

Cotton Vision 2030

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ICAC Researcher of the Year 2009



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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), *GhLM11-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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