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MALE STERILITY IN COTTON

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PREFACE

India is one of the major producers of cotton. India stands first in area and third in the production. India is the pioneer country for the cultivation of cotton hybrids on commercial scale. The first cotton hybrid (H4) was released in 1970 from Main Cotton Research Station, Surat of Gujarat Agricultural University, by Dr. C.T. Patel who is rightly called as the father of hybrid cotton. Later on, several other cotton hybrids were released for various states. Now, hybrids are grown in all the nine major cotton growing states of India.

More than 50 cotton hybrids have been released by various State Agricultural Universities and ICAR Research Institutes / Centres for commercial cultivation in different states. Equal number of hybrids or more have been developed by private seed companies. Now hybrids cover about 45% of total cotton area and contribute about 55% to the national cotton production. However, most of the hybrids under cultivation, have been developed by conventional method (hand emasculation and pollination) and their seed is very costly ranging from Rs. 600/- to Rs. 1000/- per kg. which cannot be afforded by small and marginal farmers. The use of male sterility reduces the cost of hybrid seed by eliminating the process of emasculation.

This bulletin provides comprehensive information about male sterility in cotton. Various aspects of male sterility such as types, genetics, sources, transfer to other genotypes, effect of environment, role of biotechnology, development of male sterility based hybrids, cost of hybrid production using MS lines and future thrusts have been discussed. The information contained in this bulletin has been gathered from various published sources.

Hope this bulletin would be useful to researchers, teachers, students, cotton growers and others engaged with cotton crop. Authors are thankful to Mrs. Rama Iyer for her help in typing this manuscript. Authors are also thankful to **National Agricultural Technology Project (NATP)** for financial support for publication of this bulletin.

MALE STERILITY IN COTTON

1. Introduction

Male sterility refers to a condition in which nonfunctional pollen grains are produced in flowering plants. In flowering plants, the first case of male sterility was reported by Koelreuter in 1763. Later on, numerous of male sterility were reported in Angiosperms. In cotton, the first case of male sterility was reported by Justus and Leinweber in 1960 in upland cotton (*Gossypium hirsutum* L.). Later on, male sterility was reported by various workers in upland, Egyptian and *arboreum* cottons. Now, male sterility is being used for development of hybrids in both tetraploid and diploid cottons. Male sterility helps in reducing the cost of hybrid seed production by eliminating the process of emasculation.

Male sterility is an important outbreeding device which prevents autogamy and permits allogamy. Male sterile plants have non-functional or non-viable pollen grains, which are formed through a chain of vital processes during microsporogenesis. These processes are under the genetic control of many loci that mutation of any locus may result in formation of non-functional pollen grains or microspores and hence male sterility.

2. Types of Male Sterility

Male sterility is of three types, viz. (1) genetic male sterility, (2) cytoplasmic male sterility, and (3) cytoplasmic genetic male sterility. In cotton, all three types of male steriles are found. These are briefly discussed below:

2.1 Genetic Male Sterility (GMS): The pollen sterility that is caused by nuclear genes is termed as genic or genetic male sterility. In cotton, GMS has been reported in upland, Egyptian and *arboreum* cottons. In tetraploid cotton, male sterility is governed by both recessive and dominant genes. However, male sterility governed by recessive genes is used in practical plant breeding. The merits and demerits of GMS are presented below:

Merits

1. Large number of parents can be used in crosses, because all the genotypes have dominant genes for male sterility.
2. Only female parents of a good hybrid has to be converted.
3. GMS generally does not have undesirable agronomic characters.
4. It is possible to breed the varieties from segregating population of GMS.

Demerits

1. GMS is less stable. Sometimes, sterile plants become fertile under low temperature conditions.
2. In GMS, the lines segregate into male sterile and fertile plants in 1: 1 ratio.
3. Conversion of a genotype into GMS (ms_5ms_6) needs selfing after each backcross to isolate recessive genes and hence more number of generations are required.

4. It requires more area as 50% of the population is fertile.
5. The quantity of seed produced is less.
6. There is possibility of admixture if fertile plants are not properly rogued out.

2.2 Cytoplasmic Male Sterility (CMS): It occurs due to the involvement of non-nuclear genes. This type of male sterility is determined by the cytoplasm. Since cytoplasm of the zygote comes from the egg cell, the progeny of such male sterile plants will always be male sterile. This type of male sterility is of importance in certain ornamental species where the vegetative part is of economic value.

