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Growth Performance and Instabilities of Cotton Crop- Macro Level Insights

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ABSTRACT

Cotton being the high value, non-food, fiber crop is grown across seventy countries supporting the lives of closely one billion people. Considering the global importance of crop the study was taken up to assess the growth performance of crop at different levels. Compounded annual growth rates, instability rates and source of instability were estimated for area, production and productivity of 'white gold'. Inter country, inter states and the inter districts comparison was done for the world, India and the Telangana state, respectively. At global level there was negative growth in the area but there was inclining production and productivity. Mean yield change was the major source of growth in average production at world level. India saw quantum leap in area and production after Bt cotton introduction. The instabilities among the states declined with the spread of new technology. Interaction between changes in the area variance and the mean yield was the source of growth for India. Telangana one of among major cotton producing states also went about rapid acreage expansion with the adoption of Bt cotton. Inclining mean area brought in uprising average production of the crop in the state. Recent decade has seen stagnating and lower productivities in both the state and country. Hence, there is need for new traits to offer resistance against rising pests and new innovative technologies to be developed.

Keywords Instability, Sources of growth, Bt cotton.

INTRODUCTION

Cotton is the most widely grown profitable natural fiber in the world, spread across the area of 34.50 million hectares worldwide. Its cultivated in more than seventy countries providing livelihood and financial security to nearly one billion people. It includes closely 250 million workers from the processing industry and 100 million cotton growers. Close to 90% of the growers belong to small holders' group with less than 2 hectares land holding.

Cotton is largely grown in tropical and sub-tropical areas where the hot and dry weather condition

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is prevalent. The plant grows well in the deep soils with good moisture holding ability. The crop plant yields the lint and the seed that are of high economic importance. The fiber derived is used specifically in apparels (68%), home furnishings (28%) and industrial application (8%). Therefore, acts as the backbone to global textile mills, apparel manufacturing market and fashion industry.

The world cotton production during the year 2020-21 stood at 142.78 million bales whereas the global consumption was155.84 million bales. Due to growing demand from various markets, consumption has over taken the production. Major cotton producing countries include China (37.78 million bales) followed by India (35.34 million bales) USA (18.71 million bales), Brazil (13.85 million bales) and Pakistan (5.76 million bales).

India accounted for nearly 25% of the global cotton production during 2020-21 with 35.34 million bales cultivated across major ten growing states. Despite low productivity India leads in the acreage under cotton. Introduction of Bt cotton in 2002 by Mahyco and Monsanto was a breakthrough in Indian cotton production. Following the release of Bt cotton acreage under the crop scaled up from 8.62 million hectares in 2002-03 to 13.29 million hectares during 2020- 21. Bt cotton was introduced in defiance of American Bollworm (*Helicoverpa armigera*), which caused ample crop damage, leading to low productivity. Bt laid out effective control against the American Bollworm, reducing the insecticides usage and therefore, making production eco-friendlier and more profitable. More than 90% of the cotton area was occupied by Bt cotton during 2019-20.

Telangana is the third largest cotton growing state after Maharashtra and Gujarat. The state is blessed with ambient soil and climatic conditions supporting crop growth. The state diverted larger area under millets, pulses and oilseeds after the Bt introduction causing substantial area expansion. Hence, cotton has become the major crop of the state after paddy. The state was always studied under Andhra Pradesh and hence there are very less studies on cotton area, production and productivity under Telangana.

Having noted increment not only in state level but also at national and international level it acts as commercial crop of historic importance. Henceforth, the current study was taken up to explore the growth aspects of area, production and productivity of cotton crop at global level, Country level and Telangana state level as well. Also, instabilities and sources of instabilities have been worked out for different components aforesaid.

MATERIALS AND METHODS

The secondary data on area, production and productivity for the last 30 years (1991-92 to 2020-21) was collected from published sources of FAO, Directorate of Economics and Statistics and Cotton Corporation of India. Growth performances and instabilities in area, production and productivity of the cotton crop have been worked out for triennium decades and the overall period viz., period-I (1991-92 to 2000-01), period II (2001-02 to 2010-11), period-III (2011-12 to 2020-21) and the overall period (1991-92 to 2020-21) for erstwhile districts of Telangana, major states of India and for major countries of the world.

