RESEARCH PAPER

Genetic Variation for Harvest Index in Upland Cotton (*G. Hirsutum* L.)

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Abstract

Harvest index describes plant capacity to allocate biomass (assimilates) to reproductive parts. The harvest index is an important trait for cotton breeding programme especially under rainfed conditions. Efforts were made at ICAR-CICR, Nagpur, India for developing breeding lines of upland cotton for improved plant type and better fibre properties. During the year 2016-17, an experiment was conducted comprising 14 advanced breeding lines (F8 generation) along with four released varieties for evaluation of yield and yield components and fibre properties under rainfed conditions at 150 days after sowing (DAS). Amongst the breeding lines, CNH 09-9 and CNH 09-77 recorded highest harvest index (HI) of 0.6 compared to CNH 09-78 and CNH 712-13 which recorded harvest index of 0.2 and 0.3, respectively. Breeding lines CNH 10-6-1, CNH 12-12-4 and CNH 12-4-2 recorded harvest index of 0.3 which had plant height of 127.8, 111.6 cm and 103.8 cm, respectively. The released variety LRK 516 had recorded HI of 0.6 followed by NH 615, LRA 5166 and Suraj with HI of 0.5 indicating the importance of plant architecture while selecting plant type for improving yield per plant under rainfed situations. The varieties LRK 516, NH 615, LRA 5166 and Suraj had recorded plant height of 64.3 cm, 89.9 cm, 87.4 cm, and 81.3 cm, respectively. Breeding lines CNH 09-4 and CNH 09-7 recorded harvest index of 0.5 and plant height of 71.7 and 65.7 cm, respectively. Plant height had significant genotypic and phenotypic positive correlations ($r = 0.52$, $r = 0.55$) with number of sympodia and significant negative correlation ($r = -0.61$, $r = -0.55$) with harvest index. Boll number per plant had significant positive correlations ($r=0.47$) at genotypic level with seed cotton yield. Harvest index had significant positive genetic and phenotypic correlation($r=0.66$, $r=0.61$) with seed cotton yield. Thus, selection of relatively determinate and fully indeterminate parents in breeding programme would generate large extent of variability for plant type and harvest index which would provide opportunity to select desirable compact plant type with high harvest index and productivity under rainfed situations.

Keywords : Cotton, correlation, fibre quality traits, GCV, *G. hirsutum*, harvest index, PCV, seed cotton yield, yield components

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Introduction

Cotton is one of the most important natural textile fibres and a significant oilseed crop in the world. In India, it is cultivated in three distinct agro - climatic zones of the country. In the northern zone where cotton is raised entirely under irrigation while in central and south zones it is predominantly a rainfed crop. Approximately, 65 per cent of cotton is produced under rainfed conditions in India. The productivity of Central zone is very low compared to South and North zones owing to larger rainfed area under cultivation. Though India has largest area and production of cotton under cultivation of around 12.2 million hectares and 361 m. bales but its productivity is very low (480 kg lint/ha) *i.e.,* far below the world average of 779 kg/ha (AICRP on Cotton, Annual Report- 2018). In view of this, for improving seed cotton yield under rainfed situations there is a need to understand how under limited rainfall maximum yield can be achieved with required architecture of cotton plant.

Harvest index describes plant capacity to allocate biomass (assimilates) to reproductive parts. In cotton (*Gossypium* spp.), it is the ratio of harvested product (lint and seed) to the above ground plant dry weight or biomass (stem, leaves and fruits). In indeterminate crops, concurrent vegetative and reproductive growth is maintained, resulting in competition for resources between vegetative and reproductive sinks (Constable and Gleeson, 1977; Pate and Armstrong, 1996), and flowering occurs over an extended period during which flowers and bolls may be subjected to a range of climatic stresses. Harvest index could thus be more variable in indeterminate than determinate cotton varieties. The relationship between the production of photosynthate and photosynthetic sink in cotton has been the subject of great interest because of its importance to yield. The indeterminate growth characteristics of cotton plant means that it must grow vegetatively to produce fruiting sites. It normally continues to grow throughout the season until subjected to internal and external stress (Kohel and Benedict, 1987). Different researchers (Wells and Meredith, 1984; Meredith and Wells, 1989) reported that wide variation existed between cotton cultivars in partitioning their dry matter between vegetative and reproductive organs. Cultivars that partition their greater dry matter into reproductive organs are efficient in terms of increased seed cotton yield.

