

COTTON BREEDING IN 2025

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Preface

Hazera Genetics (HG) is a seed company founded in Israel in 1939. We breed, produce and market a variety of seeds - mainly vegetables but also some field crops such as wheat, sunflowers and cotton. A few years ago, HG was acquired by the French company Vilmorin, which is a part of the Limagrain group.

HG has been in the cotton business since the 1960's when we began with the breeding of Acala (Upland) varieties and then, about twenty years ago, we started a breeding program of hybrid cotton. Now, the company concentrates mostly on developing Inter-specific hybrids (G.hirsutum x G.barbadense).

This article (and presentation) of our vision for future cotton breeding is based on our long experience in cotton breeding, variety evaluations and marketing of cotton seeds in the local (Israel) market and in other cotton-growing countries.

Introduction - Cotton industry situation

According to ICAC and other publications, cotton crop has become less profitable during recent years and therefore less attractive to growers compared to some other crops.

The provision and targets for future cotton breeding should refer and reflect the needs of the Upland (G.hirsutum) cotton – the most widely cultivated in the world.

The main important facts about the cotton industry over the last four years (2003-2006) and expected developments are summarized below:

1. Planting area – has increased from about 32 Million hectares to about 34 Mh and is expected to stay unchanged in the coming years. Most of the available adequate land for cotton is already in use. Part of this land may be allocated for more profitable crops (including the new trend for bio-fuel) or for food crops. Thus leaving only marginal or new, reclaimed land in which cotton can expand. This will probably include poor, sandy and salty soils.
2. Lint average yield – has continued to increase and has reached 745 kg/h compared to 646 kg/h in 2003/4. This was achieved by cultivating advanced varieties (including GMO) and applying improved crop management. Some new varieties have a significantly high yield potential which is obtained mainly under conditions favorable for cotton. However, the contribution of varieties to yield for the last five years has been very small; in the range of 1-17 kg/h per year (within different variety groups from different seed companies). Recently, Bt cotton varieties help growers (in certain areas) to obtain higher yield than before.

The theoretical potential lint yield in cotton is calculated at about 4000 kg/h. In Israel, up to several years ago (on a limited area of 15,000h) growers achieved the highest average yield of Acala - around 2000 kg/h). Many of the growers had obtained a yield of 4 bales/acre -(still, only about 50% of the theoretical potential).

The average yield of the 6 big producers and highest yielding countries (US, Australia, Brazil, Turkey, Greece and China) is still only about 1116 kg/h on 37.5% of world cotton area. Still, about 44% of the world production comes from regions with low yields (with an average of about 522 kg/h) on about 62.5% of the world planting area (Table 1).

This situation may become worse when cotton is less profitable for more growers, who will cultivate cotton under tough conditions and give less input and less attention to management.

3. Lint quality – In general, very little improvement has been made in fiber quality in recent years. Yet some new varieties (mainly of Acala type) have high value potential in fiber characteristics as desired by the textile industry: Length around 1.2 inches, strength up to 32 gr/tex and micronaire around 4.0. But very few varieties have all these values together (Table 2).
However, in many growing regions, the fiber quality obtained is still far below these values. Superior values of fiber quality are found only in ELS varieties of the species *G.barbadense*.
4. Lint production – has been increased from about 20.5 Million tons to about 25.3 Mt but is expected to stay at the same level in the coming years.
Some countries (led by the U.S.) are expected to reduce cotton production in order to shift to better alternative crops or because of growth conditions constraints. However, some others (like India, Pakistan and China) may increase production mainly due to some improvement in yields and profit achieved recently in these countries and because of a lack of better alternatives.
5. Lint price (index A) – has remained (since year 2000) within a limited low range level of 40-60 \$c/lb. with an average world price of around 55 \$c/lb.
Higher prices are paid by the textile industry for improved fiber quality and a desired lint appearance with minimum imperfections.
Lint price is usually projected to change in correlation with changes in the world lint stocks at the end of each production year. Governmental support to cotton growers in some countries has a great impact on international lint price regardless of lint stocks.

Mill consumption – has increased from about 21.7 Mt to 26.1 Mt and is expected to continue to increase by about 1.5 Mt in each coming year. Increase in world demand has also been affected by the general increase of income per capita in many countries which are starting to consume more textile products. There is also a demand for higher quality garments and spinning mills are seeking improved lint quality enabling them to enlarge the added value of the yarns and garments for the end customers. This could have a positive affect on the future lint quality improvement and price.

