt-toxins — *cry1Ac*, *cry1Ab*, *cry1C*, *cry1F*, *cry2Ab*, *cry2Ae* and *vip3a* — different products are available in different forms with either a single gene trait or with combinations of two or three genes. China developed transgenic cotton expressing cowpea trypsin inhibitor (*CpTi*) protein for bollworm resistance, which is confined so far only to China. In general, a combination of two or three Bt genes occupy the majority of cotton acreage in Australia, Brazil, India and USA. Eight countries — Argentina, Australia, Brazil, Colombia, Mexico, Paraguay, South Africa and USA — grow Bt-cotton and HT cotton. Developing countries such as India, Burkina Faso, China, Pakistan, Myanmar and Sudan approved Bt-cotton but have not approved HT cotton as yet.

Two phenomena, namely 'bollworm resistance to Bt-cotton' and 'weed resistance to herbicides', have emerged as challenges recently and threaten the sustainable efficacy of transgenic cotton. *Helicoverpa zea* (in the USA) was reported to have developed resistance to Cry1Ac and the pink bollworm *Pectinophora gossypiella* was reported to have developed resistance to Cry1Ac and Cry2Ab in India. Similarly, glyphosate resistance has been recorded in 13 weed species each in USA and Australia and 8 each in Argentina and Brazil. The emergence of new insect pests, development of insect resistance to Bt-cotton and weed resistance to herbicides have resulted in a constant rise in the use of pesticides over the past decade in India, Pakistan, China, Brazil and USA.

While development of transgenic cotton varieties through over-expression of insecticidal transgenes appears to have

slowed down substantially, new approaches of RNAi through gene silencing and gene editing through CRISPR CAS9 have started gaining ground in recent years to combat insect pests, weeds, diseases and climate change.

Role of Robotics, Electronics and Communication Technologies for Cotton

We are witnessing a digital revolution. Digital technologies such as artificial intelligence (AI) and social media platforms are revolutionising communication channels. New technologies such as interactive mobile applications and virtual-reality movies facilitate expert-assisted decision making and season-independent immersive learning, respectively. Robotics and drones are now being used for data collection, problem detection and the delivery of solutions.

Artificial intelligence and computer neural networks for voice recognition, two-way interaction and image recognition are being increasingly explored for use in agriculture for transfer of technology, data collection and analysis and farmer education. The advent of smart phones, with facilities of inexpensive data downloads, extensive photographing and videography recording facilities and digital editing technologies now enable the common man to become a content creator. Agricultural extension, once considered the biggest of all challenges in small-holder agricultural systems, is no longer considered difficult. The new technologies enable information communication even to the remotest of areas and also to the least literate of resource-poor farmers.

Other Exciting Novel Innovations and Game-Changing Technologies

The newly discovered genomic editing and gene-silencing tools may revolutionise health and agriculture. Over the past 20 years, insect resistant and herbicide tolerant biotech cotton have delivered impressive benefits to major cotton growing countries across the world. New exciting tools of gene silencing through Ribonucleic Acid Interference (RNAi) and genome editing through Mega-Nucleases (MN), Zinc Finger Nucleases (ZFN), Transcription Activator-Like Effector Nucleases (TALENs) and Clustered Regularly Interspersed Palindromic Repeats (CRISPR) — along with CRISPR associated protein-9 (CAS-9) — have added radical new dimensions to the prospects of biotechnological applications in cotton improvement. Genome editing, RNAi and genetic engineering can be used to develop new varieties for sustainable control of bollworms, boll weevils, sap-sucking insects, cotton leaf curl virus disease, wilts and bacterial blight while adding new traits for nitrogen use efficiency, drought-tolerance, water use efficiency, climate resilience and premium fibre qualities. Trans-gene pyramiding at a single desired locus through the recently developed CRISPR-CAS9 technology by genome edited locus-specific site directed integration will immensely accelerate introgression of the multiple traits into native varieties of new biotech cotton. There is a need to effectively utilise these next-generation tools of cotton biotechnology to either add novel genes at a

precise locus on the genome or effectively knock-out undesirable genes. There is published evidence to show that the recent advances have the potential to revolutionise the cotton sector.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges Of 2030

Look at the big picture

As scientists, all of us focus on our own specialisation, to the extent that we work harder and harder to know more and more about less and less. It is very common for scientists to examine minute details and explore micro topics that could lead to inventions, discovery or information in their respective subject fields. Most of the time, this results in scientists working in silos. We may or may not have the aptitude to look at the big picture and explore whether our science may promote a greater social good. Many brilliant scientific findings sometimes wait for their time to be noticed as key cogs in the wheel and become part of the greater picture — as with a jigsaw puzzle — before they make their way into applied sciences and technologies. It would certainly help all of us scientists, young or old, to be aware of the challenges that farmers face, of the scientific advancements in our related disciplines, however remote they may be, for they could provide the momentum that drives the wheels of sustainable agricultural development. Needless to say, good agricultural science has to be relevant for the farmer and make his life better and more prosperous. Good science has to make sense for the future either in the form of laying the foundation for technologies and strategies or by inspiring and fostering new science that is useful for farms, ecology and the environment. This becomes possible through awareness of the constant technological advances, by being sensitive to the societal changes and environmental issues, and by not losing sight of the big picture for sustainable agrarian prosperity.

Climate change, soil health and biodiversity

Whether we like it or not, the effects of climate change appear more real now than ever before. While policies can help in reducing and minimising the key causal climate-changing factors such as deforestation, burning of fossil fuels, energy and chemical inputs in cotton production and processing, young scientists could focus on developing climate resilient cotton cultivars, technologies that reduce chemical dependence, enhance biodiversity in farms, and finally, rejuvenate soil health, which shows great potential for providing resilience to crops and mitigating the negative effects of climate change.

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Cotton Vision 2030

Fred Bourland, USA

ICAC Researcher of the Year 2010



Dr. Fred Bourland was reared on a family cotton farm in northeast Arkansas where he was involved with all aspects of growing

cotton. He earned both his BS in agriculture (1970) and MS in plant breeding from the University of Arkansas. He worked on cotton genetics for MS and PhD. He earned his PhD in genetics under the direction of Dr LS Bird from Texas A&M University in 1978. He became an Assistant Professor of agronomy at Mississippi State University in 1978, where he headed a cotton breeding program and had teaching responsibilities. During his tenure at Mississippi State, Dr. Bourland was promoted to Associate Professor in 1983 and to Professor in 1987. He was hired as Professor of Agronomy at University of Arkansas in 1988 and continued his cotton breeding research and teaching. In 1997, he transferred his breeding program from the main campus to the Northeast Research and Extension Centre where he also serves as Centre Director. He has been married to his wife, Kathy, for 40 years and they have one son, Samuel.

Dr. Bourland has been primarily responsible for developing plant breeding techniques,

several field and laboratory techniques that may be used to select and characterise cotton germplasm. Dr. Bourland has been primarily responsible for the development and release of 54 cotton germplasm lines (34 lines since 2004) and one cultivar. These releases are chronicled in 34 registration articles in Crop Science Journal and the Journal of Plant Registrations. Dr. Bourland was one of four principal developers of COTMAN, a management system developed by a multi-disciplinary research team. Initially, his role was primarily the development of critical plant measurements and determining how cultivars differed with regard to these parameters. Since then, he has been integrally involved with training individuals to use COTMAN and with developing training materials. Dr. Bourland received the Arkansas Cotton Achievement Award and John W. White Team Research Award from the University of Arkansas in 1999 and the Joint Cotton Breeding Committee Genetics Award in 2001 from the National Cotton Council.

The Three Big Challenges for Cotton Sector in the Next Decade

1. Market competition from man-made yarn will likely continue to be the number one challenge for the cotton sector. Man-made yarns contribute far more pollution to the air and water than do cotton yarns. Enhanced communication of these inherent problems of man-made yarns and the inherent advantages of cotton should increase the demand for cotton over man-made yarns.
2. Obtaining competitive prices for cotton will continue to be a key challenge. Inexpensive man-made yarns restrict the market and price for cotton. Cotton producers are required to produce higher yields with lower production costs.
3. With widespread use of specific herbicides associated with transgenic cotton (and other crops), weeds evolve resistance to the herbicides, limiting weed control alternatives and frequently increasing the cost of production.

Novel Production Technologies that Can Break Yield Barriers

In most areas, yield barriers can be broken by correcting pest problems, nutrient deficiencies/imbances and water

deficiencies. Once basic needs are met, yield monitoring and precision agriculture techniques provide exciting opportunities to further enhance yields. Yield monitoring can identify problem (and exceptional) areas within a field. Many of these problems can be mediated via precision agriculture techniques to increase the total yield of the field. Other problems, such as soil issues, cannot be practically mediated, but production inputs in those areas might be reduced so as to increase profitability of the field.

Assuming nutrient and water needs are met and pests are controlled, the primary yield barrier associated with cotton production is the environment. In some areas, producers are likely approaching the maximum yield associated with their available light and heat. In these cases, yield barriers will not likely be broken with novel production technologies but will require the development of cotton lines that can more efficiently use the available light and heat.

Promising Recent Advances in the Science of Genomics, Genetics and Plant Breeding

Marker assisted selection (MAS) provides a direct link between genes and plant breeding and can greatly improve the

efficiency of the plant breeders. MAS is limited by the number and effectiveness of markers. Increased knowledge of gene action and genes associated with specific traits is needed to better utilize MAS. In particular, better understanding of quantitatively inherited traits and gene interactions will provide opportunities to engineer superior cottons.

Recently derived genomic data suggest that cultivated cottons possess a low degree of genetic diversity. Engineering cotton for specific gene combinations may further narrow the genetic diversity of commercial cottons, which will limit further genetic advances and will increase the genetic vulnerability of cotton. These same genomic data could be used to preserve and perhaps enhance genetic diversity.

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

Cotton genotypes that possess high fibre quality traits generally yield less than those with poor fibre quality. If this negative relationship did not exist, selection for higher yields over the past century would have simultaneously improved fibre quality traits. Fortunately, this negative relationship has been neutralised in some recently developed cultivars. Genomic research can help to identify specific genes that may be associated with breaking the negative relationships. Improvements in both yield and fibre quality can then be accomplished.

Yields may be enhanced by better identification of optimum levels of specific yield components. In its most basic model, lint yield is the product of lint weight per seed and number of seeds per area. Plant energy required for production of a unit weight of lint is less than that required for the same weight of seed. Genotypes that give preference to producing more lint per seed rather than more seed per area should produce higher and more stable lint yields. Yet, maximising seed per area cannot be ignored. An optimum balance of these two yield components will provide the most efficient production of yields.

Average fibre length of cultivars in the Arkansas Cotton Variety Test has increased from 28 mm (1.11 in.) in 1970 to 31 mm (1.21 in.) in 2019. This significant increase in length is having major effects on the spinning and marketing of cotton even though the amount of change is actually very small (3 mm or 0.1 inch). Cottons producing much longer and finer fibres might profoundly change the cotton industry and genomics research may make such improvements possible.

How Can Cotton Combat Climate Change?

To some extent, climate change simply alters the adaptive ranges of cotton cultivars. Since cotton is a 'heat loving' plant, yield increases (to some degree) are associated with warming of temperatures. Increased carbon dioxide released to the environment is associated with increased yield. Cultivars bred for wide adaptation are able to yield well with changes in temperature.

Climatic changes in rainfall amounts and patterns may be more detrimental to cotton production than are changes in temperature. Cotton is highly tolerant to drought but performs best with adequate water. Both quantity and quality of water will likely increase in importance.

Novel Technologies to Fight Insect Pests, Weeds and Diseases

Newly developed systems of cover crops have the potential to greatly improve weed control in cotton production. These systems are particularly important in areas where weeds having resistance to herbicides have evolved. These systems not only provide ground cover, which reduces emergence of weeds, but also greatly improve soil health and water efficiency. However, insect pests may be enhanced if the 'green bridge' — the overlapping time of actively growing cover crop and cotton plants — is not properly managed.

Development of resistant cotton lines (host plant resistance) is the most environmentally friendly and cost-effective means to control insect pests and diseases. Over time, the cotton industry has experienced multiple cycles of breeding for improved host plant resistance. Breeding efforts are increased when a pest problem arises but then often ignored when the problem subsides. Since the discovery and integration of resistant genes into adapted lines require much time, these efforts should be continuously sought without regard to the current seriousness of the pest.

Cotton Transgenic Technologies and the Way Forward

Transgenes for controlling insects (*Bt* genes) and transgenes inferring resistance to specific herbicides are the only cotton transgenes available now (and for the foreseeable future) in the market. The development of insect resistance has been a revolving door of *Bt* genes, which have provided good insect control until the insect evolved resistance to the specific *Bt* toxin. This approach has mirrored classical vertical gene approach for host plant resistance. Approaches, other than stacking vertical genes, should be implemented before *Bt* toxins become ineffective.

Transgenes have the potential to contribute needed genetic diversity and have major effects on cotton production and marketability. However, discovery and integration of new transgenes are greatly hindered by their associated costs of development and release.

Role of Robotics, Electronics and Communication Technologies for Cotton

Robotics have become common in many areas of our life but are not commonly used in cotton production. Weed control is a promising role for robotics. As robots constantly roam through a field, they can detect and eliminate individual weeds. This approach to weed control is environmentally friendly and does not encourage the development of herbicide resistant weeds.

New electronic and communication technologies provide the opportunity to greatly increase data collection in actively growing cotton crops. Precise monitoring of plant growth and pest problems via electronic means can become important tool for precise crop management. Remote sensing and high throughput technologies offer the opportunity to gather precise and massive data, which will provide better understanding of variation within a field and between cotton lines. Currently, collection of plant growth parameters, such as nodes-above-white-flower, are time consuming and cannot practically capture the true variability within a field. Precise growth and maturity data collected by remote or high-throughput means will enable the producer to make informed and precise management decisions.