2.3 Cytoplasmic Genetic Male Sterility (CGMS): Such type of sterility arises from the interaction of nuclear gene (s) conditioning sterility with sterile cytoplasm. This type of male sterility has provision for restoration of fertility, which is not possible in cytoplasmic male sterility. The fertility is restored by the R gene (s) present in the nucleus. Thus, the combination of both nuclear genes and cytoplasmic factors determines the fertility or sterility in such plants. The merits and demerits of CGMS are presented below:

Merits

1. In CGMS system, CMS is highly stable and is not affected by environmental factors.
2. In CGMS system, CMS 'A' line gives only male sterile plants.
3. Conversion of a genotype in CGMS system 'A' line is quicker and direct.
4. CMS requires less area for maintenance.
5. The quantity of seed produced is more.
6. There is no chance of admixture.

Demerits

1. In CGMS, only limited number of crosses can be made due to availability of limited number of restorers.
2. In CGMS, both male and female parents of the hybrid need to be converted.
3. CMS is solely controlled by cytoplasmic genes and hence it may have some adverse effect on other characters.
4. It is not possible to breed a variety from CMS line.

3. Genetics of Male Sterility

So far, sixteen different genes in tetraploid cottons (13 in *G. hirsutum* and 3 in *G. barbadense*) and two in *G. arboreum* have been identified for genetic male sterility. Sterility is conditioned by dominant alleles at five loci viz, MS_4, MS_7, MS_{10}, MS_{11} and MS_{12} by recessive allele at other loci viz. ms_1, ms_2, ms_3, ms_{13}, ms_{14} (Dong A), ms_{15} (Lang A) and ms_{16} (81 A).Two male sterile phenotypes viz. m_5ms_6 and ms_8ms_9 are conditioned by duplicate recessive factors. The expression of male sterility varies greatly in extent and stability among the loci.

Male sterility loci have been mapped. Both the dominant MS_{11} and the recessive ms_8 have been mapped to chromosome 12. The recessive sterility factor ms_3 and ms_9 have been

mapped to linkage group III of chromosome 16 and linkage group IX of chromosome 26 respectively. In diploid cotton, two genes have been identified for GMS from Akola and HAU, Hisar. At Akola, the male sterility was obtained from *anomalum x arboreum* crosses while at Hisar it was identified as a spontaneous mutant in *arboreum* variety DS 5.

G. hirsutum line Gregg (MS 399) from USA is the basic source of GMS possessing ms_5ms_6 gene for male sterility.

In case of CMS, the originally discovered CMS sources involving *G. arboreum* and *G. anomalum* cytoplasmic systems having interaction with ms_3 locus were not found effective or stable under different environments. The only stable and dependable CMS source under varied environment was developed through the utilization of *G. harknessii*. The complete genome of *G. hirsutum* was transferred into the *G. harknessii* cytoplasm. A single dominant gene 'Rf' from *G. harknessii* is essential for fertility restoration. Fertility enhancer factor 'E' for this CMS restorer system was obtained from a *G. barbadense* stock. The *harknessii* system is reported to contribute to good agronomic properties and attraction to honey bees.

Table-1: Male Sterility Genes Identified in Cotton

Gene	Species	Identified By
ms_1	*G. hirsutum*	Justus and Leinweber, 1960
ms_2	*G. hirsutum*	Richmond and Kohel, 1961
ms_3	*G. hirsutum*	Justus et al., 1963
MS_4	*G. hirsutum*	Allison and Fisher, 1964
ms_5ms_6	*G. hirsutum*	Weaver, 1968
MS_7	*G. hirsutum*	Weaver and Ashley, 1971
ms_8ms_9	*G. hirsutum*	Rhyne, 1971
MS_{10}	*G. hirsutum*	Bowman and Weaver, 1979
MS_{11}	*G. barbadense*	Turcotte and Feaster, 1979
MS_{12}	*G. barbadense*	Turcotte and Feaster, 1985
ms_{13}	*G. barbadense*	Percy and Turcotte, 1991
ms_{14} (Dong A)	*G. hirsutum*	Tianzhen et al., 1994
ms_{15} (Lang A)	*G. hirsutum*	Tianzhen et al., 1994
ms_{16} (81 A)	*G. hirsutum*	Tianzhen et al., 1994
ar.ms	*G. arboreum*	Meshram et al., 1997
ams_1	*G. arboreum*	Singh and Kumar, 1993