Selection for increased harvest index has been one of the major trends in modern cultivars that have contributed to increased yields (Wells and Meredith, 1984). Agronomically, harvest index is the major determinant of economic yield and, along with boll number per unit area and average boll weight, determines the lint yield. The harvest index in cotton has improved from as low as 0.08 in undomesticated cotton plants growing in the wild (Fryxell, 1979) to values of 0.47 and 0.53 in modern cultivars and as high as 0.66 in certain germplasm lines (Kerby *et al.,* 1990). Biomass production is the prerequisite of cotton yield (Bange and Milroy, 2004), and biomass partitioned to reproductive organs determines the yield (Fang *et al.,* 2009). Nalley *et al.* (2012) reviewed the work of cotton experts in the United States and estimated an average harvest index for cotton of 0.45 with values ranging from 0.24 to 0.57. The present study was therefore, conducted to characterize the released cotton varieties and advanced breeding lines to determine the interrelationship between yield component traits and seed cotton yield.

Materials and Methods

During the year 2016-17 an experiment was conducted comprising 14 advanced breeding lines along with four released varieties for evaluation of yield, yield components and fibre properties under rainfed situation. Four released varieties NH 615, LRA 5166, Suraj and LRK 516 were selected for their early maturity, sucking pest tolerance and fibre quality traits. The four plants were selected from each replication for recording observations on yield components. Each plot consisted of five 4.5 m long rows spaced 45 cm apart. Distance between two rows was 0.6 m. All the recommended agronomic practices were followed throughout the growing season for raising a good crop. The observations were recorded on plant height (cm), number of monopodia, number of sympodia, number of node to the first sympodial branch, number of bolls per plant, boll weight (g) and seed cotton yield per plant (g). The biomass (stems, fallen leaves and fruits) was collected at the time of harvesting at 150 days after sowing. After harvest, vegetative and generative plant parts were sun dried for fifteen days. The biomass of each plant was collected separately at the time of harvesting. Harvest index (HI) was used as a measure of biomass partitioning [(HI = Weight of Seed cotton) / Total dry biomass)].

Lint samples of each advanced breeding lines and released varieties were subjected to test fibre properties using High Volume Instrument (HVI) at ICAR-CIRCOT's, Ginning Training Centre, Nagpur, India. Data of upper half mean length (UHML), uniformity index (UI %), fibre strength (FS) (g/tex), micronaire (MIC) and fibre elongation (E) (%) were collected using HVI mode. The present study was conducted to investigate association of yield components and quality traits with seed cotton yield. An attempt has also been made to study harvest index and its association with seed cotton yield. The characters showing significant differences among the genotypes were further analyzed for correlation coefficients. The variance components and genotypic coefficient of variation were determined as suggested by Burton and De Vane (1953). Phenotypic and genotypic correlation coefficients were computed as per Miller *et al.* (1958).

Results and Discussion

Genetic variation for seed cotton yield, its components and fibre quality traits among genotypes

Mean values of seed cotton yield, yield components and fibre quality traits are presented in **Table 1.** Mean squares indicated significant differences among the genotypes for seed cotton yield, harvest index, plant height, number of monopodia, number of sympodia, number of bolls per plant, boll weight and ginning percentage indicating presence of sufficient amount of genetic variability in the material used in the study. However, genotypes had no significant differences for seed index and fibre quality traits UHML, UI, MIC, FS and elongation percentage. The highest coefficient of variation was shown by number of monopodia followed by number of bolls per plant, harvest index and seed cotton yield/plant indicating effect of environment in the expression of these traits. The least values were shown by fibre uniformity index, ginning percentage, upper half mean length, fibre strength and fibre elongation percentage indicating that these traits are controlled by genetic effects and less influenced by the environmental factors.