6. Cost production – has continued to increase, reaching an average range of 500 - 2500 \$US/h depending on production conditions and yield levels achieved. This is caused by raising input prices, labor costs and some necessary and complementary investments. Sometimes, inefficient use or an excess in inputs, increases costs per output unit. Production costs in most cotton growing areas are hardly covered by the output values even when a significant yield is obtained. However, many growers (families) - in India, China, Pakistan and others – spend less than US\$500/h. They usually do not count or calculate their own employment in the production costs because there is no alternative for their work (Table 3).

Despite some recent increase in cotton grains price (influenced by the Bio-fuel trend) the low lint prices (mainly for low quality), insufficient yields (mainly under tough conditions) and the relatively high cost of production – have reduced the growers' income and profit from cotton crop and made it less competitive than other crops.

For example, in Israel even growers with the highest yield have not been able to make a profit from Upland cotton and have shifted to the cultivation of E.L.S. in order to compensate for the high cost of production.

The main conclusion is that the cotton industry is reaching a plateau with a tendency to reduce its development regarding production and profit to growers.

To improve the situation, the industry must adapt and act by the common economic rule which drives every business: "Increase output value and reduce cost production per output unit".

Increasing output value could be achieved by:

- Higher lint yield – mainly in regions with yields below the average of 700 kg/h.
- Improved fiber quality – also under tough growing conditions.
- Increase grain value (and price) – as a byproduct.

Contribution of breeding to an increase in output value - will be through new varieties having the following important characteristics and capabilities:

- High lint yield potential - based on successful combinations of yield components to produce more seeds per plant and per area unit. This should be based mainly on more bolls per plant or /and more seeds per boll.
- Improved fiber characteristics - to raise the lint attractiveness for the spinning mills and gain a better price - Length over 1.20 inch, Strength over 32 gr/tex and micronaire no coarser than 4.2. Unlike with *G.barbadense*, this mission is known by the breeders to be very difficult to accomplish within the Upland cotton. Transfer of fiber quality genes from *G.barbadense* is the best solution today but also genes from other organisms (insects?) are been considered as a means to improve fiber characteristics. Reducing imperfections in the lint is also very important for the textile industry. To preserve the maximum fiber length of some long fibers varieties, ginners make efforts to gin them by roller gin. Introducing the Necked seed trait into Upland varieties can help to prevent seed coat fragments and reduce Neps in lint after ginning.
- Improved grain value as a byproduct – by developing *Gossypol* less seeds or with very low *Gossypol* concentration. This, to enable efficient oil instruction and a safe use of the grain's protein for poultry and human consumption. Improve fatty acids (unsaturated) contained in the seeds, in order to increase oil value, will be appreciated by the industry. The recent trend toward bio-fuel crops is expected to also cause cotton oil and meal prices to rise by 20-30% in 2007-08.
- General adaptation - of a variety to a wide range of growing conditions or different varieties highly adapted to different and special local conditions. Adaptability is an important key for getting the most out of the variety potential even under the unfavorable conditions prevailing in many growing regions such as:
 2. Short season – Requires capability to emerge and grow at a high pace under low temperatures at the beginning of season. Enhance fruit sites initiation and developments with early maturation before temperatures drop again.
 3. Extreme heat (mainly during blooming period) – Requires tolerance mainly at the molecular level, based on biochemical mechanisms to defend important enzymes from deterioration. Some physiologic and morphologic traits and agro-technique means may also help in reducing the heat (and drought) effect on flowers' anthers and stigma enabling fertilization and setting seeds ("cooling systems").
 4. Drought – Caused by limited water availability (from rain or irrigation) – Requires capability of plants to overcome long intervals between irrigation or rain events, ("Camel Plant"). Some morphologic traits (such as Okra leaf, large root system) and suitable (efficient) physiological processes may contribute to tolerance of drought in reducing water loss by Evapo-transpiration. High efficiency of water use by the plants is required to produce enough carbohydrates needed to develop and produce desirable yield under drought conditions.
 5. Salinity - in soil and in water irrigation. Cotton in general can tolerate salinity more than other crops, and vigorous cotton plants can better overcome a high concentration of salt in soil. However, improving tolerance should be connected to mechanisms of mineral ionic exchange through cell membranes and improve regulations of osmotic pressure in plants' cells.