4. Maintenance of Male Sterility

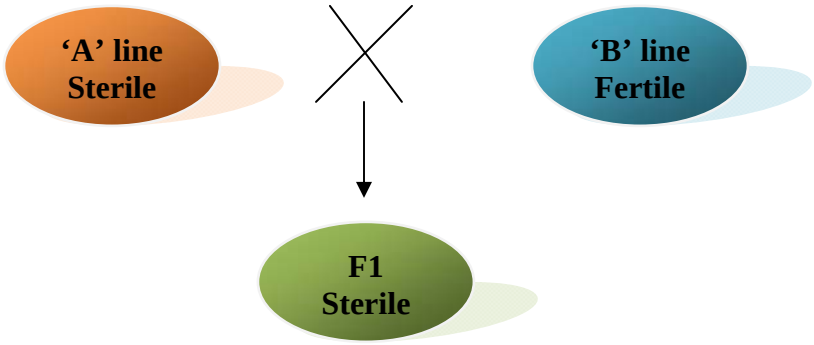
As already mentioned in cotton, two types of male sterilities are used. Maintenance procedure for each type is given below.

4.1 Maintenance of GMS lines

GMS lines is maintained by sibmating between fertile and sterile plants. The pollination is done by hand. The identification of sterile plants is easy by trained eyes and thus 50% plant population is to be rogued out.

4.2 Maintenance of CMS lines

The CMS line referred to as 'A' line is maintained by crossing to its counter 'B' line (Isogenic Line).



The 'B' line, a sterility maintainer line, is maintained by selfing.

The 'R' line, a fertility restorer line, is maintained by selfing.

5. Conversion into Male Sterile Lines

The potential female parents of hybrids can be converted into male sterile lines. To convert in GMS background, four to five backcrosses accompanied by alternate selfing is required. Finally, a line which is heterozygous for sterility and showing 1: 1 segregation is selected having all the characters of the recurrent parent.

The local genotypes with good agronomic backgrounds can be converted into CMS line by attempting five to six backcrosses. Similarly, the desired male parents can be converted into restorer lines by five to six backcrosses alongwith a 'Rf' factor. Finally, a line, which is homozygous for 'Rf' factor is selected. Many promising varieties and elite germplasm lines have been converted into CMS and restorer lines and few in GMS background (Table-2).

Table-2: Genotypes converted into CMS and GMS background

Male Sterility System	Genotypes
GMS (4x)	LRA 5166, SRT 1, DGMS 1, HGMS 2, GAK 32A, SHGMS-9, DGMS2, SHGMS-5
CMS	Germplasm - G 67, DMS A-8, RCMS A-2. GSCMS-15, 34, CAK32A, C1412, C 1998, CAK 1234, LCMS 6, JK 119, DMSA 15, IC 1547
	Varieties - Rajat, LH 900, Supriya, G. Cot l0, Laxmi, Abadhita, BN, K2, LRA 5166, H 777, G. Cot 14, Ganganagar Ageti, F 414, Bhagya, Kh3, Narmada, Deviraj
GMS (2x)	GMS 4, GMS 2, GAK 20A, GAK 09, SGMS 2, SGMS 4, RGMS A-2, RGMS 3,SGMS 13, GMS 4-1, GAK 15A, GAK 26A, Sujay, GAK 423, GAK 8615
R line	NH 258, AKH 545, GSR 22, AKH 39R, LR 29, AKH 26R, AKH 1167, GSR 6, DR 6, DR 1, AKH-01-143, LR 104

6. Sources of Male Sterility

There are three important sources of male sterility viz. interspecific crosses, spontaneous mutations and induced mutations. These are briefly discussed as follows:

6.1 Interspecific crosses

The cytoplasms of three diploid species, viz. G. *anomalum*, *G. harknessii* and *G. arboreum* interact with nuclear genes of *G. hirsutum* and produce male sterility.

The cytoplasm of *G. arboreum* and *G. anomalum* are heat-sensitive and therefore less stable. The cytoplasm of *G. harknessii* and genome of *G. hirsutum* interaction produce stable and dependable cytoplasmic male-sterility in cotton over all environments, though some adverse effects on ginning outturn, micronaire value and bacterial blight susceptibility have been reported.