Unmanned aircraft systems (drones) may potentially be used to apply pesticides and/or plant growth regulators to 'site specific' locations in georeferenced field areas. This technology is already available in some fruit production. Drone stations are placed around the orchard, and treatment recommendations/coordinates are sent electronically to the stations. The drone flies to the marked area, treats, and returns to its charging base.

Other Exciting Novel Innovations and Game-Changing Technologies

Implementation of new soil health concepts could completely change how cotton is grown in much of the world. The concepts encompass maintenance of living microbes, earthworms and other beneficial organisms in the soil. These organisms alter the texture, chemistry, water infiltration and holding capacity, and microflora of the soil. Mechanical tillage of the soil is minimised, but precise timing of inputs (optimum management) is required. Plant-based monitoring systems, noted above, might be used to establish integrated systems involving both cover crops and cotton to maximum profits and preserved the environment.

Increasing production efficiency, rather than simply increasing yield, should be a primary goal of the cotton industry. Production efficiency can now be documented with programs such as the Field-Print Calculator developed by Field to Market: The Alliance for Sustainable Agriculture (www.fieldtomarket.org). The Field-Print Calculator shows producers how adjustments in management on their farm can influence eight sustainability factors. Consequently, they are challenged to produce cotton using a smaller footprint.

Shrinking the environmental footprint will improve the acceptance of cotton as a natural fibre that is environmentally friendly. Whether true or not, most people believe cotton to be a heavy user of pesticides/water/equipment. Programs such as the Field-Print Calculator can guide producers to employ practices that minimise their footprint and help change the public's perception of cotton production.

Advice to Young Cotton Scientists: How to Gear Up for The Challenges of 2030

'Don't ignore the basics. Be a team player. Spend time in your most creative environment. Take time to smell the roses.'

Don't ignore the basics.

Consecration of new technologies and methods can sometime blind us to basic plant growth and development parameters. Most new techniques are wonderful tools, but they should not become substitutes for the hard work and time required to make careful observations. These tools only quantify what they are programmed to measure and should not circumvent field observations. Careful field observations often afford insight to better understand measured parameters by relating them to unmeasured parameters. Synthesising these field observations can be the catalyst for scientific advances.

Be a team player.

Competition for funds, desire for professional recognition and time restraints in our fast-paced world have often prompted scientists to become more self-centred. Young scientists should actively explore ways to cooperate with other scientists, particularly those in other disciplines. Similarly, institutions should encourage and reward cooperative research.

Take time to smell the roses!

Our fast-paced, technology-driven society leaves little time to think and meditate. Your brain will function most creatively when it is not bombarded with distractions. Determine what your most creative environment is and make a conscious effort to spend time in it.

Cotton Vision 2030

Sukumar Saha, USA

ICAC Researcher of the Year 2011



Dr. Sukumar Saha has thirty-five years of professional experience. He worked as an agricultural extension worker for eight years in India before immigrating to the USA. After working as a Research Assistant Professor for five years at Alabama A&M University,

Dr. Saha assumed the present position with USDA/ARS in 1997. He demonstrated outstanding stature and received significant recognition as an international authority in cotton genomics and cytogenetic resources that are being used by the scientists in the USA and around the world. In recognition of his contributions to cotton, he was awarded “2010 Outstanding Research Award in Cotton Genetics” at the Beltwide Cotton Conferences organized by the National Cotton Council of America every year. Over 5,000 researchers/farmers attend these conferences. Dr. Saha made a major contribution in developing PCR-based SSR markers (JSPER and MGES), a critical first step for the use of PCR-based marker technologies in cotton breeding programs. MGES markers were first publicly available EST-SSR markers for use as a tool for marker assisted selection program and molecular mapping in cotton. He also made a significant contribution in the discovery of molecular markers associated with important traits in cotton. Dr. Saha is one of the two lead scientists providing leadership in the release of 17 interspecific chromosome substitution lines in

cotton. This research will provide a tool to overcome the problems of interspecific introgression and in the discovery of some novel genes or traits whose effects could not be detected in the donor Pima 3-79 line. Dr. Saha helped to establish one of the most advanced molecular biology lab in the Central Asia and trained Uzbek young scientists. He is one of eight founding scientists who initiated International Cotton Genome Initiative organization (ICGI) to facilitate collaborative research work on cotton genomics at the global level about eight years ago. As the chairman of the Germplasm Work Group of ICGI, Dr. Saha provided leadership for the first time to document the current status of world cotton collection in collaboration with the curators from the major cotton growing countries and this report has recently been published in Crop Science as the cover page paper (2010. 50:1161-1179). Dr. Saha’s research productivity is well documented in about 130 publications, including 77 peer-reviewed journal articles in many prominent journals, one germplasm release notice, a co-edited book, additional multiple papers and abstracts in presentations at conferences.

The Three Big Challenges for Cotton Sector in the Next Decade

In my opinion the three biggest challenges facing the cotton sector in the next decade are:

1. Overcoming a major hurdle to improve fibre yield and quality to compete with synthetic fibre to maximise profit in the global textile market.
2. The threat of emergence of new resistant pests and diseases in many cotton growing areas of the world.
3. The effects of climate change due to global warming — with unpredictable drought, heat, cold, heavy rain — will pose a serious threat to cotton production.

Multinational, interdisciplinary, collaborative research leveraging state-of-the-art technologies will be critical to tackling these challenges.

Novel Production Technologies that Can Break Yield Barriers

- Novel transgenic technologies will play a major role in breaking the yield barrier in future cotton production. The new clustered regularly interspaced short palindromic repeat (CRISPR) transformation technology in developing improved cotton lines will play a major role in cotton production.
- An integrated method of Big Data science and precision agricultural technology will play a major role in developing information-based farm management system with efficient use of resources. This will help in the capability of researchers and farmers to decipher scientific action for improving productivity.
- Traditional farm management systems will be complemented with advanced technologies such as robotic tractor systems, smart phones, and satellite-based farm management systems using precision technologies to improve fibre yield and quality.

Promising Recent Advances in The Science of Genomics, Genetics and Plant Breeding

- CRISPR technologies in developing transgenic cotton lines: The development of genetically modified (GM) crops with current transgenic technology is very costly and time-consuming because of the stringent regulatory system to prevent any harm to humans, animal health, and the environment. Recently the Food and Drug Administration (FDA) in USA approved some CRISPR-edited crops without the requirement of the same stringent GM regulations because they did not contain any foreign DNA as is the case with traditional GM crops. The CRISPR-Cas9 system is a gene editing system using site-directed nucleases to target and modify DNA with great accuracy. The CRISPR technology was discovered based on the adaptive immune mechanism present in bacteria against invading bacteriophages and exogenous plasmids (Wang *et al*, 2019). This was first revealed in *Escherichia coli* in 1987 (Ishino *et al*, 1987) and later on officially named by the Dutch scientist who discovered the CRISPR related (CAS) genes, (Jansen *et al*, 2002; Wang *et al*, 2019). In 2005, three different research groups simultaneously discovered that specific short sequences of many CRISPR spacers were highly homologous, with sequences originating from extra chromosomal DNA suggesting an association between CRISPR and specific immunity. (Pourcel *et al*, 2005; Bolotin *et al*, 2005; Mojica *et al*, 2005). About 10 years later CRISPR-Cas9 has emerged as one of the most promising tools in transgenic research (Shan *et al*, 2013; Cong *et al*, 2013; Kaboli *et al*, 2018). The CRISPR fragment consists of short palindromic repeated DNA sequences that are regularly spaced with foreign DNA sequences from bacteriophages (viruses) that have previously attacked the bacteria. The CRISPR molecule also includes CRISPR-associated genes, or Cas genes. These encode proteins that unwind DNA and cut DNA are called helicases and nucleases, respectively (Barrangou *et al*, 2007). Scientists make use of the CRISPR-Cas9 systems' recognition of specific DNA sequences and apply it in the process of development of improved crops. Instead of viral DNA as spacers, scientists design their own sequences, based on their specific gene of interest and apply it in the process of development of improved crops. A short and simple review was published on the use of CRISPR technology for crop improvement, for more detailed information please refer to <http://www.isaaa.org/resources/publications/pocketk/54/default.asp>. The next generation of technology on the development of transgenic cotton lines resistant to abiotic and abiotic stresses, such as drought or newly emerging disease or pest problems. New genomic technologies complemented by advanced phenotyping systems using precision technology will help to identify some major factors associated with economically important traits at the molecular level. It is important to mention that the rapid change in the textile technology — from high throughput rotor spinning and subsequently to air jet

spinning machine, as much as eight times faster than their old counterparts — demands high fibre strength for efficient spinning. Normally the production rate of air jet/vortex spinning is about 3-5 times higher than rotor spinning and 10-20 times that of ring spinning (<https://www.textileschool.com/455/air-jet-spinning/>). Cotton fibres with improved qualities such as greater strength and longer staple are necessary for spinning yarns in newer technologies reducing waste the spinning process. Textile manufacturers are currently using air jet spinning machines requiring improved fibre qualities so improved fibre quality is one of the most important selection criteria to make cotton fibre competitive with synthetic fibres in the global textile market. In addition, to improve productivity and fibre quality, the breeding program should address the problem for rapid adaptation to climate change. It is important to collaborate with other breeders from different climate regions and incorporate germplasm into breeding programs from other regions experiencing the 'future climate' condition. It is important to mention that the breeding and dissemination of new and improved germplasm will remain primarily a public sector responsibility because the commercial seed industries are putting their resources primarily in developing transgenic lines with new gene(s). Therefore, it is critical to maximise the resources for public breeding programs because of the need for faster varietal replacement considering rapid environmental changes and the emergence of new diseases and pests. Cotton breeders will have to shift selection parameters from improving only yield to improving yield and fibre qualities as well as make plants more resilient against emerging threats from new pests, diseases and environmental changes.

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

Genomic research with use of new high-throughput sequencing technologies will unveil at the molecular level many important genes associated with improved yield, fibre qualities and other economically important traits. The revolution in sequencing technology with new methods of the second-generation sequence technologies including 454, ABI SOLiD Illumina and the Ion Torrent system and the latest third revolution in sequencing technology from Pacific Biosciences and Oxford Nanopore Technologies of sequencing of a single DNA molecule without the need to stop between read steps whether enzymatic or otherwise, will play a major role in next generation of genomic technologies. Integrating these advanced sequencing technologies with high-throughput phenotyping system to decode the mystery of genetic factors associated with economically important traits will have a big impact in genetic manipulation of economically important traits and marker-assisted selection (MAS) of plant breeding program.

How Can Cotton Combat Climate Change?

The following specific strategies will be very critical for

agriculture, including cotton production, to mitigate the problem of global warming:

- Develop a collaborative coordinated strategy among major scientists and policy makers of cotton growing countries to address the serious threat from climate crisis because the effects of climate change are interconnected across environmental, social and economic dimensions affecting sustainable cotton production at the global level.
- Enhance the research capacity in an effort to understand the effects of climate change and eco-friendly farm management systems in future cotton production such as conservation agriculture, no-till farming system and crop rotation based on the local needs,
- Develop a range of options for solutions against a climate crisis based on interdisciplinary approaches of genetics, plant breeding, plant physiology, agronomy, and crop management, to maximize the benefits from climate change, and,
- Bring awareness at the social and political level urgently to develop climate-smart strategies for agriculture.

Novel Technologies to Fight Insect Pests, Weeds and Diseases

Using CRISPR technology, transgenic resistant cotton lines can be developed against biotic and abiotic stresses. Genomic research using advanced sequencing technologies will open up a new paradigm to understand the complex QTL traits at the molecular and cellular level and provide tools for MAS to improve yield, fibre qualities, and other economically important traits. As discussed in the previous section, advanced phenomics technologies using computers, satellites and smartphone-based app systems with the help of advanced precision techniques, will play a major role in farm management to combat against climate change and emerging pest and disease problems.

Cotton Transgenic Technologies and the Way Forward

The next generation of cotton transgenic technologies will be dependent on the use of advanced CRISPR technology. This will save significant regulatory costs, time, and make the system more efficient for the targeted trait. Please see my comments in the previous section and consult the review paper by Lino *et al* (2018) for more detailed information with reference to CRISPR technology.

Role of Robotics, Electronics and Communication Technologies for Cotton

Robots have great potential in cotton farming and field management. They can replace many components of farm management, including planting and harvesting, replacing some of the work of conventional large tractors. For example, ordinary heavy tractors make the soil more compact, affecting soil health due because compact soil is less able to absorb and hold water along and nutrients. Using lightweight robots can overcome some of these problems. Cotton harvesting depends on

hand picking of the bolls in many developing countries such as India, Pakistan and Uzbekistan. There is great potential for small size robots with automated technologies to replace hand harvesting for use in large scale operations, like the automated robot systems used in fruit harvesting in USA and some other countries. Robots have great potential to complement much work of farm management in a timely manner, saving cost and time. For example, a robot can take images with a camera at a specific stage of the farm field and send the photo to farmers, and farmers can instruct through a smart phone using a specific app to the robot for farm operation, using precision technology such as spraying in the field to a specific field area, avoiding unnecessarily polluting the environment, and saving resources. Also, during harvesting, another small robot can go to the field to pick and collect cotton bolls with potential for multiple harvesting from the same plant at different times with potential of improving yield and fibre quality. A recent report shows that FarmLogs, a Silicon Valley startup program (founded by Jesse Vollmar in August 2012), replaces the volume of paperwork in farm management with a simple smartphone app that allows the farmers to analyse the economics of their land and plan for the future. Users pay a minimum monthly fee (a farm of less than 400 acres pays about \$20 per month). This company obtained about \$1 million in seed funding recently to expand its staff and develop the app further for the new farming season. The app improves to track everything needed in farm management from tillage, to planting, to irrigation, to scouting, to spraying, to harvest, to soil sampling. The app service also connects a working farm to make the farmer aware of completed and uncompleted tasks. Fields are divided using map data, allowing farm owners to analyse each section of their farm for profit comparing between and within crops. Other similar start-up companies are coming out to help farmers based on a mobile-friendly website instead of an app. The new technological changes will help the small individual farmer grow vast quantities of food and fibre crops in the shortest period of time. The transgenic crops are not only environmentally beneficial due to a shift in herbicide use and reduction in pesticide use, they will also have potential for developing lines tolerant to biotic and abiotic stresses, as well as nutritional enrichment.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

I am profoundly grateful to almighty God for giving me an opportunity early in my career as a graduate student at Texas A&M University to come in contact with Dr Norman Borlaug, the Noble Laureate Agricultural Scientist and Father of Green Revolution. I was deeply motivated by him to have a career as an agriculture scientist. He reminded his students in almost every class that we, as agriculture scientists, have a moral and professional duty to fight against hunger. Future agriculture scientists will face a unique challenge to produce almost double the food and fibre within the next decade, for a rapidly increasing global population under the great threat of a climate crisis due to global warming. The FAO predicts that we will

need 70% more food and fibre in 2050 than we did in 2005, to feed and clothe the rapidly increasing population (<http://investeddevelopment.com/2013/06/the-impact-of-technology-in-agriculture/> verified June 19, 2020). There will be no one-size-fits-all solution so they must be tailored according to local farming needs and problems. Sub-Saharan Africa and South Asia are projected to have the largest population growth. It is also interesting to note the percentages of people involved in agriculture in these regions are about 60% and 50%, respectively, compared to USA, where less than 2% of the population is employed in agriculture.