The computational formula is specified below.

$$Y_t = ab^t e^u \quad \text{.....(1)}$$

Where,

Y_t = Area /Production / Productivity in year t
t= Time period
b = (1+r), 'r' being growth rate
a = Intercept
e= Error term

Cuddy - Della Valle index

The instability in area, production and productivity of cotton crop in Telangana, India and world was analyzed using Cuddy- Della Valle (1978) index given as:

$$I_x = CV\sqrt{1-R^2}$$

Where,

I_x = Instability index,
CV= Co-efficient of variation

R^2= Coefficient of multiple determination obtained from the time series.

Hazell's decomposition method

The decomposition model developed by Hazell in (1982) was used to study the sources of instability in cotton production based on the time series data. The instability was worked out for quindecinnial viz., period I (1991-92 to 2010-11) and period II (2011-12 to 2020-21) and the overall period. The model is defined as:

Let Q be the production, A be the area and Y be the yield.
Then, Q=A*Y. The average production can be expressed as,

$$E(Q) = \bar{A}\bar{Y} + Cov(A, Y) \quad \text{.....(1)}$$

Where, $\bar{A}$ = Mean area and
$\bar{Y}$ = Mean yield

Therefore, other than mean area and mean yield the average production was also affected by covariance between area and yield.

The average production in period and second period is given by,

$$E(Q_1)=\bar{A}_1\bar{Y}_1+ Cov(\bar{A}_1, \bar{Y}_1) \quad \text{.....(2)}$$

And in the second period it is,

$$E(Q_{11})=\bar{A}_{11}\bar{Y}_{11}+ Cov(\bar{A}_{11}, \bar{Y}_{11}) \quad \text{.....(3)}$$

Each variable in the second period is expressed as its counterpart in the first plus the change in the variable between the two. For example,

$$\bar{A}_{11}=\bar{A}_1+\Delta\bar{A} \quad \text{.....(4)}$$

Where, $\Delta\bar{A}= \bar{A}_{II} - \bar{A}_1$
Thus equation 3 can be rewritten as,

$$E(Q_{11})=(\bar{A}_1+\Delta\bar{A})(\bar{Y}_1+\Delta\bar{Y})+Cov(A_1,Y_1)+\Delta Cov(A,Y)$$

.....(5)

The change in average production, $\Delta E(Q)$, is obtained by subtracting equation (2) from equation (5). Therefore,

$$\Delta E(Q)=E(Q_{11})-E(Q_1)$$

Table 1. Components of change in average production.

Sl. No.	Sources of change	Symbol	Component of change
1	Change in mean yield	$\Delta\bar{Y}$	$\bar{A}I\Delta\bar{Y}$
2	Change in mean area	$\Delta\bar{A}$	$\bar{Y}I\Delta\bar{A}$
3	Interaction between change in mean area and mean yield	$\Delta\bar{Y}$, $\Delta\bar{A}$	$\Delta\bar{Y}$, $\Delta\bar{A}$
4	Change in area – yield covariance	ΔCov (A,Y)	ΔCov (A, Y)

Source: Hazell (1982).

$$\Delta E(Q)=\bar{A}_1\Delta\bar{Y}+\bar{Y}_1\Delta\bar{A}+\Delta\bar{A}\Delta\bar{Y}+\Delta Cov(A,Y) \quad \text{.....(6)}$$

This change in average production has four different components of change. These include the changes in mean area ($\Delta\bar{A}$), changes in mean yield ($\Delta\bar{Y}$) known as 'pure effects', 'interaction effects' it gives interaction between changes in mean area and mean yield ($\Delta\bar{A}\Delta\bar{Y}$) and the changes in the variability of area and yield (ΔCov (A, Y) known as 'variability effects'. These components of change in average production are presented in the (Table 1).

The sources of change in average production can be displayed under the simplifying assumption that COV (A, Y) = 0. This method of analysis uses the first period as the base, but based on the second period, an alternative procedure can be developed (Hazell 1982).

The variance of production, V (Q), can be expressed as,

$$V(Q)=\bar{A}^2 V(Y)+\bar{Y}^2 V(A)+2\bar{A}\,\bar{Y}\,Cov(A,Y)-Cov(A,Y)^2+R \quad \text{..... (7)}$$

Where, R is a residual term which is expected to be very small.