G. harknessii was the only available source of CMS until 1997. After concerted efforts, the cytoplasmic lines with *G. aridum* Skovt. (D4) has been developed by the Cotton Research Unit, PDKV, Akola. A new system of CMS has also been developed at the University of Arkansas, USA wherein *G. trilobum* cytoplasm was utilized. The new system of cytoplasm called CMS 8 (D-8) has undergone extensive testing to eliminate undesirable effects (eg. Low fibre maturity) of the *G. hirsutum* nucleus interaction with the *G. trilobum* cytoplasm. Another different source of CMS i.e. CMS-C1 has been recently developed by using *G. sturtianum* cytoplasm.

Very recently, a new male sterility system of cytoplasmic nuclear genic male sterility has been evolved through interspecific breeding using a synthetic allopolyploid between *G. anomalum* x *G. thurberi* at Akola. The new male sterility system enables to avoid tedious work of incorporation of R genes into cultivated species / genotypes which is the main bottleneck of CGMS.

6.2 Mutations

Mutation is a sudden heritable change in an organism which does not arise due to recombination or segregation. This phenomenon leads to change in a gene, resulting in male sterility. Mutations are of two types, viz. spontaneous and induced. Spontaneous male sterility has been observed in upland and *arboreum* cottons.

Male sterility can also be induced through the use of physical and chemical mutagens. Mutagen included male sterility has been reported in as many as 35 crop species including cotton. In *G. arboreum*, the first spontaneous male sterility mutant was identified in variety DS-5 at Haryana Agricultural University, Hisar. The gene is designated as ams_1. The semi and complete male sterility has been isolated by various workers from the material treated by X-rays, gamma rays and Ethyl Methane Sulphonate (EMS). At Dharwad, cotton variety Abadhita was treated with gamma rays and various concentration of EMS. Male sterile mutant was obtained in case of double mutagen at 10 kR + 0.2 per cent EMS. In M_2 generation, the segregation pattern of male sterile to fertile was 1: 1, indicating presence of GMS which was conditioned by post meiotic pollen abnormality.

7. Induction of Male Sterility by Male Gametocides

Male sterility can be induced through the use of chemicals, which are commonly known as male gametocides. Some of the chemicals used for induction of male sterility is FW 450(Sodium B-Dichloro-iso-butyrate) or MH-30 (Maleic hydrazide) and Ethidium bromide (a potent mutagen).

Spraying of aqueous solution of FW-450 or MH30 induces male sterility in cotton. Pate and Duncan (1960) found that application of 2-3 dichloro-iso-butyrate at the rate of 1.02 lb per acre showed selective toxicity to the male gametes. Higher concentration of treatments caused male as well as female sterility and various adverse effects like reduction in yield, boll and seed size and increase in lint percentage. Singh *et al.* (1989) studied the effect of some gametocides on pollen sterility and anther development in *G.arboreum.* The effect of FW 450 (Mendok), maleic hydrazide (MH) and Coumarin applied before and during bud initiation or at anthesis were examined. Highest pollen sterility was caused by 1.5% FW-450, ranging from 76.3 to 97.8%. Treatment twice, one before bud initiation and the second during bud initiation gave the highest rate of pollen sterility.

Trials with selective male gametocides like FW 450, MH etc. has not been encouraging. The new selective chemosterilants like CHA (Chemical hybridizing agent) promoted by an American Company Chembred Inc. may be tried for this purpose.

8. Effect of Environment on Male Sterility

Environmental factors like temperature, photoperiod etc. have influence on male sterility. The *G. harknessii* cytoplasmic male sterility is very stable and is least affected by the environmental conditions and therefore can be utilized in varying environmental condition. The CMS lines of *G. hirsutum* with *G. arboreum* and *G. anomalum* cytoplasm were studied and it was observed that day temperature above 33°C was required for the consistent expression of male sterility in the sterile 'A' line. Increased day length generally led to increased level of sterility. It was reported that male sterility in cotton was induced mainly by high temperature. Temperature above 35°C in the active crop period resulted in abortion of flower buds and splitting of anthers.

Genetic male sterility is unstable and there are chances of male sterile plants becoming male fertile under low temperature condition. Out of 16 different genes reported in *G. hirsutum* ms_5ms_6 is the stable source. However, both the *arboreum* GMS sources were found to be temperature sensitive. The sterile plants have been found to produce pollens when the temperature falls below 16°C. This type of temperature sensitive male sterility is referred to as T GMS. The advantage of this system is that such lines do not require separate maintenance as it produces viable pollen below 16°C.