Contribution of breeding to reduce cost production can be achieved by:

- Offering short and medium growth cycle varieties rather than late ones - to enable the reduction of input costs accordingly.
- Further introduction of genetic resistances and tolerances into varieties will help growers manage the crop efficiently and save labor and inputs costs.

Especially, with the existence of virulent races of soil born and leaf diseases, viruses, pests or weeds that no chemical or other solution to control them is available. In most of these cases, only adequate genetic resistances (to the pathogen or herbicide) will enable cotton cultivation.

However, some morphologic traits like hairy leaf, nectar-less leaves and presence of gossypol glands on vegetative parts of the plans can help to avoid severe damage by some sucking pests like Jassids (*Empoasca* Spp.) and other pests.

It should be noticed that the experience so far with very strict plant resistance, shows that sooner or later such resistance causes heavy stresses and selection pressure on the pathogens and weeds. This has resulted in the development of new resistant and more violent races of pathogens or new weed types resistant to the selective herbicide (like Galyphosate).

Moreover, under conditions where only one type of pathogen is eliminated successfully - due to plant resistance (as Bt) or by eradication, other pests may take over the bio-system and create new problems (like sucking pests, red spider and others). This will require additional costs for handling, while reducing the contribution of the former resistance in saving costs.

Therefore, it is suggested that consideration be given to preferring varieties with a wider range of resistance even if not with full effectiveness, but effective enough to keep damage to a low level without giving any advantage to a particular pathogen ("Field resistance").

Breeding should offer the cotton industry and growers the best combinations of traits to enable the achievement of the highest possible economical yield under a given set of growing conditions. It does not necessarily mean the highest yield or the best superior fiber quality.

Reducing crop production is most important for growers who are already achieving the most of the variety potential. Any attempt by these growers to improve yield or quality will require more inputs and costs while risking the grower's profit.

Notes about crop management

Even having the best potential adapted variety, adequate management and sufficient inputs should be applied to the crop in order to achieve its full potential.

In many areas, adjustments in local growing practices must be made to gain the desired lint yield and quality from a given variety.

These include – land preparation, planting, irrigation and fertilizing at the proper times and in the proper doses. Efficient plant growth control, pest management and proper termination of the crop are also required.

Governments and growers organizations have much to do in helping growers to achieve better results by training, technical support and ensuring availability of inputs.

Having a good variety is not enough to achieve the goal!

About breeding process and method

Cotton breeders are aware of all the above mentioned characteristics and needs for future breeding. Most of the above characteristics and probably more are at the research stage or already included in breeding programs and work.

Most of the characteristics (and genes) exist in the genus *Gossypium* in different species (including diploids wild types). Other characteristics and genes can be introduced into cotton from other crops, plants or organisms (such as bacteria and insects) by biotechnology (GMO).

The important questions are:

Is it possible to combine all or some of the desired characteristics together in one plant?

How long it will take to have them in varieties which have also been adapted to marginal/tough conditions?
At what cost? Who will do the work?

Breeding process is a long one that consumes much time and investment (See Appendix).

It is very frustrating and highly risky because of many possible unexpected events.

Sometimes a pre-breeding work is needed to isolate, prepare and study some aspects of the new trait. It is not obvious that introducing every new desired trait is likely to succeed.

It might be happen that adding of new trait (gene/s at homozygous state) to plants of a given variety may fail due to negative interaction with the already existing genes/traits. Sometimes the new trait cause undesirable performance of the entire plant.

After breeding and preliminary evaluation, a long procedure (involving years) is also required for registration of the new variety or a patent. Introducing more than one trait will take longer time or much more investment needed to work in larger plants populations.

These difficulties may increase the development period and costs and delay the launching of a new variety by up to 15 years or more. Thus, breeding new varieties with significant desired advantages for 2025 should start as soon as possible.

Therefore, breeders (and seed companies) chose subjects and characteristics according to the expected size of the future target market that can compensate their investments.

Hence, breeding for small or local markets, still has to be supported by governments or any local interested body/organization. This need is true especially in countries where the cotton crop is of national (economic or social) importance.

However, to shorten the process and reduce risks of failure, breeders use different technical means and methods to gain more generations per year and use gene markers to help them in plant selections. They also prefer working with traits of dominant or additive mode (rather than recessive ones) to facilitate selections and breeding process. In fact many of the engineered (GMO) traits have a dominant effect.