From equation (7) it can be seen that V (Q) is not only a function of the variances of yield and area sown, but also of mean area and yield and of the covariance between area and yield. Change in any one of these lead to change in V (Q). The basic objective of decomposition analysis is to partition the changes in the variability in production to its constituent parts by taking the values of the variables in the initial period as base.

Table 2. Components of change in variance of production.

SI. No.	Source of changes	Symbol	. Components of change (Percentage)
1	Change in mean yield	$\Delta\bar{Y}$	$2(\bar{A}_I\Delta\bar{Y}CoV(A_1, Y_1) + [2\bar{Y}_I\Delta\bar{Y} - (\Delta\bar{Y})^2]\ V(A_I))$
2	Change in mean area	$\Delta\bar{A}$	$2\bar{Y}_{II}\Delta\bar{A}Cov(A_1 Y_1) + [2\bar{A}_I\Delta\bar{A} - (\Delta\bar{A})^2]\ V(V_1)$
3	Change in yield variance	$\Delta V(Y)$	$(\bar{A}_I)^2\,\Delta V(Y)$
4	Change in area variance	$\Delta V(A)$	$(\bar{Y}_I)^2\Delta V(A)$
5	Interaction between changes in mean yield and mean area	$\Delta\bar{Y}, \Delta\bar{A}$	$2\Delta\bar{Y}\Delta\bar{A}\,CoV\,(Y_I, A_I)$
6	Change in area-yield covariance	$\Delta Cov\ (A, Y)$	$[2\bar{A}_I Y_I$-2CoV $(Y_I, A_I)] \Delta$ CoV-$[\Delta$CoV(A, Y)$]^2$
7	Interaction between changes in mean area and yield variance	$\Delta\bar{A}$, ΔV(Y)	$[2\bar{A}_I\Delta\bar{A} + (\Delta\bar{A})^2]\ \Delta V(Y)$
8	Interaction between changes in mean yield and area variance	$\Delta\bar{Y}$, ΔV(A)	$[2\bar{Y}_I\Delta\bar{Y} + (\Delta\bar{Y})^2]\ \Delta V(A)$
9	Interaction between changes in mean area and yield and change in area-yield covariance	$\Delta\bar{A}$, $\Delta\bar{Y}$, ΔCov (A, Y)	$[2\bar{Y}_I\Delta\bar{A} + 2\bar{A}_I\Delta\bar{Y} + 2\Delta\bar{A}\,\Delta\bar{Y}]\ \Delta$ CoV (A, Y)
10	Change in residual	ΔR	ΔV (A–Y) − sum of other components

Source: Hazell (1982).

The change in the variance of production can also be decomposed in the similar way. Taking the variance of production and applying the variance formula given below leads to the decomposition as shown in (Table 2). Here also the results are obtained by taking first period as the base.

Ten sources of change in variance in output can be identified. The components 1, 2, 5 and 6 represents the sources of change in mean output as shown in earlier case of decomposing the average production. But change can also occur through changes in variance of area, yield and the interaction between them.

Among the ten components of change in variance of production, the first four describes the pure effect and are of huge importance from variability point of view. The fifth component contributes towards the interaction effect, which is the outcome of simultaneous occurrence in change in mean area and yield. Sixth component accounts the change in variability in area, yield and from changes in correlation between area and yield. The seventh and the eighth components refer to second- and third-degree interaction between changes in mean area, yield and also the variability in them. The last two components of change are not significant because they can't be directly controlled.

RESULTS AND DISCUSSION

The pictorial representation of area, production and productivity of cotton at world level in the (Fig. 1). imparts that the area during 1991-92 was 33.83 million hectares but had during 2020-21 it was 31.66 million hectares. There was nearly stagnation in the area increase. The production and productivity of the crop also was varying throughout the period.