9. Development of MS Based Hybrids

Male sterility has important application in the development of hybrids. All the three types of male sterility are used in crop improvement programme. In India, several hybrids have been developed in cotton using the GMS system. CPH_2 (Suguna) was the first male sterility based hybrid released in as early as 1975 from CICR Regional Station, Coimbatore. However, this GMS based hybrid did not spread much for lack of seed production efforts. The *G. harknessii* cytoplasmic male sterility with fertility restoration gene sources were used in developing the hybrid CAHH 468 (PKV Hy-3). A brief comparison of MS based and conventional hybrids is given in Table 3.

Few private seed company hybrids also represent this category. Table-4 shows some public and private bred MS based hybrids.

Table 3: Comparison of MS based and conventional hybrids

MS Based Hybrids	Conventional Hybrids
1. Planting ratio for female to male is 4: 1 or 3: 1	1. Planting ratio for female to male is 2:2.
2. Half day labours are required for pollination case of GMS (in few labours are required for identifying and roguing of fertile plants)	2. Full day labours are required for emasculation and pollination.
3. For one kg seed production, one female labour	3. For one kg of seed production, three female labours are required per day.

is required per day.	
4. One female labour can pollinate 2000-3000 flowers	4. One female labour can emasculate and pollinate 200- 300 flowers.
5. Quantity of seed produced is more due to high seed setting as there is no mutilation of the female part.	5. Quantity of seed produced is less as there are more chances of mechanical injury during emasculation.
6. Immature seed % is low.	6. Immature seed % is high.
7. Shedding % of crossed bolls is negligible.	7. Shedding % of crossed bolls is more due to mechanical injury.
8. Self pollinated bolls is negligible (chance only in GMS) 9. Spread of hybrids is rapid.	8. Self-pollinated bolls are high. 9. Spread of hybrids is slow.
10. Use of F_2 seed as planting material is not possible.	10. Use of F_2 seed, as planting material is possible.

Table-4: Main features of hybrids released using male sterile line

Name of hybrid	Year of release	Yield (q/ha)	GOT (%)	MFL (mm)	Spinning counts	Area in which released	Type of hybrid
Suguna	1978	30	35	25	40	Tamil Nadu	HH
ANKUR 15	1983	30	35	26	50	Vidarbha	HH
MECH 11	1984	25	38	28	50	MS and AP	HH
MECH 4	1990	25-30	35	29	50	MS,GS, MP,RS	HH
PKV HY-3 (CAHH 468)	1993	15R	36	25	40	Vidarbha	HH
PKV HY4 (CAHH 8)	1996	20R	35	30	50	Vidarbha	HH
ANKUR 09	1997	30	37	27	40	MS,GS, MP	HH
AAH 1	1999	24	38	16	<10	Haryana	AA
PKV HY5 (CAHH 99)	2000	15R	35	26	40	Vidarbha	HH
AKDH 7 (PKV DH1)	2000	12R	38	24	30	Vidarbha	HH
G.COT MDH II(GSGDH 2)	2002	20	36	23	27	Gujarat	AA

10. Role of Honey Bee in Cross Pollination

The cultivated cottons have attractive large, showy, white, cream, light yellow to bright yellow flowers with species to species variation for dark pink / maroon blotch at the base of the flower / claw. Both intra and extra floral nectaries are also present. All these morphological features attract honey bees, bumble bees and other insects, which serve as the pollinators.

Reports are available which states that ten bees per 100 flowers are sufficient for excellent crosspollination particularly when the crop is grown under isolated condition. Studies have shown that honey bees and other insect visitors / pollinators are more attracted towards male sterile genotypes than normal genotypes. In some cases, reports are available that yield in 'A' lines could be obtained equal to that of B-line when 13-14 bee colonies were provided in a hectare.

11. Role of Apomixis

Apomixis is production of seed without fertilization and is considered as one of the tool in plant breeding. So far, apomictic gene has not been reported in cotton. However, use of certain chemicals like dimethyl sulphoxide and colchicine in combination have been effective when applied to 16 to 20 days old flower buds. Occurrence of apomictic plants have also been reported in some interspecific crosses of cotton.