Suggested breeding approach and method

An important aim is to facilitate and cut the development period of new varieties while making the breeding process more flexible to meet today's and future growers' needs.

One of the solutions, is to adopt the breeding method for hybrid varieties which been successfully used in many other crops and also by some cotton breeders in certain countries.

Why hybrids?

The breeding process for conventional (OP) varieties ends mostly with few improved lines from which one will be selected to be the new variety having the new trait. Much time and effort is needed to add several desired characteristics in one given variety by a gradual process of the full progeny breeding method.

Instead, in the hybrid method many new varieties are obtained by crossing the improved lines to other successful lines or varieties having complementary desired characteristics and adaptability. These F1 hybrids possess several desired characteristics from both lines including the new trait introduced increasing flexibility and probabilities for success under various growing conditions (See Appendix).

In conventional varieties all traits must be in homozygous states to preserve genetic uniformity in next generations. But in hybrids most of the traits are in heterozygous state enable to gain from the expression interaction of both alleles of the genes. This helps to overcome the negative effects of some traits (when they are in homozygous state) and benefit from the new positive additive or dominant effects of the genes' alleles. Of course, all plants have the same genome (with the same combination of traits and alleles) which ensures high uniformity of the variety.

When the genetic distance between the parent lines of a hybrid is wide enough, Heterosis effect is obtained too. This effect is also unique only to F1 hybrids and causes high expression of traits over their expressions in the parent lines (over-dominant).

Among the possible cotton hybrids, those which are produced by crossing parent lines from the different species *G. barbadense* and *G. hirsutum* are the most promising in their potential for yield and quality.

These Inter-specific hybrids (ISH) combine alleles of traits that are usually found only in one of each species and so increase the range of the traits' performance. Combining traits from these species usually fails in breeding OP varieties because of special gene groups' linkages in both species.

The great variation in traits between the two species increases the possibilities for Heterosis effects in more traits bringing the following (already proven) desired advantages:

- Strong vigor at early growing stages - including germination, emergence and root development under low temperatures – needed for early planting and short season cultivation.
- High efficiency in water use – require less water (or tolerate large intervals between irrigations)
- High tolerance to drought and salinity – due to efficient physiologic processes (Heterosis) and strong plant with deep root system.
- Combine tolerances (to soil born and leaf diseases) and traits (large bolls with high fiber quality) that usually found only in either species.
- Higher potential of lint yield also under marginal growing conditions.
- Superior fiber characteristics than usually found in the best Upland varieties.

The suggested breeding method enables the development of various ISH types differing in earliness, plant shape and growth habit. But all perform the above common traits.

Due to tendency of ISH to grow at a high pace and their efficiency in water use, adjustments in crop management should be made mainly to restrain the growth when necessary. Particularly, avoidance excess watering and maintain the right balance between vegetative and reproductive development.

Two main weaknesses in ISH development and utilizing are still to be solved:

- Presence of motes (un-fertilized ovules or aborted seeds) in the lint. This phenomena resulted from some incompatibility still exists between the different species. These may increase the imperfections in the lint after ginning.
- Absence of efficient seed production system resulted in low seed yield with high cost production.

Despite the difficulties, some commercial ISH are grown successfully in Peru, California, Spain, Greece and Israel ([Table 4](#)).

We believe that when more breeders and researchers will adopt the hybrid breeding approach, these problems and some others (less significant) could be solved for the benefit of the growers and the cotton industry.

Perhaps ICAC may consider promoting the new concept of variety development and utility.

Table 1

ICAC publication	World cotton lint production statistics 2006-2007								
	WORLD TOTAL	USA	BRAZIL	CHINA	AUST-RALIA	GREECE	TURKEY	TOTAL SIX *	WORLD LESS 6
Area 1000h	33,987	5,152	1,065	5,399	140	300	700	12,756	21,231
	%	15.2	3.1	15.9	0.4	0.9	2.1	37.5	62.5
Yield kg/h	745	911	1335	1246	1810	1067	1170	1116	522
Production 1000T	25,333	4,696	1,422	6,729	253	320	820	14,240	11,093
	%	18.5	5.6	26.6	1.0	1.3	3.2	56.2	43.8
Consumption 1000T	26,142	1,078	840	10,824	11	72	1,550	14,375	11,767
	%	4.1	3.2	41.4	0.04	0.3	5.9	55.0	45.0
* Note:	Six producer countries with yield over 900kg/h and more than 250 T.tones								