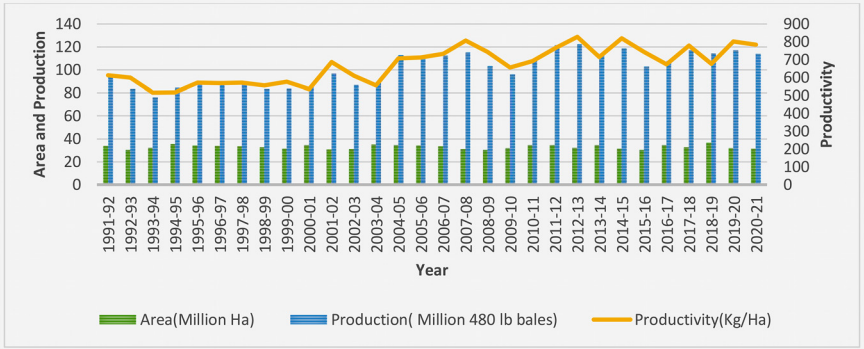

Fig. 1. Area, production and productivity of cotton in world.

Table 3. Growth rates in area, production and productivity in cotton crop across major countries and at world level.

	China	India	USA	Brazil	Pakistan	World
I Period						
Area	-5.82***	2.18*	0.15	-10.30	0.27***	0.23
Production	-1.46	0.24	-0.44	7.97	0.24	-0.26**
Productivity	4.64***	-1.89*	-0.59	8.75***	-0.50	-0.49
II Period						
Area	1.13	14.20***	-5.45**	0.66	0.30	0.07
Production	3.76*	3.22***	-3.95	3.87	0.79	1.58
Productivity	2.60**	10.69***	1.02	2.85***	1.75*	1.51
III Period						
Area	-3.87**	1.03	2.55	3.78	0.17***	-0.22
Production	-1.69	0.25	4.40**	-2.46	-7.65***	-0.52
Productivity	2.26	-0.77	1.80	3.97***	-4.15***	-0.29
Overall						
Area	-1.32***	1.99***	-1.51***	0.43	0.27***	-0.02
Production	1.34***	5.59***	-0.10	6.29***	0.22	1.34***
Productivity	2.70***	3.52***	1.42***	5.83***	0.76**	1.36***

Note: *** Significant at 1% level, ** Significant at 5% level and *Significant at 1% level of significance.
Period I: 1991-92 to 2000-01, Period II: 2001-02 to 2010-11, Period III: 2011-12 to 2020-21, Overall period: 1991-92 to 2020-21.

Growth rates in area, production and productivity across major countries and at world level

The decadal growth rates in area, production and productivity of the cotton was computed for the triennial period (1991-92 to 2020-21) and furbished in the (Table 3). Inter country comparison disclosed that India had positive significant growth during the overall period and in period II. Period II in India was epoch-making for cotton crop because, the Bt era embarked. The release of Bt hybrids in cotton brought about rise in area, production and productivity in the states as well as at national level (Suresh *et al*. 2013). China despite of negative area growth managed to be the global leader with positive production (1.34 %) and productivity growth rates (2.70%) during the overall study period. This was due to intensive and high efficiency cultivation techniques practiced (Lu *et al.* 2022). USA being another major producer faced negative growth (-1.51 %) in the cotton area due to reduction in the area harvested. But, cultivation of high yielding varieties through both genetic modification and conventional breeding sustained the fiber yields during the last 30 years.

Brazil, the fourth largest cotton producer during 2020-21 had decadal productivity growth due to technological investments in biotech varieties. Growth rate under cotton area was 0.27% for Pakistan which was lower than other countries. This was due to pest attacks and erratic weather conditions and thus, leading to shift in area under cotton to other remunerative prices (Ashraf *et al*. 2019). The scenario was different at world level where, cotton area exhibited negative growth rate with -0.02% as many countries had declining area under cotton crop but there was influential growth in production and productivity which was due to adoption of new technologies.

Instability in area, production and productivity across major countries and at world level

The instability hinders the growth agriculture and hence its of the major concern. The instability analysis at global level perusal in the (Table 4) for the three study periods reflected that the instability in area under cotton increased from 4.96% in period I to 6.35% in the Period III (2011-12 to 2020-21) at world level. The instability in production had declined in USA, Brazil and Pakistan while for India and China there was fall in the instability during Period II over Period I but again there was increased instability in

Table 4. Instability in area, production and productivity of cotton crop across major countries and at world level.