Apomixis will be of great help when the breeder desires to fix the hybrid vigour. Thus, once the desirable combination has been selected, the hybrid could be multiplied and maintained by apomictic progeny. It will increase the efficiency of the hybrids by three or two line breeding system apart from the use of seed every year. The availability of large number of hybrids will help to increase genetic diversity and reduce genetic vulnerability

12. Role of Marker Characters in Hybrid Seed Production

Marker characters viz. okra, super okra leaf, petal spot / blotch, plant pigmentation, coloured anther filament, hairiness, nectariless, glandless, etc. are some of the marker characters available in cotton. These marker characters are useful in identification and maintaining genetic purity of the hybrid. Early seedling markers will be of great help while dealing with GMS lines.

13. Role of Biotechnology

Biotechnology has now become one of the most important tool in genetically modifying the crop plants. It has been extensively used in transferring 'Bt gene' which provides resistance

against *Helicoverpa armigera* and resistance to bialiphos herbicide in cotton. This technology has been utilized in transferring male sterility in few crops such as mustard, tobacco, rapeseed, rice, sesamum, wheat, soybean, vegetables and citrus using particle bombardment and *Agrobacterium* mediated methods of genetic transformation.

The male sterility induced by the technique of genetic engineering is called **transgenic male sterility.** The gene *'barnase'* causing male sterility is integrated into 'A' line. Another gene *'barstar'* suppresses the activity of male sterility gene *barnase* and hence can be used for fertility restoration.

The transformation frequency of 1-2% has been observed. The transgenic plants upto 50% have been reported to be stable in phenotype (male sterility) and in certain cases up to 90% of the transgenic plants were male sterile and were stable. Hence, this technique can be utilized for commercial hybrid seed production in near future in cotton.

14. Histological Studies of CMS and GMS

Histological basis of GMS has been studied by number of workers. It is reported that the process of microsporogenesis in male sterile and fertile anthers are same but the pollen development in the sterile anthers begins to diverge from the fertile anthers just after tetrads formation by not releasing them from the callose wall. As the development progresses, the pollen wall does not appear in the same way as in fertile anthers. The deformed microspores ultimately breaks down leading to pollen sterility.

In case of CMS, tapetum abnormality is found to be the cause of sterility. The microsporogenesis in sterile and fertile lines is similar in early stages but in the later stages the tapetum in the anther sac of sterile lines disintegrated at pollen mother cell stage. Thus, premature degeneration of tapetum in the sterile lines bring starvation to the meiocytes as a result of which normal course of development of meiocytes in sterile lines is arrested.

The histological basis of sterility in diploid GMS is similar to the one observed in tetraploid GMS.

15. Cost of Hybrid Seed Production using MS system

More than one hundred and fifty varieties and hybrids have been released till now. Few of them are widely cultivated in different agroclimatic regions and are responsible for increase production and productivity. The intra-*hirsutum* hybrids occupy about 45% of the total cotton area in the country. Interspecific hybrids occupy about 4 lakh ha in the Commond Area of Karnataka besides considerable area in Tamil Nadu and Gujarat while *desi* hybrids occupy negligible area.

More area of cotton can be brought under hybrid by reducing the cost of hybrid seed by developing MS based hybrids. Though male sterility systems were available in cotton long back but concerted efforts for its use in hybrid seed production has been made only after 1989.

The cost of production has been worked out for GMS based intra-*arboreum* diploid hybrid, GMS based intra-*hirsutum* hybrid and CGMS based intra-*hirsutum* hybrid. The cost of 1 kg hybrid seed of GMS based diploid hybrid was worked out to be Rs. 151.00. The detail expenditure incurred under various heads for different hybrids are given in Table 5, 6 and 7:

Table 5: Cost of seed production of GMS based intra-*arboreum* hybrid
(Study conducted at HAU, Hisar) For area 210 m^2 + 35 m^2

S.No.	Particulars / Item	Expenditure (Rs.)
I.	Inputs	
	a. Cost of cultivation	Rs.286.00
	b. Parental seed cost	Rs.104.00
	c. Roguing charges	Rs.60.00
	d. Pollination charges	Rs.780.00
	e. Packing charges	Rs.60.00
	Total cost	Rs.1290.00
II.	Seed Cotton Production	
	a. Hybrid seed cotton	12.200 kg.
	i. Hybrid seed	7.800 kg.
	ii. Lint	4,400 kg.
III.	Net cost per kg.	Rs.151.00

In another study carried out by that station for upland cotton, the cost of hybrid seed production for GMS based hybrid was worked out to be Rs. 102 while it was Rs. 547 for conventional hybrid.