A recent FAO News source shows that India is the second most populous country, with a population of about 1.27 billion. Agriculture plays the most important role in the Indian economy. It is the world's largest producer of milk, pulses and jute, and ranks as the second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit and cotton. Farming contributed 23% of India's GDP and employed 59% of the India's total workforce in 2016 (<http://www.fao.org/india/fao-in-india/india-at-a-glance/en/> verified July 7, 2020). Recently, the Economics Times reported that India will have the youngest populace in the world in 2020, with an average age of 25, and 28% of its population will be 10 to 24 years in age (<https://economictimes.indiatimes.com/news/politics-and-nation/india-has-worlds-largest-youth-population-un-report/articleshow/45190294.cms> verified July 6, 2020). Agriculture, including the allied sectors, provides the largest source of employment in India. It is strange that after having achieved food sufficiency in production, India still represents a country with about a quarter of the world's hungry people and over 190 million undernourished individuals because of poverty and poor access to food. Women play an important role both in farm as well as non-farm activities as an extension of their household work with dual responsibility in the society. There is a recent trend in India of increased roles for women in agriculture, primarily due to an increase in rural-urban migration of men from the family to explore better earning sources and also growth in the production of labour intensive cash crops (<http://www.fao.org/india/fao-in-india/india-at-a-glance/en/> verified on Jul 7, 2020). A young scientist from a developing country like India will face a daunting challenge on both professional and personal levels to solve problems in Agriculture. A country like India, with about 82% of farmers being small holders, will have to address improving research and management on multiple fronts in agriculture, such as increasing incomes of farming households, diversifying production of crops, empowering women, strengthening agricultural diversity and productivity, and developing policy with careful price and subsidy policies to encourage the production and consumption of nutrient-rich crops (<http://www.fao.org/india/fao-in-india/india-at-a-glance/en/> verified July 6, 2020). It is important to mention that in last few decades consumers have migrated more to urban areas away from farmers in many countries, including USA. Most of the population are not aware directly of the effect of climate change in agriculture. Perhaps the greatest challenge facing agriculture is improving the consumer's perception on the

unpredictable effect of climate change in agriculture. It will be the responsibility of future scientists to strengthen consumer education to make them aware of the effect of climate change due to global warming in agriculture. However, among these enormous challenges, the next generation of young scientists will also witness a revolutionary change in technologies such as the potential of smartphone-based agriculture management systems, revolutionary changes in plant biotechnology, application of advanced precision and robotic tools in agriculture, etc. It will be very important for young scientists to learn and associate with the technological changes in their career. I also suggest from my personal experience the following:

- Don't listen to detractors or believe that there's knowledge beyond your reach.
- Respect others.
- Work together across the disciplines as a team to solve a problem.
- Improve your 'emotional intelligence' — an individual's ability to manage his/her own emotion and the emotions of others in every-day situations.
- Be honest and love your work.
- Give your best to accomplish your goal without thinking about the expected result.
- Develop a habit of self-awareness of how to react in a difficult situation with others and change habits, learning from your mistakes.
- Young agriculture scientists will be at the forefront of an exciting but challenging and difficult period where the future of humanity will depend on them for a better future that produces enough food and fibre to feed and clothe the growing world population.

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Cotton Vision 2030

Yusuf Zafar, Pakistan

ICAC Researcher of the Year 2012



Dr. Yusuf Zafar, USDA Cochran Fellow, was a pioneer in establishing modern agriculture biotechnology in Pakistan. The first GMO crop (*Bt-cotton*) was developed and locally released by NIBGE, Faisalabad, under his leadership. He served as Minister Technical in Vienna, Austria. He also served in International Atomic Energy Agency (IAEA) in Technical Cooperation Division before joining as Chairman, Pakistan Agriculture

Council (PARC) in 2016, an apex agricultural research body of Pakistan. Dr. Zafar received the ICAC Researcher of the Year Award in 2012. PAEC awarded him 'Best Scientist' award in 2000. He was awarded Pakistan's civil award, Tamgha-i-Imtiaz (Medal of Distinction) in 2004. He also served as elected Chairman of Asia & Pacific Association of Agriculture Research Institutes (APAARI) in Thailand from 2016-2018.

Challenges And Solutions For 2030

Cotton, the provider of most of the natural fibre to the global community, is under severe challenges. In a few leading countries either the production is static or it is declining as it is in Pakistan, Iran and even in some African countries. The biggest challenge is from the cheaper, stronger and more stable supply of high-quality synthetic fibres due to declining prices of fossil fuel. The global investment in renewable energy alternatives, emphasis on electric/hybrid vehicles and the glut of petroleum — combined with lower demand — resulted in historically low prices of petroleum products which are the feed stock of synthetic fibre. Moreover, immense technological advances resulted in the availability of varied types of improved synthetic fibres such as nano-fibres, with increasing utilities in the garment industry. The second biggest challenge relates to climate change. Though this has impacted all crops, cotton crop — being of longer duration and more prone to multiple diseases — is at higher risk and more vulnerable to total crop failure or lower productivity. The low R&D public sector investment by developing countries has resulted in a slower pace of the development of SMART cotton. The third major challenge relates to higher risk and lower profitability of cotton farmers especially in developing countries. The input cost of fertilisers, pesticides and machinery are on the rise while productivity is generally on a downward trajectory. The static or poor genetics of seed, high labour-intensive tasks during crop management and volatility in the price of raw cotton has resulted in

shrinkage of area under cotton crop. In Pakistan there is 35% decline in area under cotton in 2019 and production is 45% less than what was in 2014. This is alarming despite the fact that >60% is exported to earn foreign currency. The major reason in developing countries is low investment by the public sector which made cotton a less attractive crop.

GM cotton emerged as a promising tool and to some extent promoted as a panacea in the late 1990s. Adoption was fast and India and Brazil benefited immediately. However, the success was short-lived. The technology was not only highly controversial but required exorbitant up-front investment to comply with the ever-rising biosafety standards that kept the release of new products limited or delayed for a very long period due to weak or nonexistent approval processes. Added to this was higher product cost (GM seed) and even barriers (such as patents) for adopting new technology. The advancement in Gene Editing (GE) technologies, especially the CRISPR system, ignited new hope that is touted as relatively safe because no exogenous material is planted in the host genome. In USA and some other countries, GE technology-based products are released without undergoing a tough and cumbersome biosafety regulatory process. However, the European Union (EU) still insists on its usual regulatory process. This eclipsed the newer technology during its initial phase. Needless to say, further refinement and adoption of GE technologies by most of the cotton producing countries will allow for the delivery of a large number of cotton varieties with desired traits. The

innovative GE technology has provided new hope and if pursued at the present pace will definitely bring a paradigm shift in transforming cotton plant for vital traits. The tailor-made GE cotton will reach cotton growers in the next decade. So far genomics research has been very impressive, but molecular assisted selection is still complex and is yet to be adopted by cotton breeders as a routine. The traits that breeders are looking to improve in cotton (especially fibre quality) are really complex. The recent trend of resolving Big Data and bio-informatics is the new hope. The application of such new tools in solving complex traits is destined to be promising during the next decade. The supersonic speed of advancements in ICT will have a very positive impact on solving the riddles of complex traits. This in turn will enable science to make strong, knowledge-based decisions that enhance cotton production. Utilisation of drones for various management processes of crops including cotton is on the horizon. This will be routine in the upcoming decade.

All major crops such as wheat, maize, rice, pulses, potato, vegetables and even bananas have dedicated international centres (CGIAR) with huge treasures of diverse germplasms and a global effort to improve all aspects of that particular crop. These multilateral centres gathered international expertise and contributed to surplus food production in many parts of the globe. However, there is no such international centre for cotton, denying us a global resource of cotton germplasm, knowledge and technologies covering aspects of production. ICAC may approach International donors to establish an International Cotton Centre. I have a dream: that we will have an international cotton centre like other crops do. The global consolidation of resources, wealth and knowledge could not only preserve the existing cotton germplasm but also have a

fair and un-restricted reach and distribution of such material to the global community. Regional inter-country panels especially BRIC, OAU or OIC could take initiative to establish such centre during next decade.

Unfortunately, most of the advanced technologies for growing and harvesting cotton remain confined to few developed countries. These developments, like the first green revolution, bypassed the African continent. The resource-poor farmers of Africa need access to all modern technologies in order to earn a better living — not just enough to survive in poverty. This is the area that must be looked at with special and focused attention. The next decade should bring appreciable change by initiating 'Look Africa' or a similar program. As there is little chance for more than an incremental increase of area under cotton, the best available strategy is to enhance the productivity in Africa and some emerging Asian countries like Vietnam, Thailand, Myanmar and Iran. There is also a dire need to expand and strengthen the international donors and/or national programs such as the Better Cotton Initiative and Fair-Trade.

In conclusion, it is justified to acknowledge that cotton is under a great threat from competing synthetic fibres, not to mention the added burden of climate change. These extraordinary challenges can only be overcome through our extraordinary effort. Establishing an International Cotton Centre like the CGIAR centres is the need of the hour and should be established during the next decade. The improved cotton varieties developed through gene editing are expected to be freely available to resource-poor farmers. As a cotton scientist I have a dream to see the doubling if not tripling of the productivity of cotton in Africa. Cotton associations as well as producing and consuming nations must strive to make this happen during the next decade.

Cotton Vision 2030

Ibrokhim Y. Abdurakhmonov, Uzbekistan

ICAC Researcher of the Year 2013



Dr. Abdurakhmonov, Professor of Cotton Molecular Biology, is currently the Minister of Innovational Development for the Government of Uzbekistan. He is a globally renowned biotechnologist and currently serves as a Director of the Centre of Genomics and Bioinformatics, Academy of Sciences of Uzbekistan, Ministry of Agriculture and Water Resources, Tashkent. Dr. Abdurakhmonov has received numerous awards and honours from the Government of Uzbekistan and from international organizations. He is member of the Executive Committee of the International Cotton Researchers Association (ICRA) and is on the editorial boards of many journals. He is a leader in the field of cloning and characterisation of several important cotton

gene families. In 2010, Dr. Abdurakhmonov received the government award 'Sign of Uzbekistan', 2010 The World Academy of Science (TWAS) prize, and ICAC Cotton Researcher of the Year in 2013 for his outstanding contribution to cotton genomics and biotechnology. He was elected as The World Academy of Sciences (TWAS) Fellow (2014) on Agricultural Science and as a co-chair/chair of 'Comparative Genomics and Bioinformatics' workgroup (2015) of the International Cotton Genome Initiative (ICGI). He was elected (2017) as a member and Vice-president of Academy of Sciences of Uzbekistan. He was appointed (2017) as a Minister of Innovational Development of Uzbekistan.

Cotton science in Uzbekistan and rest of the world

Uzbekistan is the northernmost cotton growing country. It is the sixth largest cotton producer and the second largest cotton exporter in the world with annual production of 0.85-1.0 million tonnes of fibre valued at about US\$0.9 to \$1.2 billion. Cotton is grown on about 30% of the land available for crop cultivation in the country. Uzbekistan's cotton yield was close to the world average of 752 kg/ha in 2010/11 and was estimated at 804 kg/ha in 2012/13 and 812 kg/ha in 2013/14.

Major challenges for cotton farming in Uzbekistan are the commonly observed cotton pathogens and pests, as well as major environmental stress factors such as salinity, drought, heat, etc., that greatly impact the quality and yield characteristics of cotton cultivars. Accordingly, the major objectives of the cotton breeding programs of Uzbekistan are improving cotton fibre quality, lint yield, agronomic productivity, maturity, and resistance to various diseases, pests and abiotic stresses.

Due to the importance of cotton production for the country and the historic expertise on cotton farming and production gained during the past century, Uzbekistan has prioritised and promoted breeding programs, leading to a collection of one of the richest cotton germplasm resources in the world. Cotton germplasm collections that have been developed and

maintained by several leading cotton research institutions in Uzbekistan, preserving over 25,000 major cotton germplasm accessions of *Gossypium* species; wild, primitive, pre-domesticated landrace stocks, cultivars and breeding lines; mutants; genetic and cytogenetic stocks; and various types within and between cotton gene pool hybrids.

There are over 5,000 novel germplasm resources that were developed over the past decade with collaborative efforts on molecular genetic characterization of cotton germplasm resources and the establishment of modern methods of market assisted selection (MAS) and genetically modified (GM) programs. The modern cotton genomics and bioinformatics programs, in combination with conventional cotton breeding efforts, will further enhance characterisation and utilisation as well as efficient documentation and systematisation of the germplasm resources in Uzbekistan.