Amongst the breeding lines, CNH 09-9 and CNH 09-77 recorded highest harvest index (HI) of 0.6 as compared to CNH 09-78 and CNH 712-13 which had recorded lowest harvest index of 0.2 and 0.3, respectively. Breeding lines CNH 10-6-1, CNH 12-12-4 and CNH 12-4-2 recorded harvest index of 0.3 which had plant height of 127.8 cm, 111.6 cm and 103.8 cm, respectively. CNH 09-4 and CNH 09-7 recorded harvest index of 0.5 had plant height of 71.7 cm and 65.7 cm, respectively. While the released variety LRK 516 had recorded HI of 0.6 followed by NH 615, LRA 5166 and Suraj with HI of 0.5 indicating the importance of plant architecture specially plant height while selecting desirable plant type for improving seed cotton yield plant under rainfed situations. Thus, breeding lines CNH 7012-13, CNH 09-78, CNH 10-6-1, CNH 12-12-4,CNH and 12-4-2 had plant height of >100cm have lower values of the harvest index (0.2-0.3). Varieties LRK 516, NH 615, LRA 5166 and Suraj had

Table 1: Mean values of seed cotton yield, yield components and fibre properties of advanced breeding lines

Breeding line/Parent	PH	NM	NS	BN	BW	GP	SI	UHML	UI	MIC	FS	E	HI	SCY
								(%)		(mm)	(%)	(µg/inch)		(g/tex)
(%)	(g)													
CNH 7012-13	115.4	2.1	16.6	22.5	4.5	32.6	9.7	29.0	84.0	5.1	28.3	5.5	0.3	44.9
NH09-4	71.7	1.1	13.6	18.9	4.6	33.4	10.5	30.7	85.5	3.2	32.2	5.4	0.5	71.5
CNH09-62	82.4	2.0	16.5	22.2	3.6	34.3	9.2	28.0	83.5	4.1	32.5	5.3	0.3	37.9
CNH2-2	74.3	1.6	14.8	17.0	4.6	34.7	10.5	31.1	84.5	3.7	31.4	5.6	0.4	36.3
CNH09-9	73.7	1.4	14.4	21.9	4.8	33.3	9.2	30.0	84.0	4.5	28.9	5.4	0.6	59.1
CNH09-7	65.7	1.3	12.7	14.5	4.2	34.1	9.1	31.3	85.5	4.0	31.2	5.1	0.5	47.4
CNH09-77	94.5	1.9	16.4	20.8	5.1	35.3	10.2	29.5	83.5	3.9	30.3	5.5	0.6	67.1
CNH09-78	105.4	2.0	20.1	22.1	5.0	34.2	10.9	29.3	84.5	4.1	30.4	5.4	0.2	36.1
CNH10-6-1	127.8	1.4	21.9	25.4	4.4	35.6	11.3	31.6	85.5	4.6	32.7	6.0	0.3	66.4
CNH 12-12-4	111.6	2.9	13.6	23.6	4.5	31.5	9.6	30.3	84.5	4.0	28.6	5.8	0.3	55.5
CNH 12-4-2	103.8	2.7	16.9	16.1	4.7	29.6	11.5	31.1	85.5	4.8	29.6	5.7	0.3	56.5
CNH 18-8-3	85.2	1.8	17.0	16.3	5.3	33.8	9.6	29.8	83.5	4.6	30.8	5.5	0.5	63.4
CNH09-5	72.8	2.3	18.4	34.1	4.0	34.3	10.0	30.4	85.5	4.2	32.6	6.0	0.3	51.6
CNH09-98	90.5	1.6	16.4	17.6	4.3	32.9	9.0	28.9	84.5	4.3	31.6	5.8	0.4	50.2
NH 615	89.9	1.4	15.3	28.3	3.6	36.2	9.0	30.2	82.5	3.7	31.2	5.7	0.5	61.0
LRA 5166	87.4	1.5	19.3	15.6	3.5	33.6	9.1	31.6	83.5	4.4	31.8	6.1	0.5	69.7
Suraj	81.3	1.8	18.0	31.0	4.2	31.8	10.0	32.2	83.0	4.3	33.1	6.2	0.5	84.8
LRK 516	64.3	3.5	15.0	34.0	4.0	34.2	8.3	29.6	83.5	3.4	29.9	5.9	0.6	74.4
Mean	88.7	1.9	16.5	22.3	4.4	33.6	9.8	30.2	84.3	4.1	31.1	5.6	0.4	57.4
C.V.	8.3	27.1	9.7	23.5	11.3	3.9	9.6	3.9	1.4	14.5	5.4	5.7	18.2	16.1
Mean squares	**	*	**	*	*	*	NS	NS	NS	NS	NS	NS	**	**
C.D. 5%	15.6	1.1	3.4	11.1	1.0	2.8	-	-	-	-	-	-	0.2	19.5