	China	India	USA	Brazil	Pakistan	World
I Period						
Area	20.30	6.30	9.62	42.35	7.56	4.96
Production	11.13	13.09	9.54	29.67	14.77	6.16
Productivity	8.19	9.41	8.51	15.62	15.55	5.44
II Period						
Area	19.99	7.40	8.14	10.57	4.47	6.20
Production	9.38	14.16	8.49	27.63	14.51	10.18
Productivity	11.00	14.18	7.09	21.51	13.09	9.19
III Period						
Area	20.21	5.60	11.05	23.05	3.22	6.35
Production	10.75	5.96	7.22	19.30	8.53	5.35
Productivity	14.24	7.71	9.34	25.21	10.69	7.19
Overall						
Area	20.10	8.81	8.38	30.06	7.43	5.50
Production	9.55	20.65	9.61	14.39	14.78	8.19
Productivity	6.15	18.44	8.81	25.21	14.21	8.75

these countries. Brazil had the highest and increasing instability in the yield from period I to period III. Further, during the overall period the instability in area and productivity was highest in Brazil.

Components of change in the average production of cotton in world

The contribution of different components for changes in the average production was analyzed and is presented in (Table 5). At world level the increased production accounted for increased yield. The increase was 110.5, 50.82 and 103.71% during Period I, Period II and overall period. The area contributed negatively during Period I (-11.48 %) and the overall period (-2.74 %). Yield and area interaction also affected negatively during Period I (-1.47 %) and overall period (-0.83 %). This justified that area under cotton was stagnating and the production increase was mainly due to increased yields.

The components of variance in production depicted in (Table 6) displayed that during Period I and Period II change in yield variance was the major component of change while in overall period the major component was change in residual (82.56 %). This might be due to the impact of other factors like Bt cotton, increased market demand. This was supported by the results of Shashikiran *et al.* (2018).

India and major states

India initially witnessed negligent growth in the area and production during the first decade. During the second decade, the introduction of Bt cotton caused significant rise in cotton area with growth of 14.20% during the period II and led to increased production and yield during the same period (Fig. 2).

Growth in area, production and productivity of cotton crop across the selected states of India

Computation of growth rates for major cotton pro-

Table 5. Components of change in the average production of cotton in world.

Sources of change		I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	110.50	50.82	103.71
Change in mean area	$\Delta\bar{A}$	-11.48	43.16	-2.74
Interaction between change in mean area and mean yield	$\Delta\bar{A}, \Delta\bar{Y}$	-1.47	0.98	-0.83
Change in area-yield co-variance	ΔCov (A, Y)	2.45	5.04	-0.15
Total		100.00	100.00	100.00

Table 6. Components of change in variance of production of cotton in world.

Sources of change	Symbol	I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	-8.20	180.06	18.66
Change in mean area	$\Delta\bar{A}$	-0.07	8.78	-1.00
Change in yield variance	$\Delta V(Y)$	68.62	267.95	-6.97
Change in area variance	$\Delta V(A)$	7.04	122.92	5.08
Interaction between changes in mean area and mean yield	$\Delta\bar{Y}, \Delta\bar{A}$	0.00	0.10	-0.03
Change in yield and area covariance	$\Delta Cov (A,Y)$	-0.06	-0.36	0.00
Interaction between changes in yield variance and mean area	$\Delta\bar{A}, \Delta V(Y)$	-1.82	10.45	0.11
Interaction between changes in area variance and mean yield	$\Delta\bar{Y}, \Delta V(A)$	1.92	5.65	3.52
Interaction between changes in mean yield and area and change in area-yield covariance	$\Delta\bar{A}, \Delta\bar{Y}, \Delta Cov (A,Y)$	5.01	13.79	-1.92
Change in residual	ΔR	27.55	-509.33	82.56
Total		100.00	100.00	100.00

ducing states and India (Table 7) uncloaked that, India leading in area and production suffered from negative productivity growth as observed in the Period I and Period III. India contributed nearly 25% to the world production which was noticeable, but the productivity of the country stood at 452 kg/ha i.e., nearly 58% lower than world productivity (772 kg/ha) during 2020-21.