Globally, cotton research has witnessed many progressive developments over the past half-century to address the above-mentioned challenges and limitations, and cotton researchers worldwide have initiated and performed largely coordinated research projects in almost all aspects of cotton science. These efforts have greatly accelerated cotton research worldwide and helped to address the key issues of cotton production and farming.

Over the past decade, orienting itself to global cotton science developments, the Uzbekistan cotton research community continuously updated its primary research directions and successfully implemented an innovative research agenda that resulted in a number of key innovations that are now being applied to cotton production in the country.

Some of the best examples of these progressive developments in cotton research include the tremendous progress in cotton germplasm development, application of molecular markers and de novo gene/small RNA/microRNA characterisations to the development of molecular breeding and cotton biotechnology in Uzbekistan.

For instance, scientists succeeded in characterising cotton germplasm resources using both traditional quantitative trait loci (QTL) and modern linkage disequilibrium (LD)-based association mapping strategies. As a result, cotton breeding research has been enriched with molecular breeding techniques and 'breeding by design' approaches such as modern marker-assisted selection and genomic selection. This has not only accelerated the development of superior cotton cultivars with lower costs and less time, it also helped in widening the 'conventionally narrow' genetic base of novel cultivars via introduction of 'yet-unexploited' genetic diversities from cotton germplasm resources.

Development of cotton genetic engineering (GE) and somatic embryogenesis research have further revolutionised cotton science in Uzbekistan, resulting in the development and commercialisation of Uzbekistan's own RNAi-based 'biotech' cotton varieties with early maturity, increased yields and superior fibre quality traits. Global achievements on GE research with transgenic, cis-genic, and intergenic approaches — in addition to its integration with traditional and modern breeding methods such as backcross, gene stacking, and forward breeding — carry great potential to boost the yields and quality of cotton, which undoubtedly ushered in a new era for cotton research and production in Uzbekistan.

Due to improved understanding of cotton genomes and genetic signatures, cotton researchers have discovered the key genes that govern many of cotton's major fibre quality traits. The improvement of key fibre quality characteristics is the top-most priority of cotton biotechnology in Uzbekistan and many other parts in the world.

These innovative developments in cotton research have provided golden opportunities for improving fibre quality parameters; oil and seed quality traits; cotton fertility and embryogenesis; and resistance to pests, viral, bacterial, and fungal diseases; and abiotic stresses through application of novel trans-genomics (eg antisense and RNAi) and genome editing tools (eg CRISPR/Cas) in cotton. Cotton research advances over the past 10 years in Uzbekistan include also the development of cotton bioinformatics research and resources to analyse and utilise a large volume of 'gossypomics' data in the plant genomics and post genomics era.

These achievements have greatly accelerated current cotton research programs in Uzbekistan. They will undoubtedly foster

the exploitation of genetic signatures underlining key cotton traits, helping to overcome existing negative correlation and narrow diversity obstacles through a 'skilled' utilisation and introduction of the complex-effect genetic signatures.

However, as we move toward 2030, Uzbekistan's cotton research community extensively intends to develop fine-tuned innovations for cotton breeding and farming with the integration of knowledge gained from '-omics' sciences, system biology, and chemical genomics as well as from the translation of the concept of 'personalised agriculture', which should also be beneficial for cotton production worldwide.

We work on understanding cotton crop physiology in a holistic view from seed germination to maturation stages under different temperatures, water, light, and nutrient applications, as well as in the event of global climate change scenarios. The key research between now and 2030 in Uzbekistan will focus on cotton farming and management practices, as well as the utilisation of new generation agrochemicals and bio-fertilizers and their assessment tools, including modern conservation tillage, winter cover cropping, site-specific nutrient application methods and remote sensing technologies. Research on integrated pest and disease management programs and cotton seed science development will be of great importance in the movement towards sustainability.

The priority tasks in the short- and medium-term research agenda toward 2030 under the current and projected global climate change scenarios will be as follows:

- Building inventories, unification and digitalisation of existing microbial strains and plant germplasm collections in the country including cotton,
 - ^a Fostering the use of germplasm resources in genetics and breeding research targeting to study:
 - ^a genotypes or genes conditioning increased photosynthesis rate, CO₂ uptake and heat resistance,
 - ^a genes or microbiota helping to improve plant root development and accumulation of specific carbons resistant to decomposition (such as suberins), and
- efficient genotypes suitable for agriculture.
- Conducting biologic research on nitrate uptake and water use efficiency in the global warming environment and revisiting current 'nitrogen: phosphorus: potassium' (NPK) fertilisation ratios for cotton farming and correcting NPK-based plant physiology under global warming will be key research directions to address current yield decrease in cotton production of Uzbekistan.
- Improving the soil fertility in cotton farms that have been depleted of carbon and other nutrients after decades of intensive modern farming will be another priority area.

The Ministry of Innovative Development of the Republic of Uzbekistan — the country's representative government organisation for scientific and innovation development — is taking several practical actions and steps to address and develop research activities.

These include but are not limited to:

- Development and approval of two legislative documents –the decrees of the President of Uzbekistan on development biology-chemistry sciences (<https://regulation.gov.uz/uz/document/14140>), and biotechnology (<https://regulation.gov.uz/uz/document/15603>) in Uzbekistan. These two documents consider all aspects of scientific and infrastructure reforms including adding more financing resources, as well as the creation of modern platforms for research and commercialisation of its results. We aimed to create a national microbial collection centre and a national centre for cotton germplasm that unifies all existing cotton collections in the country. Efforts to establish a new plant seed science research institute in Tashkent and ‘soil clinic’ centres across the regions that are equipped with mobile testing laboratories are in progress.
- Establishing a new research grant call system (<https://mininnovation.uz/uz/competitions>) and monthly announcement for thematic grant calls for above-mentioned priority directions that has helped to increase 5-fold research funds to these directions compared to past three

years (https://mininnovation.uz/uploads/mininno/tanlov/tur_19/Bilogiya%20fanlari%20bo'yicha%20NEW.pdf).

- Commercialise scientific results of the research institutions through the establishment of small investment companies and start-ups. Because of the evolving cluster cotton farming practices over the past three years, the Ministry initiated the new 50:50 funding mechanisms for research projects in which 50% of funding comes from private cluster companies. Furthermore, in order to attract more funding for these priorities, Ministry officials are working closely with the World Bank to initiate a ‘science commercialisation’ project that will incorporate key steps in scientific development in Uzbekistan, including cotton science (<https://www.uzdaily.uz/en/post/52112>).

In summary, cotton science development remains the key focus in Uzbekistan, and its development agenda and priority directions as we move toward 2030 target the current problems of cotton farming. Some of the scientific discoveries in Uzbekistan are expected to be useful for global cotton production.

Cotton Vision 2030

Mehboob-ur-Rahman, Pakistan

ICAC Researcher of the Year 2014



Dr. Mehboob-ur-Rahman has been working as Group Leader and Deputy Chief Scientist of Plant Genomics & Molecular Breeding (PGMB), Agric. Biotech Division National Institute for Biotechnology & Genetic

Engineering, Faisalabad, Pakistan. He is experienced in cotton genome research as an active partner in various international mega-genome sequencing projects, studying the extent of genetic diversity among various cotton species and utilisation of DNA markers for cotton. The information generated has been published extensively in various journals as a submitting author or as a co-author. His total number of publications is close to 100 including 17 chapters in foreign books. He also edited a book on cotton. His total Impact Factor exceeds 200 with more than 5,000 citations (Google citation). He supervised >30 PhD/MPhil students and >25 researchers (national); most of them established the genomic facility in their host institutes. In 2016, he acted twice as 'Expert' by the FAO/IAEA Vienna for training scientists (>30) of 18 countries (mostly developing) for using next-generation genomic techniques for the development of improved crop cultivars. Using various genomic tools,

Dr. Rahman has developed nine cotton varieties as a Principal Breeder. All these R&D activities were supported by winning 20 projects (18 as PI and two more as Co-PI) from various national and international funding agencies. All these efforts were appreciated and acknowledged by the International and National Agencies including Govt of Pakistan by bestowing him with several recognitions including *Outstanding Scientist: Biotechnology (1st Position) Award-2009*, *LCCI Research Scientist Award-2010*, Third World Academy of Sciences Award in Applied Science-Technology in Agriculture (under 40 in Agriculture)—2011, *Presidential Award for Pride of Performance—2012* and ICAC Researcher of the Year in 2014. Dr. Rahman has been an invited speaker and attended many international conferences in Austria, Brazil, China, India, Italy, Japan, South Korea, UAE and USA.

Last year, two remarkable milestones have been witnessed for cotton. It was the first-ever plant species grown on the moon. On the genomic front, high-quality contiguous genome assemblies of tetraploid cultivated cottons were constructed. This genetic information paved the way in elucidating the evolution, adaptation and redesign of the genetic circuits of high quality fibre. These genetic discoveries together with the parallel progress made in 'omic' science can be instrumental for overcoming the challenges depressing cotton production in several cotton growing regions.

The Three Big Challenges for Cotton Sector in the Next Decade

1. Insect pests & diseases

A cotton crop that is protected from the infestation of insect pests and diseases produces high yields. Protection against insect pests (particularly chewing pests) achieved by incorporating Cry genes has weakened and now requires supplemental chemical insecticides for achieving control for bollworm management, particularly pink bollworm. Similarly, the evolution of new strains of diseases (especially cotton leaf curl disease and bacterial blight) remains a potential threat to cotton production. Cotton leaf curl can spread to other countries where whitefly is prevalent. If these two factors are not properly addressed, I am afraid they could eliminate cotton from several cotton growing regions. The potential of minor pests to evolve into major pests could be a future challenge as well; for example, infestation of mealy bug and dusky cotton bug

in Pakistan appears concerning. This scenario could also arise in other countries.

2. Changing climate (excessive heat)

Like many other crops, cotton has been adversely affected by global warming and its impact has been witnessed in the form of high temperatures, aberrant rainfall, unpredictable climatic adversities, etc. It has been reported that the temperature will continue to increase in the 21st century. High temperature retards cotton growth that may lead to the shedding of small fruiting bodies (square) and reduced boll size; together these factors lower lint yields. Also, the high temperatures could render pesticides ineffective. This phenomenon can be more detrimental to those cotton growing regions where temperature often exceeds 40°C.

3. Competition with other crops as well as synthetic fibres

In the present scenario, area under cotton can decline due to the low price of lint in the international market, and

secondly due to the availability of synthetic fibres at very low prices. Synthetic fibres may continue to pose a big challenge to cotton because their prices can further shrink due to the low price of petroleum, as production costs of cotton continue to rise over the years. Ultimately, farmers could shift to cultivation of other crops to increase their profitability. For example, in Pakistan, area under cotton has significantly been reduced by about 30% in recent years. Major factors include the high cost of production and higher infestation levels of the pink bollworm.

Novel Production Technologies That Can Break Yield Barriers

Yield losses during harvesting and trash contamination in cotton remain the areas where sophisticated mechanical pickers are needed most. In the future, the issue of contamination will be more serious in countries that grow cotton varieties containing trichomes which make the leaves entangle with the harvested fibres. Best agronomic practices that can conserve water in the future should be adopted. For example, the use of mulch as well as drip irrigation in cotton cultivation help in reducing the amount of irrigation water and reduces the need for herbicides. Best management practices including the smart use of fertiliser, selection of varieties that support high population density and the application of micronutrients (particularly in developing countries) will also be useful for achieving high cotton yield.

Promising Recent Advances in the Science Of Genomics, Genetics and Plant Breeding

The milestones of cracking the genome sequences of all cultivated cotton species as well as possible progenitors — followed by the construction of high-quality contiguous genome assemblies — have been achieved. All these efforts resulted in elucidating the evolution and adaptation and redesigning the genetic circuits of high-quality fibre of these polyploids. The journey was started by Prof Andrew H Paterson and colleagues in 2006 by conceiving the concept of sequencing the *G. raimondii* (one of the progenitor's species). Resultantly, two papers appeared in 2012 on the sequencing of D-genome by two independent studies followed by sequencing of *G. arboreum*. Thereafter, two papers on genome sequencing of *G. hirsutum* (known for high yield) were published independently by two different research groups in 2015 from China, while *G. barbadense* (known for high quality lint) by two different groups in 2015. However, the previous genome assemblies of tetraploid cottons were not contiguous, thus rendering a lot of information inaccessible to the researchers. This mammoth task was achieved by Professor Zhang and colleagues for two cultivated cotton species in 2019 by generating a huge number of sequence-reads (800 Gb, >330x) — sufficient to differentiate errors from the actual sequence. They also constructed an ultra-dense genetic map by placing 6.1 million SNPs. Hence, several long-awaited puzzles — including the evolutionary dynamics of the cotton genome, functional dynamic of genes

after combing in one nucleus and getting genomic insight of the traits that played a gigantic role of adoption of both the cotton species in various environments as well as cultures — could be solved.

Producing quality lint/fibre together with high productivity have remained the central focus of cotton breeding programs; however, the traits are difficult to bring together in one cultivar due to the complex genetics of ESL. More than 50% of genes (~45,000) contribute to shaping the fibre phenotype in tetraploid cotton. It was also shown by Zhang and his co-workers in 2019 that sucrose transporter (*GbTST1*), Na⁺/H⁺ antiporter (*GbNHX1*), aluminium-activated malate transporter (*GbALMT*) and vacuole-localized vacuolar invertase are responsible for long fibre (ELS) in *G. barbadense*. Secondly, the preferential expansion of a few gene families, such as the ADP-ribosylation factor (ARF) GTPase family, also plays a role in conferring long but strong fibre in ELS cotton. This information can be used for initiating targeted breeding programs for improving high quality traits in cotton.

Similarly, on the breeding front, a major germplasm transfer from USA to Pakistan (sponsored by USDA through cotton the productivity enhancement project, ID-1198) has resulted in the identification of several cotton accessions conferring resistance to cotton leaf curl disease. Among these, Mac-07 has been extensively used in developing cotton cultivars with improved tolerance to the disease. Similarly, another joint activity was initiated (through a Pakistan-China project entitled 'mining genes for high yield, super fibre and heat tolerance, PSF/NSFC-AGR/P-NIBGE (12)') for screening germplasm against heat as well as studying fibre traits in various environment. Through this project, heat-tolerant cotton genotypes were identified and more than 500 genotypes were sequenced. Hopefully this project will yield important findings that can be instrumental in understanding the genetic circuits of heat tolerance together with high yield.