Table 2

Lint yield and Fiber characteristics of Upland varieties (picker) - 2006					
Data are averages from several trials and publications					
VARIETY	lint Yield kg/h	Length inch.	Strength gr/tex	Fineness micron.	Notes
MAXXA	1380	1.16	25	4	Full season
ULTIMA	1380	1.2	27	3.7	Full season
PHY 78	1690	1.19	33.5	4.2	Early-Mid
FHY 72	1950	1.21	32.5	4.2	Early-Mid
SIOKRA V-18	1800	1.13	32.3	4.2	Early
SICALA 43	1755	1.14	32.5	4.2	Early
ST 474	1400	1.1	28	4.7	Early-Mid
ST 4793 R	1350	1.1	28	4.7	Early-Mid
FM-966 LL	1700	1.14	32.7	4.8	Early-Mid
DP-444 BR	1930	1.12	30.2	4.7	Early-Mid

Table 3

Lint average cost production - 2005				Support
Country	\$/h	\$/kg	\$/lb	\$/lb
ISRAEL	2500 - 3010	1.1 - 1.54	0.5 - 0.7	non
USA	500 - 2200	1.1 - 1.54	0.5 - 0.7	16
CHINA	300 - 1200	0.66 - 1.1	0.3 - 0.5	6
TURKEY	400 - 1200	0.66 - 1.1	0.3 - 0.5	11
GREECE	600 - 1300	0.88 - 1.32	0.4 - 0.6	33
INDIA	200 - 750	1.1 - 0.88	0.3 - 0.4	non
S. AMERICA	400 - 1400	0.88 - 1.54	0.4 - 0.7	?

Table 4

Lint yield and Fiber characteristics of Inter-specific F1 hybrids
Data are averages from several years of commercial cultivation







HYBRID	lint Yield kg/h	Length inch.	Strength gr/tex	Fineness micron.	Notes
HA-195 (Acalpi)	2000	1.38	37	3.9	Mid season
HA-175 (Europa)	1750	1.29	35	3.8	Early
HA-211	1900	1.41	37	3.8	Determinate
OMRI 5	1900	1.32	36	3.8	Hairy leaf

Appendix

MAJOR STAGES IN COTTON BREEDING METHODS

Of Conventional (OP) and Hybrid Varieties

Description example of introducing new trait with dominant (D) or additive (AD) effects, into a chosen (Target) successful variety:

Pre-breeding work – for isolating, studying and prepare the new trait in a proper plant (donor) for introducing into target variety. May last few years				
Season 1	Crossing donor plant with plant of chosen var.	Donor X Target	Common Stages of Backcross breeding method for Introducing a trait of D or AD genes to OP varieties or to parental lines of F1 hybrids	
Season 2	Imposed self -pollination (SP = )	F1 plants 		
Season 3	Selecting (SL) plants with the new trait and cross them to Target	F2 population X Target		
Season 4	As in season 2	BC1 -F1 		
Season 5	As in season 3	BC1 -F2		
Seasons 6 - 10	Repeating 3 cycles of seasons 2 -3	BC2		
		BC3		
		BC4		
Season 11	SL and SP of lines most resemble to Target	BC4 -F2 		
Seasons 12 -13	Generations to get high Homozygosis and further SL among best lines.	F3 		HYBRID Pathway
		F4 		Crossing the best lines with several others (10).
End of introducing the trait		OP Pathway	@ @ @ @ X * * * * * * * * * *	
Main Season/ one year	Preliminary evaluation and selection of the best	@ @ @ @ Up to 4 selected promising lines	40 hybrids based on elite lines or successful varieties - for evaluation under different growing conditions	
Main Season/ one year	Choosing the best performed line	1-2 lines for final selection	Continue evaluation of 20 best performed hybrids with the new trait and adapted to different regions	
2-3 main seasons = 2-3 years	Yield trials – regional, national, for registration and adaptability evaluation	One new variety with the new trait and same performance and adaptability of the Target	10 (at least) new hybrids to launch in different regions	

Total development period - 13 seasons (6 -7 years) + 5 years of yield trials = 11 -12 years (without pre -breeding)