PH - Plant height (cm), NM - No. of Monopodia, NS - No. of sympodia, BN - Number of bolls per plant, BW - boll weight (g), SCY - Seed cotton yield per plant (g), GP - Ginning Percentage, HI - harvest index

recorded plant height of 64.3 cm, 89.9 cm, 87.4 cm and 81.3 cm, respectively. Kerby et al. (1990) found harvest index values of 0.47 and 0.53 in modern cultivars of cotton and as high as 0.66 in certain germplasm lines. Nalley et al. (2012) estimated an average HI for cotton of 0.45 with values ranging from 0.24 to 0.57.For boll weight, breeding line CNH09-66 had highest boll weight of 5.0g followed by CNH09-9 with boll weight of 4.8 g. Among breeding lines, the number of sympodia varied from 12.7 (CNH09-7) to 21.9 (CNH10-6-1), seed cotton yield per plant from 36.1g (CNH09-78) to 71.5g (CNH09-4).

For fibre quality traits, among breeding lines, CNH10-6-1 had the highest fibre strength of 32.7 g/tex followed by CNH09-5 with 32.6g/tex. The released variety Suraj had highest fibre strength of 33.1 g/tex. Among the breeding lines, CNH 10-6-1 had highest upper half mean length of 31.6 g/tex followed by CNH 09-7 (31.3 mm) and CNH 2-2 and CNH12-4-2 (31.1 mm). Majority of the breeding lines had fibre quality traits at par with the released varieties selected for this study. The results showed that the breeding lines CNH 09-4, CNH 09-9, CNH 09-7 and CNH 18-8-3 with better fibre quality traits also had high harvest index of 0.5 to 0.6. These results clearly demonstrate development of breeding lines with better fibre quality traits along with high harvest index is achievable under rained conditions.

Variance and heritability of yield and its components : The estimates of range, phenotypic and genotypic variance, phenotypic and genotypic coefficient of variability (PCV, GCV) and heritability are presented in **Table 2.** Knowledge of the nature and extent of genetic variability, heritability is an important pre-requisite in framing of crop improvement programme. The estimates of phenotypic variance and phenotypic coefficient of variability were high for seed cotton yield, plant height, number of bolls per plant, number of monopodial branches, number of sympodial branches, ginning percentage and harvest index. Pundhir *et al.* (2018) reported PCV greater than GCV for yield components. Large differences between PCV and GCV values were observed for number of monopodia, boll number and ginning percentage indicating that these traits were more influenced by the environment. However, small differences between PCV and GCV were observed for number of sympodia, boll weight, harvest index and seed cotton yield indicating less effect of environment on the expression of these traits. The selection for these traits is expected to be highly effective. Patil *et al.* (2016) reported that phenotypic coefficient of variation (PCV) was higher in magnitude than genotypic coefficient of variation for number of monopodia, seed cotton yield, plant height, number of bolls per plant and boll weight. Similar results have also been reported earlier by Kulkarni *et al.* (2011) and Pundhir *et al.* (2018).