Contribution of Genomics Research For Yield Enhancement and Fibre Quality Improvement

Cotton varieties with outstanding genetics, together with the application of best management practices, can ensure harvesting the maximum yield with improved lint quality. Cotton varieties have achieved maximum yield potential. Future yield enhancement with improved lint quality is expected to be derived from cultivating the resilient cotton varieties. Thus, the role of genetics of a cotton variety will be more important particularly for helping the resource-poor cotton farming communities.

Several genomic assays including transgenic approaches as well as DNA markers are being used to improve yield as well as fibre quality. DNA markers can be deployed in interspecific and intraspecific populations for screening plants containing the desirable loci. For developing such populations, an adapted elite cotton cultivar can be crossed with obsolete varieties, accessions, and even wild species. For example, several QTLs were introgressed for high fibre quality traits from *G.*

barbadense (ELS) to *G. hirsutum*. Similarly, resistance to cotton leaf curl disease has also been partly transferred to *G. hirsutum* from *G. arboreum*. A successful introgression breeding program relies on the availability of DNA markers which can help in cutting down the number of breeding cycles as well as avoid the dragging of unwanted genes. Since both species have been sequenced, and the number of important loci involved in conferring high lint quality trait can be easily tagged by designing new markers, the new approaches can revive introgression breeding work.

High lint production can also be achieved by enhancing the lint-to-seed ratio beyond 50%. Natural genetic variations are present for this trait in a few accessions of *G. hirsutum*. A few genotypes exceed 50% ginning out turn. In most countries, lint recovery of cotton ranges from 30% to 45%. This trait is very complex but it can be tailored using DNA markers; it is otherwise difficult to improve using conventional breeding approaches.

Another option could be the exploitation of hybrid vigour. For instance, hybrid vigour in corn resulted in a multi-fold increase in corn production worldwide. Developing cotton hybrids showing 30% increase in lint production over the standard cotton variety may convince farmers to cultivate hybrid cotton. This task is difficult but achievable through exploring the best combiners. Also, breeding hybrid cotton is handicapped due to the non-availability of reliable genetic and/or mechanical procedures for emasculation. Various genes encoding sterility and restoring the fertility have been identified; however, most of these are temperature sensitive. Work on understanding the genetics of hybrid vigour can be a useful option that will help in targeting important genes for amending their expression, thus hybrid vigour can be fixed.

Genomic science is heavily dependent upon the availability of genetic resources followed by associating the phenotypic diversity with the sequence diversity. The extensive re-sequencing that will be required is now possible, and many groups are doing this. It will help in exploring genetic mechanisms for a particular trait. Once trait-linked genes are identified, they can be used for higher expression through adopting transgenic approaches or can be directly mutated for altering their expression using targeted approaches like RNAi and CRISPR.

How Can Cotton Combat Climate Change?

Climate change is largely driven by escalating temperatures which makes cotton vulnerable to several other stresses including drought, waterlogging due to excessive rainfall, etc. These factors also interfere with management practices including efficacy of pesticides, etc. One of the best strategies to combat escalating heat is to develop cotton varieties that can tolerate a 50°C day temperature and a 30°C night temperature. In this regard, a trait such as boll retention at high temperature is considered as the most appropriate selection criterion. However, such varieties are usually high input demanding. When inputs are scarce, such varieties do not show their yield potential. Thus, selection for varieties that can grow indeterminately — even by sacrificing a few bolls on the first few sympodial

branches — would be the desirable feature for encountering scarce water resources as well as high temperatures. Secondly, breeding for small-to-medium size leaves would allow sunlight to reach the lower leaves and open bolls, thus avoiding boll rot during the rainy season. A canopy of such cotton varieties also facilitate the uniform application of pesticides on even the lower leaves of cotton plants.

Genetic resources — particularly land races that have been evolved in low-input regions — can be utilised. The deployment of genomic-based selection procedures would be the best choice for transferring genes into domesticated high yielding varieties. For this, extensive screening of germplasm would be required to identify genotypes exhibiting traits such as resistance to various insect pests and diseases, better nutrient economy, delayed leaf senescence, and yield consistency across the environments. Germplasm originated in different cotton growing regions can be screened in countries that are facing the impact of climate change. Segregating populations can also be screened through joint collaboration. Later, the newly developed candidate lines can be tested in different environments for studying their adaptability. This approach is straightforward and does not require significant resources. Thus, the exchange of cotton germplasm will remain the most valuable tool for cotton development across the globe. DNA markers also can be very instrumental in this endeavour because the trait is not as complex as drought tolerance.

Genetic introgressions from *G. hirsutum* into *G. barbadense* genome and vice versa geared up the rapid evolution of both species that help them to adapt in new environments. This information suggests that the introgression breeding programs should be continued for widening the adaptability of newly developed cultivars especially in changing environments. The handicap in introgression breeding can be improved by deploying DNA markers for help in monitoring the introgression of genetic loci coming from the wild cotton species. It will cut down the number of breeding cycles by avoiding the linkage-drag of unwanted genes.

Another option is to deploy genes from other organisms, including distantly related plants growing under harsh climatic conditions. Efforts are underway, including the introduction of drought-tolerant genes including *TsVP*, and the H⁺-PPase-coding gene derived from *Thellungiella halophila* in cotton resulted in improved shoot and root growth compared with that of their wild types. Similarly, *ScALDH21* taken from *Syntrichia carninervis* exhibited greater plant height, larger bolls and greater fibre yield in cotton. Single gene introduction for complex traits in cotton would not be successful until and unless the genetic mechanism for heat tolerance is fully understood.

Novel Technologies to Fight Insect Pests, Weeds and Diseases

Resistance to insect pests in the cotton genome has been developed using genes (*cry* genes) derived from a soil bacterium and success has been demonstrated worldwide. Now the resistance conferred by these genes has been broken down by

insects in different part of the world. Also, the potential for the emergence of minor pests into major pests is another threat to cotton sustainability. For example, before the cultivation of *Bt*-cotton in Pakistan, mealy bugs and dusky cotton bugs remained unnoticed on cotton — because they were indirectly controlled by the application of insecticides used to kill lepidopteron pests. Now farmers are expected to control these newly emerged pests. Such a scenario could emerge in other cotton growing countries. Improving the genetics of cotton by adding a range of novel genes derived from other alien sources under the tissue-specific promoters would be very handy in combating insect pests more effectively. For example, efforts to identify new genes from other sources such as the *hvt* gene derived from a spider was tested in cotton for studying its response to chewing insect pests and produced encouraging results. Similarly, several other genes encoding phytohormones (such as jasmonates, which can aid the defence against insect herbivory) have recently been characterised, which have the potential for combating bollworms in the future.

Also, the genes and or their transcription factors (DREBs, ERFs, ZIP, WRKY etc.) derived from other plant sources including wild species can be characterised by their introduction in cotton. It is worth mentioning that the protein expressed by the *cry* genes did not interact with the complex pathways involved in shaping the phenotype as these were novel; however, genes of a plant may interact with other host proteins, which could change the expression of the transgene. New horizons for controlling insect populations, such as production of intact RNA molecules of essential proteins in plastids, should be undertaken. New genes conferring resistance to herbicides (other than *EPSPS*) are required to suppress the emergence of herbicide-tolerant weeds in cotton. However, the plant's source genes would have a high chance of acceptance by the end-user. Identifying new marker genes (other than the conventional antibiotic gene) would be another step toward increasing the acceptability of GM crops worldwide.

Other approaches — including the pyramiding of *Bt* protection and RNAi against *Helicoverpa armigera*, one of the world's most destructive pests of cotton — can be done to build a bridge against the new strains of lepidopteron insect pests and also to substantially delay the evolution of resistance.

Another menace on the Indian subcontinent is the infestation of the most invasive insect pest whitefly (*Bemisia tabaci*), which is also the vector for viruses causing leaf curl disease in cotton. RNAi can also be used to engineer resistance to CLCuD by targeting important whitefly genes. Various genes of pathogens can be targeted using RNAi as was previously shown by targeting virus genes (REP, CP, V2, etc.) for reducing the virus titre in the infected cotton cells, and also to control the whitefly populations using sex-lethal genes. These new strategies can complement host plant resistance to buffer the rapidly evolving viral genomes. Similarly, cotton verticillium wilt, called 'cotton cancer', is detrimental to cotton in China. RNAi and virus-induced gene silencing (VIGS) were deployed to demonstrate the efficacy of 14-3-3c/d, NINJA, and CYP82D genes for controlling this disease.

Cotton Transgenic Technologies and the Way Forward

Until now, constitutive promoters were used for expressing transgenes in cotton that make the transgene express in every part of plant including developing seed. Such kind of gene expression-initiated a debate on acceptability issues of GM cotton products in several international markets. The use of alternative promoters that can only express in the required organs (green part) may help to settle this issue. In this regard, the green-tissue-specific promoter PNZIP was stacked with *Cry9C* gene. Relatively 100-time lower expression of *Cry* protein was detected in fruiting parts including in developing seed. Thus, the safe use of cotton seed cake can be ensured in the future. It is therefore suggested that the use of some alternative promoters (tissue specific) may be used for addressing the concerns of end-user. Also, the identification of new marker genes (eg genes conferring fluorescent proteins) instead of using conventional marker genes (eg an antibiotic-resistant gene) would be useful in making GM foods safer. These genes should be tested for an extended time period by exposing them to multiple model organisms that will convince end-users that they are safe. Similarly, efforts should be made to introduce new genes and their transcription factors which are derived particularly from wild species including cotton. Such transgenes would have a high chance of acceptance by the end-user.

Cotton seed oil for human consumption is extracted in several cotton growing countries including India, Pakistan, China and USA. The quality of the oil is not as good as other edible oils due to the presence of anti-nutrients such as gossypol, a naturally occurring terpenoid compound that is found in pigment glands. These glands are present in almost all upper parts of the cotton plant. The gossypol glands provide a defence against pests and diseases. However, they are toxic to animals and humans. Efforts were made to eliminate gossypols from the seed while retaining gossypol in all other plant tissues to protect them from insect pests.

Apart from the aforementioned traits, transgenic strategies including RNAi and the enhanced expression of transgenes have also been demonstrated to introduce several important agronomic traits in cultivated cotton, such as cotton fibre's development and responses to stress. However, these studies have largely been performed under controlled conditions. Their applied efficacy under natural field conditions still needs to be assessed. Currently, a newly discovered genome-editing technology called CRISPR-Cas has shown the potential to edit genes and enhance and/or silence their functions. For example, gossypol-free cottonseed can be produced by silencing the genes conferring gossypols to the seed. A major advantage of this assay is that the function of the gene can be characterised and new cultivars can be evolved without introducing any foreign genes; hence, the technology may be acceptable to countries that have sceptical views about GM technology.

It is suggested that if all tools, including conventional and non-conventional genetic assays and the application of best management practices, could be applied together it would help in

developing resilient cotton varieties that will pave the way for achieving sustainability in cotton production.

Role of Robotics, Electronics and Communication Technologies for Cotton

I certainly believe that robotic technologies that can collect data and spray cotton plants in the shortest amount of times will certainly help in elucidating the genetic mechanisms of various traits. The huge amount of data can be analysed very quickly using bioinformatics assays. The effective communication among the scientific community as well as farmers will ensure the efficient flow of knowledge pertaining to the new discoveries and inventions. The role of communication technologies will be more useful for extension workers and farmers.

Other Exciting Novel Innovations and Game-Changing Technologies

There are three genomes in a plant cell; however, the success story of genetic transformation came from the nuclear genome transformation. The insertion of foreign genes is random. Secondly, the expression of the introduced gene in a nuclear genome could either be low or completely silenced; the insertion of transgene in chloroplast is site-specific and also results in very high expression (>70% of total soluble proteins). The genome of chloroplast does not travel through pollen, particularly in field crops, and thus the transgene can be contained. Until now, chloroplast transformation was ineffective to the laborious and lengthy tissue culture-based protocols for recovering trans-plastomic plants. Any successful effort will lead to over-expression of the transgenes, thus better protection to insect pests and harvesting of high cotton yields with improved quality can be achieved.

In the future, efforts towards pan-genome studies of the genus *Gossypium* will help in elucidating genetic circuits of important complex traits in cotton. This will lead to the initiation of targeted breeding in cotton. Thus, the desired genetics of a cotton

plant can be designed in a computer. To achieve this, collaboration among cotton experts — including molecular biologists, bioinformatics specialists, breeders, agronomists, physiologists and extension workers — is necessary to make the cotton crop more competitive and profitable.

Automation gadgets such as robots are being used for collecting field data from each cotton plant, something that was not possible previously. Such technologies will facilitate the characterisation of several hundreds of accessions in one experiment and limited hands can do it in the shortest possible time.

Earlier, science's emphasis was to explore the upper parts of cotton plant. A diversion of that focus is required to study the root traits that will help in identifying genes conferring high root biomass. These studies would also help in studying the interaction of microbes with roots, which may lead to lessen the dependency on chemical fertiliser.

In summary, the adoption of high-tech management practices, utilisation of untapped genetic resources in breeding, cultivation of cotton varieties with excellent genetics, monitoring of risk and efficacy of transgene in ecosystem, and the continued search for new genetic resources would help achieve sustainable cotton production.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

Most students like to work in labs to unravel the various mechanisms of cotton plants as a part of their PhD studies, or they started their careers as researchers or university teachers. Once the information is generated and published, however, very few scientists translate that lab knowledge into studying the impact on cotton in the field — and then to farmers, either in the form of improved seed or recommendations for growing better cotton. The key message is: Develop your projects (preferably collaborative ones) with the aim of solving the real needs of the cotton farming community rather than pursuing aimless science.