Table 6: Cost of seed production of GMS based intra-*hirsutum* hybrid (Study conducted at HAU, Hisar) Area - 254 m^2

S.No.	Particulars / Items	Actual cost incurred (Rs.)	
		GMS based hybrids	Conventional hybrids
1.	Cost of cultivation	318	318
2.	Parental seed cost	79	79
3.	Roguing/ emasculation / Pollination charges	560	1120
4.	Delinting grading and packing charges	60	60
	Total cost	1017	1577
	Hybrid seed obtained (kg.)	10.00	2.880
	Net cost per kg	Rs. 102.00	Rs.547.00

The cost of hybrid seed production can be further reduced through the use of cytoplasmic genetic male sterility. This has been very well established by the Akola centre. The cost of production has been worked out based on three years of intensive studies. The cost of one kg. of hybrid seed was Rs. 31.51 and that of conventional hybrid was Rs. 192.59.

Table 7: Cost of seed production of CGMS based intra-*hirsutum* hybrid (Study conducted at PDKV, Akola)

Sr.No.	Particulars	Conventional	Male sterility	Rate (Rs.)	Cost (Rs.) Average of 3 years	
					Conventional	Male sterility
1.	Labour engaged	41	11	16.6/ day	33009.30	8636.00
2.	Total days of working	47.6	58	-	-	-
3.	Thread required (kg.)	28.74	-	56.75 / kg	1631.41	-
4.	Butter paper bags required (nos.)	92073.3	-	14.6/ 1000	1350.25	-
5.	Total cost of cultivation spraying. fertilizer etc.	-	-	-	6581.93	6668.54
6.	Total cost of seed production	-	-	-	42566.27	16973.20
7.	Yield of seed cotton (kg/ha)	350.13	678.22	-	-	-
8.	Weight of clean seed (kg)	207.74	411.22	-	-	-
9.	Weight of cut seed (kg)	12.05	26.13	5.3/ kg	65.48	145.28
10.	Weight of lint (kg)	130.73	230.89	18/kg	2413.32	4271.74
11.	Total cost of cut seed and lint	-	-	-	2478.80	4417.02
12.	Net cost per kg	-	-	-	Rs.192.59	Rs.31.51

The genetic male sterility is however, not much favoured by the seed producers because of the following reasons:

(i) The 50% plants are to be rogued out at the time of crossing.
(ii) There is possibility of admixture if fertile plants are not properly rogued out.
(iii) The quantity of hybrid seed produced by GMS is less than that produced by CMS system.

Future Thrusts

In cotton, now both genetic male sterility and cytoplasmic genic male sterility are available. These are being used for developing MS based hybrids and some GMS based hybrids have been developed in both tetraploid and diploid cottons. The future research work on male sterility needs to be directed towards following thrust areas:

1. In GMS, 50% population is male fertile and the same is identified after flower initiation. There is need to use marker genes in GMS for early identification and removal of fertile plants.
2. The GMS is sensitive to temperature which sometimes become fertile at low temperature (below 16°C). Efforts are needed to identify temperature insensitive and highly stable GMS lines.
3. Male sterility has been developed through genetic engineering in various crops. Efforts should be made to develop male sterile lines in cotton through genetic engineering.
4. There are only two sources of CGMS at present, viz. G. *harknessii* and G. *aridum.* Efforts should be made to identify additional sources of male sterility to avoid danger of uniformity.
5. In CGMS system, the male sterile cytoplasm has some adverse effects on insect resistance and fibre quality. Hence, efforts should be made to eliminate undesirable effects of sterile cytoplasm.
6. In CGMS system, the restoration capacity of R lines is generally low which leads to poor yield of CGMS based hybrids compared to GMS and conventional hybrids. Hence, efforts are needed. to identify restorer lines with high restoration capacity.
7. The CGMS system is so far available in tetraploid species. Efforts should be made to develop / identify CGMS system in diploid cottons.
8. The cost of the seed of conventional hybrids is very high (Rs. 600-1000) which cannot be afforded by small and marginal farmers. Hence, concerted efforts should be made to develop MS based hybrids to provide hybrid seed to the farmers at cheaper rate.
9. The fibre strength of most of MS lines is not adequate. Hence, efforts are needed to improve fibre strength of both GMS and CGMS lines.

Suggested Further Readings

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