Table 2 : Estimates of variability parameters for seed cotton yield and yield components of *Gossypium hirsutum* genotypes

Estimates	PH	NM	NS	BN	BW	GP	HI	SCY
Mean	63.5	2.4	7.4	19.5	1.8	6.6	0.4	48.7
Maximum	127.8	3.5	20.1	34.0	5.3	36.2	0.6	84.8
Minimum	64.3	1.1	12.7	14.5	3.5	29.6	0.2	36.1
Genotypic Variance	297.3	0.2	4.5	24.0	1.5	0.15	0.01	148.0
Phenotypic Variance	351.8	0.5	7.0	51.5	3.3	0.38	0.01	233.6
Genotypic Coefficient of variation (GCV, %)	19.4	27.0	12.8	21.9	3.8	8.82	24.5	21.1
Phenotypic Coefficient of variation (PCV, %)	21.1	38.3	16.1	32.1	5.4	14.30	30.5	26.6
Heritability (Broad sense)	0.85	0.5	0.6	0.46	0.4	0.38	0.64	0.6

PH - Plant height (cm), NM - No. of Monopodia, NS - No. of sympodia, BN - Number of bolls per plant, BW - boll weight (g), SCY - Seed cotton yield per plant (g), GP - Ginning Percentage, HI - harvest index

The heritability estimates ranged from 0.85 for plant height to 0.38 for ginning percentage. High heritability estimates were also observed for number of sympodia, harvest index and seed cotton yield suggesting additive gene action and selection based on these traits would be more reliable. Results are in agreement with the finding of Shakti *et al.* (2007) and Pundhir *et al.* (2018).

Genotypic and phenotypic correlation coefficients analysis : Phenotypic and genotypic correlations were calculated for all possible combination among various yield components traits **(Table 3).** Correlation coefficient analysis measures the magnitude of relationship between various plant characters and determines the component character on which selection can be based for improvement of seed cotton yield. It is observed that for boll weight, harvest index and seed cotton yield genotypic correlation coefficients were higher than phenotypic correlation coefficients indicating strong inherent association between the characters studied. The results also showed that yield component traits were significantly correlated with seed cotton yield. Plant height had significant genotypic and phenotypic positive correlations (rg=0.52, rp = 0.55) with number of sympodia and significant negative correlation (rg = -0.61, rp = -0.55) with harvest index. Pujer et al. (2014) also reported that seed cotton yield was found to be positively and significantly correlated with traits like bolls per plant, plant height, seed index, boll weight and lint index.

Significant negative association of plant height and harvest index imply that higher plant height does not contribute to the harvest index. Boll number per plant had significant positive correlations (rg=0.47) with seed cotton yield. It is interesting to note that, harvest index had significant positive genetic and phenotypic correlations (rg =0.66, rp =0.61) with seed cotton yield. Rajamani (2016) reported significant association of bolls per plant, boll weight, harvest index with seed cotton yield. Such positive association of seed cotton yield per plant with these traits was also observed by Yadav *et al.,* (2000). These results are in conformity with earlier work of Leelapratap *et al.,* (2007).