Cotton Vision 2030

Greg Constable, Australia.

ICAC Researcher of the Year 2015



Dr. Constable is former Principal Research Scientist, CSIRO Food and Agriculture, Australia. He served as the Director at CSIRO, Australia. He is considered as the leader of cotton research in Australia and the world. In 2003, the influential Australian business magazine the *Bulletin*, named Dr. Constable 'Australia's smartest scientist'. Some of Dr. Constable's other awards include: CSIRO Chairman's Medal in 2011; Outstanding Research Award in Cotton Physiology at the US Beltwide Cotton Conferences in 2008; ATSE Clunies Ross Award in 2006;

Australian Cotton Growers Research Association Researcher of the year in 2006; Australian Government Prize for Rural innovation in 2005; CSIRO Chairman's Medal in 2003; Centenary Medal for services to plant production and processing in 2001; and the Australian Cotton Growers Research Association Researcher of the Year in 1984. In 2001, Dr. Constable was elected a Fellow of the Australian Academy of Technological Sciences and Engineering for his cotton research.

Three Big Challenges for the Cotton Sector in the Next Decade

1. Competition with synthetic fibres is a challenge for cotton in terms of price, demand, reputation and marketing. Continued promotion of cotton's advantages is necessary, particularly among urban populations. Further gradual improvement in fibre quality also is important to attract buyers in the spinning industry.
2. Water (and land) availability are critical issues in many cotton production systems, due to drought and/or competition with urban needs. This is particularly difficult due to the rapid increase in urban population and decrease in rural population in many countries. World Bank data shows that cotton producing areas in India, Francophile Africa and China have more than a 40% rural population; USA has 18% and Australia, Brazil and Argentina have 14% or less. Mechanisation is one large difference between those groups. High water use efficiency is an important target with crop agronomy.
3. Crop protection from diseases, weeds and insect pests. Integrated Disease Management (IDM) aims to utilise several methods, one of which is breeding cultivars that confer resistance. Crop rotation can reduce disease incidence as well. Integrated Weed Management (IWM) relies on a system where weeds are controlled by a range of methods, rather than reliance on herbicides alone. There are many

instances of continued use of the same herbicide leading to the weed developing resistance. Crop rotation is also a strong component of weed management. Integrated Pest Management (IPM) also requires a range of control measures and as cotton is attractive to many insect pests, cotton entomology is strong in cotton literature. Transgenic insect and weed traits have required a stack of up to three different genes each for insect and weed traits to combat resistance (covered below).

There are always challenges for agricultural industries and cotton has had its share over many years, with issues such as labour, water requirements and pesticide use/contamination. One general challenge is to raise yields in some of the low-yielding production systems. Across the globe there is a very wide range, from 350 to 2500 kg lint/ha, in commercial yields. Francophile Africa is one example of low yield and if the solution were easy, there would have been improvements by now. A concerted effort is required and it must involve socio-economic issues as well as the development of economically productive cropping systems.

Novel Production Technologies that Can Break Yield Barriers

We have estimated the theoretical yield of cotton to be around 5,050 kg lint/ha (Constable and Bange, 2015). That figure is unlikely to be achieved in large scale commercial practice

because it is rare to have perfect conditions throughout the season. However, the extremes of commercial yields across the globe are considerably different: from <400 kg lint/ha to >2500 kg lint/ha. The constraints to production also vary. Liu *et al* (2013) published data from a 30-year study comparing new locally bred Australian cultivars with older standards. The data involved multiple sites each season, covering a range of environments; it was found that there is a strong interaction between Genotype (G), Environment (E) and Management (M). Yield gain for new cultivars from 1995 to 2009 was 18.3 kg lint/ha/year. Recent cultivars also had increased stability across environments. Overall yield gain was attributed to genetics (G) (48%), management (M) (28%) and GxM (24%). The magnitude of GxM differed across production environments (GxExM). The lesson from this study was that modern management was necessary to achieve the best performance from new cultivars. Interaction and compounding between stresses is important in determining yield: Occasional stress during the season can reduce yield more than expected. For example, one day of moisture stress can reduce yields by as much as 15 kg/ha. With three one-day stresses at different times in the season, the yield loss is 65 kg/ha — much more than 3x15 kg/ha. Thus, in rainfed systems with low rainfall, yield can be very low.

The concept of Integrated Crop Management (ICM) highlights the need to ensure all necessary aspects are covered. IPM, IDM and IWM have been covered above, but two other important elements of production are Integrated Soil Management (ISM) and Integrated Quality Management (IQM). ISM ensures that soil health and the practices of soil and seedbed preparation, fertiliser rates and application are all addressed months before sowing the cotton crop. Fallow, crop rotation and appropriate tillage are essential elements of ISM. IQM focusses on ensuring the delivery of the best fibre quality. This will include defoliation timing (if necessary) and harvest to ensure clean and mature fibre all the way through ginning (the grower and ginner need to understand each other's constraints). ICM is not necessarily novel — but the integration of practices is vital.

Promising Advances in the Science of Plant Breeding, Genetics, Genomics and Transgenics

A recent development is the production of high-quality cotton reference genomes (for *G. hirsutum* and *G. barbadense*). That has opened many new options for genetics, functional genomics and mutant gene identification in cotton. Much of that is still used strictly for academic applications but a possible game changer is the rapid reduction in the cost of genome sequencing; there are new protocols that might reduce the price of sequencing to US\$100. This would enable sequencing individual plants in a breeding program, for example, and the ability to apply genomic selection to real breeding problems. Whether it will be better than traditional phenotypic selection is yet to be proven, but it should be used to add value. The development of automation and robots to sample the DNA of thousands of individual seeds speeds up genotyping.

Transgenic cotton with insect and herbicide resistance has been used commercially for 25 years. The value of Bt cotton, for example, depends on the severity of Lepidopterous pests. In Australia, once two and three Bt gene stacks were available, there was good control of *Helicoverpa* sp., the most damaging pest. The number of insecticide sprays was reduced by 90%. There had been a very aggressive IRM protocol established when it was first released in 1996. There is less value in herbicide-resistant traits in Australia so the use of residual herbicides has declined, providing significant environmental benefits. Other desirable targets such as stress tolerance, yield enhancement and others, tend not to have worked because the interactions between genes and pathways are not well understood to engineer them. Many possible traits have patents held by large companies.

How Can Cotton Combat Climate Change?

Climate change (especially warming) and climate variability (especially rainfall) are major global issues that cotton farmers need to deal with. The management options are:

- avoid the problem by changing sowing time or moving to another location,
- tolerate the conditions through breeding for heat tolerance and water use efficiency/water stress tolerance, or
- apply enhanced agronomy systems.

Uneconomic systems should cease. Production systems with reduced greenhouse gas emissions are expected by the general public.

Role of Electronics, Communication Technologies, Models and Apps

With internet and handheld devices, it is possible to have comprehensive apps for many aspects of managing cotton crops. The accurate identification of weeds, pests and diseases, and weather forecasts are possible. Models can be used to optimise irrigation scheduling, fertiliser requirements and yield.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

Research into different aspects of cotton production; breeding and processing are very interesting and rewarding. Young scientists need to learn, and perhaps specialise, but it is critical for them to understand the system at a level above and below their chosen area of specialisation. A breeder, for example, should have knowledge of molecular and genomic tools and also of the chosen target agronomy production system. This ensures an appreciation of research gaps and collaboration with other scientists throughout the research spectrum.

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Cotton Vision 2030

Jack C. McCarty Jr., USA

ICAC Researcher of the Year 2016



Dr. McCarty works for Agriculture Research Service of the US Department of Agriculture. Currently, he is an Adjunct Professor at the Mississippi State University, Mississippi, USA. Dr. McCarty's research area is Agronomy/Breeding with emphasis in expanding cotton's genetic diversity, conversion of photoperiodic primitive races of cotton to day-neutrality, germplasm enhancement for improved fiber quality, and breeding for root-knot and reniform nematode resistance. During his research career he has had enough success to remain motivated and enough failure to remain well grounded. He has published 163 peer reviewed manuscripts and

102 non-peer reviewed papers. Dr. McCarty's innovative research developed over 500 germplasm lines. He was awarded as the Senior Research Scientist of the Year, USDA in 2014; Alumni Achievement Award, College of Agriculture and Life Sciences, Mississippi State University in 2012; Outstanding Paper-Plant genetic resources, Crop Science Society of America in 2000; Agronomist of the Year - Mississippi Chapter, American Society of Agronomy in 1997; Cotton Genetics Research Award - National Cotton Council of America in 1990 and Outstanding Young Men of America in 1979.

The Three Big Challenges for Cotton in the Next Decade.

1. Probably the biggest challenge is for the cotton industry to remain a profitable enterprise, particularly at the farm level. This will require careful planning and management of input cost, much of which is dictated by suppliers. Every input cost such as equipment, seed, fertilizer, irrigation, pesticides, land, labour, and others must be evaluated, and efficiencies will need to be gained in all areas. New technologies such as precision planting, improved irrigation systems, site specific fertilization and pest management, should improve efficiencies; however, they will probably come as a cost. To offset these costs yields will need to increase and the price for seed and lint will need to increase. The demand for seed with value added traits and fibre by the textile industry will need to grow. Consumers must be educated to the benefits of using cotton textile and seed products that are produced from a sustainable renewable resource. The overriding issue for the cotton industry over the next decade will be the ability of all sectors to remain profitable.
2. The ability of cotton production to adapt to a changing environment will present challenges. Cotton is currently grown over a wide range of climates throughout the world; however, there appears to be greater extremes in weather patterns. Many parts of the world are facing water shortages, not only for crop production but for human consumption. Research efforts must be increased and expanded to address this challenge in the coming and future decades.
3. Protection of our soil resources for future generations is an ongoing challenge. Depletion of soil nutrients without supplemental fertilization, water and wind erosion, compaction due to heavy equipment use, reduced soil organic matter, build-up of salts, and a general decline in soil health must be addressed. Research and education efforts must be increased to maintain and improve this vital resource for future sustainable crop production.

Novel Production Technologies that Can Break Yield Barriers.

Yield barriers will be broken by the adoption of several new technologies each of which makes a small incremental increase in yield. Technologies such as precision planting, site specific management of fertilization, weed, nematode and insect control should improve crop production. New technologies to detect water stresses coupled with the use of precision irrigation systems should improve plant efficiency and overall production. Development of technologies to detect seed quality with high germination and rapid growth will aid in the establishment of an optimum healthy stand for improved yields.

Promising Recent Advances in the Science of Genomics, Genetics and Plant Breeding.

From an applied breeding standpoint, the association of QTLs with important traits and the development of molecular markers has greatly reduced the time to develop elite germplasm and cultivars. The use of marker assisted selection will greatly expand during the coming decade as molecular tags are associated with more and more useful traits. Gene editing technology will expand as we identify gene functions.

Contribution of Genomics Research for Yield Enhancement and Fiber Quality Improvements.

Yield and fibre quality are controlled by multiple genes; therefore, many QTLs will be involved in the improvement of these traits. Genomic will aid in identifying potential hot spots where genes are located. With the development of new computer software with the aid of artificial intelligence (AI), researchers will be able to analyse genomes and genomic data faster and more efficiently. This will allow for the targeted improvement of important yield and quality traits.

How Can Cotton Combat Climate Change?

A considerable amount of genetic diversity is present in the multitude of cultivars that are grown in warmer climates throughout the world. In addition, germplasm collections house thousands of accessions that contain a wide range of diversity for traits that will allow cotton to adapt. Researchers must identify traits that provide plasticity to heat, cold, and drought stresses. Improved photosynthetic efficiency under adverse growing conditions needs to be identified or developed. Strong plant breeding programs will be needed to address this challenge. An alternate approach to consider may be the development of short season cultivars that have less exposure to a harsh environment.

Novel Technologies to Fight Insect Pests, Weeds and Disease.

The use of drones and other remote sensing technologies for early and precise detection of pest problems and plant stresses with the aid of AI will be useful for consultants and producers. The use of precision spray technologies when and where needed. The use of robots to control or remove problem or resistant weeds from the field. Development of technologies that would turn on plant defence genes when they are attacked by insects and diseases.

Cotton Transgenic Technologies and the Way Forward.

Current transgenic technologies have provided a benefit to cotton producers for the control of insects and weeds. Their use

has reduced the number of pesticides that are used for insect control which has benefited the environment. Improved plant regeneration methods and the precise placement of the foreign gene into the plant genome would benefit this technology. Even after 25 years of use many consumers are still concerned about the safety of this technology. The development of new technologies that provide effective containment of transgenes should help ease consumer fears. Continued research and education will be needed for transgenic technologies to remain part of the needed options available for cotton producers for the control of insects, diseases, nematodes and weeds.

Role of Robotics, Electronics And Communication Technologies for Cotton.

Robots have been used in textile mills in the processing of raw fibres into textile products for several years. Their use will increase and expand to cotton gins and seed handling facilities. Electronics is present in every sector of the cotton industry from sensors to monitors, to bar codes for identify preservation, from processing to marketing, all the way to the consumer. Communications by cell phone and the internet will continue to play vital roles in cotton production and marketing. The use of cell phones to transfer digital photos from the cotton field by growers and consultants has greatly enhanced the diagnosis time for insect, weed and disease problems by specialist located hundreds of miles from the field. The rapid increase of information instantly available on hand-held devices will continue to expand during the coming decade. The challenge will be how to manage, analyse, and utilize this information for the benefit of all sectors of the cotton industry.

Any Other Exciting Novel Innovations and Game-Changing Technologies.

With the rapid expansion of electronic technologies into every facet of our daily world we can expect the development and deployment of yet un-imagined technologies that will impact cotton in the coming decades.

Advice to Young Cotton Scientists – How to Gear Up for the Challenges Of 2030.

A good education will provide the foundation that will be vital for success. The information over-load will continue, and scientists must remain focused on identifying problems and develop solutions for all sectors of the cotton industry. Young scientist should seek mentors and develop relationships that can provide guidance that will aid their career development. Their collaboration with other cotton researchers will increase efficiency in solving problems that require a multi-discipline approach. New technologies will continue to be developed at a rapid pace and young scientist will need to develop strategies to evaluate their benefit and economic impact. The ability to be an effective communicator (oral and written) will be vital for career development and success.

Cotton Vision 2030

David M Stelly, USA

ICAC Researcher of the Year 2017



Dr. Stelly is a Professor in the Department of Soil & Crop Sciences at Texas A&M University and Texas A&M AgriLife Research. Dr. Stelly is a world-renowned geneticist and cotton breeder. He has more than 40 years of breeding experiences with diploid and polyploid crops such as potato, tomato, soybean, maize, conifers, sorghum and cotton. His research also includes germplasm introgression, reproductive biology and cytology, cytogenetics, genetics and genomics. Dr. Stelly served as Chair of the International Cotton Genome Initiative, is a former President of the National Association of Plant Breeders (NAPB), an external reviewer of the USDA's Plant Genetic Resources, Genomics and Genetic

Improvement program, and a member of both the International Organizing Committee for WCRC-6 and the National Academy of Sciences GE Crops Committee. He has twice received the Cotton Genetic Research Award and recently became a Fellow of the Crop Science Society of America. He is the recipient of the 2018 Cotton Biotechnology Award at the Plant and Animal Genome Conference held in San Diego, California. Dr. Stelly is a Fellow of the American Association for the Advancement of Science awardee and received the Lifetime Achievement Award from the University of Agricultural Sciences in Dharwad, India.

The Three Big Challenges for Cotton Sector in the Next Decade

1. Elevate preferences for cotton-rich textile products that benefit the consumer and society, including:

Cotton vs. petroleum-based and other synthetic alternatives

- Comfort; 'breathability'; better hygiene
- Renewable unlike fossil-fuel-based fibres; cotton captures rather than releases carbon
- Helps millions of growers rather than executives at just a few chemical companies
- Reduces ocean and fresh water-way pollution by virtually non-degradable synthetic textile fibres
- Sustainability improvements

1. Economic yield to producers

- Cost-effective seed options
- Maximised differential between cost inputs to revenue from products, with options for different levels of production investment and detailed oversight
- Reliability of yield, quality (fibre & seed) and the ability to market products

1. Heritable improvements are among the most cost-effective means of crop improvement because they are easy to distribute widely and largely accrue across time. Among

the focus areas that seem likely to lead to novel benefits:

- Root system improvement (needs major focus)
- Genetic solutions that enable producers to use fewer and safer chemical protectants against pests, pathogens and weeds
- Fibre length, quality features and uniformity
- Seed and oil quality factors as oilseed and animal feed as well as potential human foodstuffs

Production Technologies to Break Yield Barriers

- Adapt, adopt and adeptly use integrated satellite, UAS and ground surveillance systems to aid production-related GPS-guided decisions (irrigation; pests; pathogens; weeds; growth stages; field variability/amendment)
- Solar-powered GPS robot systems for worker-limited production areas, to help with field monitoring and weeding, especially at early-growth stages. This could become all the more important if health-based or other concerns severely constrain the availability of migrant workers, or as weeds adapt to herbicides
- Smartphones to deliver relevant production and marketing information and consultation to remote small holder farmers in countries with a poor or uneven educational infrastructure

Promising Recent Advances in the Science Of Genomics, Genetics and Plant Breeding

- ª Rapidly increasing public genomic resources (types and volumes of data and tools)
- ª ‘Tools’ to use resources will continue to evolve quickly
- ª Cost of using genomics tools will continue to fall but seem likely to be more than offset for a while by a global economic downturn due to COVID-19
- ª Genome selection
- ª Greater recognition, new tools and methods for using epigenetics
- ª Progress in manipulation of homologous recombination
- ª (Epi)Genetic engineering — transformation and editing
- ª Roles of dispensomes in fungal diseases? Could this lead to improved control over certain pathogens? Or new fungi as pest control agents?

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

- ª I feel like there is the need for a lot of exploratory research in this area.
- ª Can we achieve scientifically designed approaches to fibre enhancement by better defining the differential genetic amplification, epigenetic modifications, transcription, RNA processing and translation in fibre cells?
- ª Can cisgenic and allied types of gene replacement or augmentation approaches be helpful?
- ª To what extent are epigenetic alterations heritably affecting key traits?
- ª Can we characterise and understand the relative importance of transcription factors in variation of economic traits and their inter-relationships?

How Can Cotton Combat Climate Change?

- ª Shift production areas and seasons or vary planting areas and time
- ª Genetically improve resilience
- ª Enhance relevant production practices

Novel Technologies to Fight Insect Pests, Weeds and Diseases

- ª Gene drives
- ª Confusing pheromones
- ª Altering cotton’s signature odours

Cotton Transgenic Technologies and the Way Forward

- ª Public researchers need to help society by delivering traits that help with economic yield and sustainability
- ª Need more methods and ‘tools’ that are free from IP protection
- ª Continue improving the speed of transformation and editing

Role of Robotics, Electronics and Communication Technologies for Cotton

- ª Production decisions using integrated sensing platforms (integrated satellite, UAS & ground surveillance)
- ª Improved methods for characterising root systems and genetic effects on them, as well as the use of model systems to expedite cotton root system knowledge and improvements, including scalable root-growth monitoring systems, genomics; ground-penetrating radar methods.

Any Other Exciting Novel Innovations and Game-Changing Technologies

- ª Epigenetics — We need to fully explore the degrees to which epigenetics affect traits of importance and how we might leverage that control to enhance cotton
- ª Gene editing (DNA sequence and epigenetic status)
- ª Possibly gene-drive systems — if they are effective and safe to deploy for controlling serious sexually reproducing pests

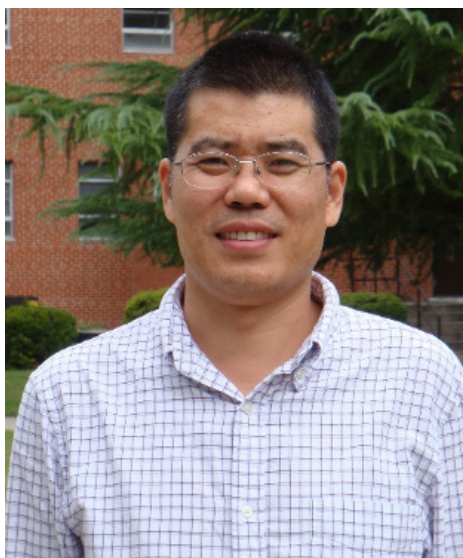
Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

- ª Stay alert and keep a broad view of science. It will change a lot in 10 years, likely including one or several major fundamental scientific and technological innovations that can affect your work
- ª Promote international scientific cooperation to improve cotton globally, strengthen its sustainability characteristics and bolster its baseline competitiveness in the market
- ª Use new technologies to enhance communication, interaction and cooperation with others. These will help you spawn new ideas.

Cotton Vision 2030

Baohong Zhang, USA

ICAC Researcher of the Year 2018



Dr. Baohong Zhang is currently working as a distinguished professor at East Carolina University (ECU, US). Dr. Zhang graduated from China Agricultural University. After he received his Bachelor's degree, he worked on cotton biotechnology at the Chinese Academy of Agricultural Sciences and received his PhD from Texas Tech University in 2006. Dr. Zhang has authored more than 200 publications with more than 13,000 citations; many of them are listed as highly cited papers by the Web of Sciences (his h-index is 53). Dr. Zhang frequently reviewed manuscripts for many international journals, including Nature and Nature Biotechnology. He also served as an Associate Editor or Guest

Editor for seven journals, including Scientific Reports and Plant Biotechnology Journal. He has reviewed proposals for more than 40 funding agents, including NSF, US DoE, US USDA, and NSFC. Dr. Zhang was elected to the Fellow of the American Association for the Advancement of Science (AAAS) in 2018. He won the 2018 ICAC Researcher of the Year 2018 and the following year he won the THCAS Distinguished Professorship and the Highly Cited Scholar awards. Recently, he won the Lifetime Research Achievement Award, the top honour for ECU faculty. He also has won the Cotton Biotechnology Award.

The Three Big Challenges for the Cotton Sector in the Next Decade

There are many challenges for the cotton sector in the next decade; I think the three biggest will be:

1. How to produce enough fibre to meet the consumption demand.
 - ^a World cotton consumption will increase smoothly but the increase of cotton production is much slower and could even decrease as more farmers switch to other crops.
 - ^a Pests and diseases may be a big problem cotton will have to face. Although transgenic Bt cotton has solved a lot of problems for controlling certain pests, those pests may generate resistance to Bt cotton and other pests could become the dominant pest in cotton field. Pathogens may cause new diseases in the cotton field.
 - ^a Cotton will face more competitive pressure from old and new materials, including polyester.
2. Novel production technologies that can break yield barriers

Transgenic and genome-editing technologies will become major tools for cotton-precise breeding to increasing cotton yield, quality and resistance to various environmental stresses, including newly emerging pests and pathogens. The application of artificial intelligence (AI) on cotton

production and the market may also break the yield barriers for cotton.

3. Promising recent advances in the science of genomics, genetics and plant breeding

The recently completed and ongoing cotton genome sequencing research projects open a new era for studying gene function in cotton as well as precise cotton breeding. In the next 10 years, the majority of genetic studies in cotton will switch to gene functioning to enhance our knowledge for precise breeding in cotton.

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

In the next 10 years, traditional cotton breeding will be integrated with modern molecular breeding, including transgenic breeding and genome-editing-based breeding. Genomics research will contribute much more than ever on cotton improvement. As more cotton genomes are sequenced, the genes and their involvement in gene networks controlling cotton yield and quality as well as responses to biotic and abiotic stresses are being identified and characterised. These genes and/or gene networks will soon become targets for transgenic and genome editing for breeding new cotton cultivars for yield enhancement and fibre quality improvement.

How Can Cotton Combat Climate Change?

Climate change is a global issue that threatens all plant species and our entire society. To face climate change, cotton breeding may play more important roles, including new cotton cultivars with tolerance to high temperature (for summer), low temperature (for early planting), and drought (for water saving).

Novel Technologies to Fight Insect Pests, Weeds and Diseases

Transgenics and genome editing will play a huge role in breeding new cotton cultivars that can fight pests, weeds and disease. Artificial intelligence (AI) technology will be used to monitor and manage pests, weeds and diseases.

Cotton Transgenic Technologies and the Way Forward

Cotton transgenic technologies, including advanced genome editing technologies, will play an increasingly larger role in cotton breeding, including improving cotton yield fibre quality as well as fighting environmental stresses.

However, there are a few issues that need to be addressed:

- A novel strategy for obtaining transgenic and genome editing plants is needed to provide a wider range of cotton genotypes; this may be achieved by improving current transformation methods or developing completely new approaches for obtaining transgenic plants.
- New genes for cotton yield, quality and tolerance; this could be discovered in cotton's own genome (wild species)

or from other resources.

- Diversity of transgenes, which could be an area of emphasis for scientists. When quickly adopting transgenic cotton, the diversity of cotton cultivars could be decreased, which would generate new risks for cotton production systems.

Role of Robotics, Electronics and Communication Technologies for Cotton

It is certain that robotics, electronics and communications technologies will have more applications in cotton production, harvesting, management and marketing.

Any Other Exciting Novel Innovations and Game-Changing Technologies

Artificial intelligence (AI) and digital agriculture will play a greater role in cotton production and markets.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

The next 10 years will be a promising and challenging decade for cotton scientists, with rapidly developing technologies, so young cotton scientists need to adapt quickly — and even develop their own new technologies to use for cotton research and development. Over the next 10 years, interdisciplinary and international collaboration is crucially important, so young scientists need to master the knowledge and principles of their own field but also that of closely-related fields, especially those in different countries.

Cotton Vision 2030

John Zhihong Yu, USA

ICAC Researcher of the Year 2019



Dr. John Zhihong Yu is a Research Geneticist with USDA-ARS in College Station, Texas. He earned his PhD in plant genomics and

molecular genetics at Cornell University and has been working with the USDA-ARS since 1995. Dr. Yu has demonstrated outstanding dedication, with 36 years of professional experience, and received significant recognition as an international authority in cotton genomics for developing genetic resources that are currently being used by scientists worldwide. He made major contributions to cotton genomics and germplasm, including genome mapping and sequencing, characterization of gene pools, and identification of QTLs for molecular breeding. Dr. Yu developed the world's first integrated genetic, physical and transcript maps of cultivated tetraploid cotton chromosomes with large insert DNA clones, molecular markers, and EST genes; and high-density cotton genetic maps of portable SSR and SNP markers. Dr. Yu led international efforts to develop and release genome sequences for *G. arboreum*, *G. herbaceum*, *G. raimondii* and *G. hirsutum*, among other cotton species. The research opens a new paradigm in cotton genomics

that revolutionizes the genetic improvement of cotton plants through better exploitation of genetic variation otherwise buried in *Gossypium* germplasm. His discovery of gene-rich islands and sub-genomic roles in upland cotton provides critical information for genetic applications. His development of new concepts and methodologies for standardising characterization of *Gossypium* germplasm makes it possible for cotton researchers worldwide to collaborate, relate and utilise genetic diversity data among cotton germplasm collections.

Dr. Yu was twice elected in 2005 and in 2015 to serve as the Chairman of the International Cotton Genome Initiative (ICGI). He is a member of USDA National Life Science Patent committee. He has received several national and international awards and published more than 100 peer-reviewed papers, with more than 10,000 citations. Dr. Yu has also delivered more than 60 presentations to the global scientific community.

The Three Big Challenges for the Cotton Sector in the Next Decade

The global cotton sector will face many challenges in the next decade. Among the biggest ones are the climate change, trade barriers, and polyester (a non-renewable petroleum product). Additional challenges for the cotton sector include the recurrence of an emerging pandemic or natural disaster and the current lack of an international cotton research institute like those established for food crops.