Conclusion

Amongst the breeding lines, CNH 09-9 and CNH 09-77 recorded highest harvest index (HI) of 0.6. For fibre quality traits, CNH10-6-1 had the highest fibre strength of 32.7 g/tex followed by 32.6 g/tex (CNH09-5). It is observed that for boll weight, harvest index and seed cotton yield genotypic correlation coefficients were higher

Table 3: Genetic and phenotypic correlation coefficients for seed cotton yield and yield components of *Gossypium hirsutum* genotypes

	PH	NM	NS	BN	BW	HI	SCY
PH	G	0.11	0.52*	-0.18	0.32	-0.61**	-0.19
	P	0.14	0.55*	-0.01	0.17	-0.55*	-0.07
NM	G		-0.05	0.41	-0.51	-0.33	-0.03
	P		-0.05	0.41	-0.35	-0.12	0.04
NS	G			0.23	-0.03	-0.45	0.04
	P			0.17	-0.01	-0.44	0.10
BN	G				-0.45	0.02	0.47*
	P				-0.26	-0.04	0.24
BW	G					0.09	-0.16
	P					0.02	-0.04
HI	G						0.66**
	P						0.61**

than phenotypic correlation coefficients indicating strong inherent association between the characters studied. The results also showed that yield component traits were significantly correlated with seed cotton yield.The identified promising breeding lines CNH 09-4, CNH 09-9, CNH 09-7, CNH 09-77 and CNH 18-8-3 possess better fibre quality traits with higher harvest index of 0.5 to 0.6. The result showed that development of breeding lines with better fibre quality traits along with high harvest index is achievable under rainfed conditions.

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Cotton facts: Fiber Quality (ICAC, 2003)
Fiber Formation

- Each cotton seed is capable of producing up to 20,000 single hairs/ fibers. Formation of fiber hairs on the seedcoat is not unusual, but the characteristics of such hair are unique and largely dependent on species. Each cotton fiber is a single cell emerging from the seed coat. Cotton fiber grows from the epidermis of the seedcoat cell. Fibers begin to elongate from the day of anthesis (flowering) and this growth is completed in 15-25 days.
- Fibers consist of a primary wall and a secondary wall, both mainly comprising cellulose fibrils. The primary wall is covered with a cuticle consisting of mainly wax, pectinous substances and reducing sugars. Entomological sugars, if any, are deposited on the cuticle (upper surface of fiber) and may cover the natural wax.
- In the primary wall, fibrils are placed in a wide angle with the fiber axis, and thus the primary wall has no effect on fiber strength. In the secondary wall, the cellulose fibrils are laid side by side following a helical course, making a small angle known as the spiral angle. Thus, the secondary wall thickening has a significant effect on fiber strength. The spiral angle in varieties differs greatly. As a general principle, a smaller spiral angle forms steeper spirals and thus stronger fibers. The spirals occasionally reverse direction resulting in structural reversals, which are potentially weak points in the fiber.
- The secondary wall forms more than 90% of the fiber weight. Fiber strength is directly related to yarn strength. Strong fibers make a strong yarn. However, this relationship is affected by fineness, length and length uniformity.
- The diameter of fiber is reached soon after it originates, and thus intrinsic fineness is established at an early stage and remains constant afterward. Elongation of the single cell forming the fiber continues for 15-25 days, depending on species as well as variety. This is the time when fiber length and length distribution are established. Once the fiber length is established and it ceases to grow, the second stage of fiber formation takes place during which cellulose is deposited in successive layers on the inner surface of the primary wall. Cellulose dep- osition is completed in about 25-35 days.
- When the boll opens, the fibers dry, losing their cylindrical cross section into a flat ribbon shape with many convolutions along their length.
- Effects of acids: Cold concentrated acids or hot dilute acids hydrolyze cellulose and disintegrate cotton fibers. Weak cold acids are unable to initiate hydrolysis.
- Effects of alkalis: Cotton shows excellent swelling (mercerization) in caustic, but no damage.
- Effect of heat: Cotton has high resistant to thermal deformation and degradation but may turn yellow after five hours at 248ºF.
- Dead cotton: An extremely immature cotton, having a thin fiber wall, is called dead cotton.