Novel Production Technologies that Can Break Yield Barriers

Cotton yield has been stagnating but its potential barriers can be broken by broadening the cultivars' genetic base with favourable alleles and by exploiting the heterosis in desirable hybrid cotton. Free exchange and utilisation of cotton germplasm is essential for cotton breeders to broaden the genetic base of cultivated cottons. The ideal cultivation management system should be designed for and practiced in each production environment.

Promising Recent Advances in the Science of Genomics, Genetics and Plant Breeding

Since a wild diploid species, *Gossypium raimondii*, was first sequenced in 2012, more than a dozen *Gossypium* species have been sequenced, including all cultivated cotton species and all tetraploid cotton species. These advances provide fundamental knowledge and genomic resources for cotton molecular breeding. Molecular breeding can empower cotton producers with an efficient means of improving fibre yield and quality — but only if accurate marker-trait association is developed. Now the global cotton research community is positioned to launch a post-genomics era in which such advances will soon bring the focus back to the functional traits of the cotton plant.

Contribution of Genomics Research for Yield Enhancement and Fibre Quality Improvement

Cotton is comprised of many genetically complex species and is experimentally difficult to tackle. In the most cultivated

tetraploid species *Gossypium hirsutum*, approximately one half of the 77,000 protein-coding genes directly or indirectly contribute to the development and growth of upland cotton fibre. These genes are often organised as clusters or islands in the cotton genome and they function through gene networks or pathways at the initiation, elongation, and secondary cell wall biosynthesis of cotton fibre. Many DNA markers associated with fibre yield and quality traits are developed and they are being used to guide cotton breeding efforts to improve cotton yield and fibre quality.

How Can Cotton Combat Climate Change?

Climate change causes profound environmental stress to a developing cotton plant. In addition to deploying the best management practices to cotton cultivation, breeding for more abiotic-stress-tolerant cotton is essential. In the *Gossypium* genus, many wild species likely contain undiscovered genetic elements for tolerance to drought, heat, and other environmental stresses. Exploiting the *Gossypium* germplasm for such desirable genetic elements is necessary to develop cotton cultivars that can adapt to and perform well in undesirable environments due to climate change.

Novel Technologies to Fight Insect Pests, Weeds and Diseases

To minimise the amount of chemical spraying that otherwise pollutes the environment and increases production costs, identification and incorporation of resistance genes into elite cotton cultivars can be achieved through transgenic breeding or marker-assisted selection. While transgenic strategy usually takes advantage of major genes, a marker-assisted approach is being designed for a range of mono-genic to polygenic resistance. Cotton genomics advances provide an opportunity to incorporate that new resistance to insect pests, weeds and diseases.

Cotton Transgenic Technologies and the Way Forward

Cotton transgenic technologies are powerful tools for cotton improvement. Progress has been made, from incorporation of

single genes to multiple genes in genomes that are subsequently backcrossed into an elite cotton cultivar. Future transgenic advances may be possible with cotton genomic knowledge and tools, if the physical location and targeted function of cotton transgenes can be determined precisely.

Role of Robotics, Electronics and Communication Technologies for Cotton

In the next decade, the use of robotics for phenotyping traits in the cotton field will increase so as the use of electronic notebook to record and monitor the cotton production. Contemporary communication and database technologies make information exchange quicker and more efficient, which will translate into enhanced cotton productivity. Cotton producers will have more support as it becomes available online.

Any Other Exciting Novel Innovations and Game-Changing Technologies

Currently, gene-editing technology is the most exciting new innovation that has the potential to create desirable genetic variation for cotton improvement. This technology is being applied in cotton and genome sequences, including gene annotations, are released to the public. Knocking out or editing genes in the same species are not considered transgenic, thus simplifying the improvement and production of modified cotton cultivars.

Advice to Young Cotton Scientists: How to Gear Up for the Challenges of 2030

In the history of humanity, challenges often turn out to be a benefit in disguise. As long as a challenging problem is clearly identified and well understood, scientists should be able to develop a cutting-edge technology to tackle it. Many big challenges in the coming decade will require collaborative research across multiple disciplines. We must envision the whole landscape as we search for the solutions to our problems. Persistence in research, collaboration and coordination will prevail as the cotton sector faces new challenges and opportunities over the next decade.

Cotton Vision 2030

Raja Reddy, USA

ICAC Researcher of the Year 2020



Dr. K Raja Reddy is a Research Professor in the Department of Plant and Soil Sciences at Mississippi State University. He is an accomplished researcher in the realm of agricultural science, a respected teacher and mentor to many, while also a leader among his peers.

Dr. Reddy has trained over 35 visiting and 15 postdoctoral scientists and 30 students (15 Ph.D., 11 MS, 5 Undergraduate and others as committee members) from across the world in multiple areas such as crop stress physiology, climate change, crop modeling, remote sensing, and global food security.

He has a very impressive publication record with a high citation index of 11,160. Dr. Reddy's research interests include the impact of anthropogenic climate change, remote sensing, and crop modeling applications on agricultural resource management through the lens of environmental plant physiology. He has over 32 years of research experience at Mississippi State and is responsible for and credited with many critical discoveries across multiple facets of agriculture. His research includes the impact of climate change

on cotton and other crop physiology, growth, and development of several outstanding foods, fiber, and native grasslands and forages crops of global importance, cotton, soybean, rice, corn, sorghum, peppers, sweet potato, switchgrass, Bahia grass; remote sensing and stress physiology; and crop model applications.

In addition to his research obligations, he developed a capstone graduate-level course, "environmental plant physiology," that interfaces research, teaching, and learning based on research work he conducted using state-of-the-art sunlit plant growth chamber facilities at Mississippi State.

Dr. Reddy has received several recognitions and awards: Fellow of the American Association for the Advancement of Science, the Crop Science Society of America and the American Society of Agronomy; the Ralph E. Powe Award, the Highest Research Honor at Mississippi State University; and the Outstanding Research Award in Cotton Physiology, presented by the National Cotton Council of America.

How Can Cotton Combat Climate Change?

Since cotton is grown under a wide range of climatic conditions, the challenges and strategies are different under those climatic conditions. Changes projected in climate, including carbon dioxide, that will deeply affect lint yield and fiber quality, thus producing cotton growers' livelihoods. The recent review by Bange et al. (2016) provided an excellent summary, outlining many of those challenges and opportunities in a changing climate facing cotton production.

In temperate climates, early-season cool temperatures and sometimes waterlogging are typical, and therefore, we need to develop cold- and waterlogging tolerant cultivars, focusing on early-season vigor. Systematic evaluation of germplasm for early-season vigor through various phenotype platforms will benefit the industry. Early-season drought and other stresses are also common in subtropical and tropical climates. On the other hand, a regional-scale increase in seasonal cloud cover and warming temperatures is an unobserved silent threat to crop quality, including in cotton. Cotton breeding strategies should focus on improving traits associated with multi-stress tolerance. A simple breeder-friendly trait and numerical

stress-specific cultivar scoring system would help cotton breeders or producers select cultivars tolerant to multiple abiotic stresses with high-yielding capabilities in the niche area.

Cotton is grown in a wide range of environments and is often subjected to high temperatures and/or low precipitation during flowering and boll-filling periods. Such uncontrollable extreme stress events cause lower yields and poor-quality fiber. The use of sensor-based management systems such as efficient irrigation systems will alleviate the drought and high-temperature conditions where irrigation is available to a certain extent. Therefore, developing drought- and heat-tolerant cultivars will be needed to combat these yield-limiting stresses sustainably. However, there is no easy way to evaluate stress tolerance among cotton cultivars, as canopy level traits are affected differentially by growth stages.

Moreover, most morph-physiology-based phenotyping techniques are weakly correlated with reproductive tolerance or yield potential due to the indeterminate nature of cotton. Measuring pollen germination ability traits are informative but are tedious and low throughput. Thus, the integration of automated machine learning technologies to count and estimate pollen viability may expedite ongoing reproductive stress

tolerance breeding. Another solution to address reproductive stress tolerance would be developing biomarkers such as metabolite or hormonal markers to overcome the phenotyping limitations for genomic studies. Multidisciplinary teamwork is required to develop drought- and heat-tolerant-ready cotton cultivars. Another aspect is increasing light- and carboxylation-use efficiencies and increasing potential photosynthesis. Strategies to develop such cultivars will positively affect cotton production, especially for a wet climate region where high cloud cover is coupled with warmer night temperatures. Besides, the development of breeder-friendly remote-sensing indices as surrogates for canopy and flower temperatures, pigment composition, water content, and ground cover are the pre-requisites for cotton improvement for stressful environments.

Also, mechanistic simulation models that simulate seed cotton yield and fiber quality will aid many policy decisions in a changing climate (Reddy et al., 1997; Thorp et al., 2014). As pointed out by Bange et al. (2016), multi-faceted, system-based approaches are needed to assist policy and to adapt cotton production in a changing climate. More importantly, we are responsible for educating the general public about climate change and its implications on food, fiber, and ecosystem services. This will lead to changes in the society-level perceptions leading to innovative and transformative policies.

Exciting Novel Innovations and Game-Changing Technologies

Developing smartphone-based applications that integrate GIS and sensor-based information into a predictive simulation capability will be game-changing technologies for resource-rich production systems. Besides, transformative phenotyping technologies will aid in developing climate-resilient cotton cultivar development. Creating a global phenotyping network and developing a targeted environmental phenotypic library can help to streamline cotton phenotyping strategies. Deployment of rapid and automated phenotypic data collection and processing tools would help develop multi-stress tolerant donors. Creating transdisciplinary centers of excellence combining the above- and the emerging technologies will transform the cotton industry in the coming years. For an immediate benefit, resource-poor countries should adopt management systems from resource-rich countries proven to boost yields. Collaborative public and private system biology research help to develop climate-resilient cotton.

Advice to Young Cotton Scientists -How to Gear Up for the Challenges of 2030

The challenges I faced during my career may differ from the challenges the young scientists face in today's environment. However, those lessons that I have learned and implemented may provide insights for aspiring young scientists. I am a life-long learner and student and a very hands-on researcher. During my graduate studies, I took applied plant physiology and botany as my domain subject areas. My graduate work focused on controlling less productive semiarid shrub species

through herbicidal means and is practiced widely today to control weedy native plants and replace them with more productive species adapted to that part of the world. Later I worked at the Biology Department of S.V. University, Tirupati, India, where my colleagues and I compiled medicinal and wild edible plants by learning systematic botany. We documented the use of about 216 formulations of plant products for medicinal purposes in the region. Their use had been handed over from generation to generation by oral communication. Thus, there was no written record or only limited documentation of plants used for medicinal purposes, and our work filled that void.

Then, an opportunity came to enhance my career opportunities to study abroad, and I joined the USDA-ARS Crop Simulation Research Unit and Mississippi State University, Mississippi, USA. Before that time, I was not even aware of crop simulation models and never learned or worked with computers. I had to learn agricultural systems and cotton for the first time quickly. I attended all Beltwide Cotton Conferences and learned a lot about cotton research and, more importantly, the people and their contribution to cotton science. That helped me tremendously to jump-start my career in cotton physiology. I also learned how to read FORTRAN code, the logic behind modeling, and understanding the whole-plant system. Even though my systematic botany expertise helped me understand the object-oriented logic in crop simulation modeling methodologies, I regretted not having opted for a high-rigour mathematics choice at a very early age. However, I realized that the logic and basic understanding of cotton growth to abiotic stress conditions and modeling cotton processes don't need complex algorithms.

I had the good fortune of working with a team of scientists and modelers, and that teamwork paid dividends to mold my career in cotton science, modeling, and agriculture. I was also fortunate to work with the state-of-the-art sunlit plant growth chambers facility known as the soil-plant-atmosphere-research (Spar, <https://www.spar.msstate.edu/>) system. This is a biologist's dream facility that keeps me designing new experiments to test many hypotheses that is not easy to test in other facilities in crop stress physiology arenas. Our laboratory generated the most comprehensive quantitative functional database for cotton and other crop's growth and development as affected by environmental stress conditions from seed to fiber quality in the world. That work improved the GOSSYM/COMAX and other cotton models (Reddy et al., 1997; Thorp et al., 2014) for field applications and policy decisions. I want to point out that I had only a ruler and a small leaf area meter in the laboratory, and we used those to upgrade existing and new subroutines in the model. The lessons that I learned working with cotton are that now I could develop a similar database for any given crop in the less than five years that I did for 15 years or so in cotton.

Funding was essential to expand my research and teaching programs. Expanding our program to a new field, extending to climate change areas is very logical, but embracing new areas needed collaboration and learning new domains such as remote sensing, phenotyping, genomics, and the molecular areas

was also important. Few other things that enhanced my career and program were embracing diversity and inclusiveness in hiring Postdocs (>15), visiting scientists (>35), and students (>30 students) from around the world. They brought culture and ideas to enhance my program, and thus I didn't need to take a sabbatical for international exposure or to learn new things. Mentoring students and letting them understand the work ethics, conference participation, competing for various categories for presentation and other awards, and networking are foundations for a successful career. Besides, I have emphasized the importance of community service and engagement for leadership development and request them to be part of my community service projects and more.

Finally, I learned that telling our science stories through scientific journal publications and books is not enough to reach the general public. During my career, I had opportunities to work with excellent writers who featured our research work many times at Mississippi State University, Mississippi State, MS, USA (<https://www.mafes.msstate.edu/discovers/article.asp?id=13>), the Crop Science Society of America through their CSS News or science news (<https://www.agronomy.org/news/science-news/preparing-plants-our-future-climate/>) or through briefing the capabilities of our facilities and science to the visitors and administrators again and again. These stories gained more importance and momentum that I could

communicate in a journal paper, reaching millions of people across the web and different audiences.

I hope that my life journey will inspire other young cotton scientists to emulate some of the proven and successful career activities during my journey from farmer's son in southern Indian State of Andhra Pradesh to the ICAC Cotton Researcher of the Year Award by peers. Of course, my mantra behind my success story is a healthy and supportive family.

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