Nearly 93% of the cultivated area in India was occupied by Bt hybrids by the end of 2017 (ISAAA, 2017). Despite widespread of Bt cotton the decline in the yield was due to inappropriate hybrids, inclusion of more marginal land into cotton production, increased damage by sucking pests and less adoption of refugia (Srivastava and Kolady 2016). During the period of 30 years from 1990-91 to 2020-21 the area under cotton increased significantly at a rate of 1.99 annually.

During the Period I (1990-91 to 2000-01), the states of Maharashtra, Gujarat, undivided Andhra Pradesh and Telangana had significant growth rates. All the states had significant growth rates in area under the cotton crop during Period II except Haryana and Punjab which had negative growth rates due to pest attack. Regardless of fluctuations in the area, the production had gained momentum across the states during the study period (1990-91 to 2020-21) from 97.06 lakh bales to 353.47 bales. All states had significant growth in the production and productivity during the over-all period of study. The state of Telangana had witnessed annual growth rate of 6.32% under the area which was highest among all the states further leading to remarkable growth in the production (9.88 %) during the over-all period of study.

Instability in area, production and productivity of cotton crop across selected states in India

Introspection of instability across the states and India

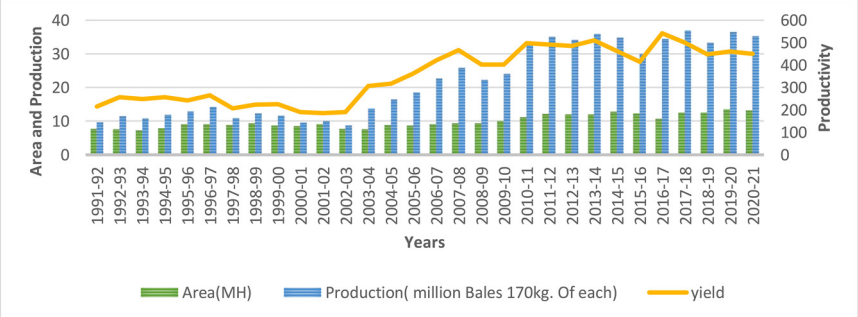

Fig. 2. Area, production and productivity of cotton in India.

Table 7. Growth in area, production and productivity of cotton crop across the selected states of India.

	Maharashtra	Gujarat	Telangana	Karnataka	Andhra Pradesh	Haryana	Madhya Pradesh	Rajasthan	Punjab	India
I Period (1991-92 to 2000-01)										
Area	2.87***	4.90***	4.63***	-1.04***	5.02***	0.93	-0.27	-0.73	-7.94*	2.18*
Production	4.20	3.56	11.82***	-0.19***	3.14**	-1.20	1.47	-0.05	-5.36	0.24
Productivity	1.28	-1.3	2.74*	0.85	-1.76	-2.10	1.75	-3.826	-8.71**	-1.89*
II Period (2001-02 to 2010-11)										
Area	2.94***	5.80***	6.31***	0.29	1.49***	-2.37***	1.88***	-2.54***	0.63	14.20***
Production	13.72***	21.33	13.29***	12.34***	13.97***	8.58***	14.71***	12.69***	7.04***	3.22***
Productivity	10.47***	14.70	5.83***	12.02***	6.38***	11.21***	12.56***	15.61***	6.37***	10.69***
III Period (2011-12 to 2020-21)										
Area	0.89*	-1.2	3.22**	3.66***	1.40	2.35**	0.03	7.206***	-9.03***	1.03
Production	1.91	-3.17**	9.12***	4.36***	-0.13**	-1.96	-1.82	11.65***	-9.81***	0.25
Productivity	0.99	-1.99***	6.15**	1.16	-1.51	-4.21	-1.90	3.76***	-0.85	-0.77
Overall (1991-92 to 2020-21)										
Area	1.91***	3.24***	6.32***	0.48	-1.67***	0.52**	0.83***	-0.36	-3.69***	1.99***
Production	6.59***	7.71***	9.88***	3.84***	1.42**	2.37***	7.94***	4.34***	-0.19	5.59***
Productivity	4.59***	4.33***	3.27***	3.41***	2.83***	1.83***	6.98***	3.33***	1.90**	3.52***

Note: *** Significant at 1% level, ** Significant at 5% level and *Significant at 1% level of significance.

furnished the (Table 8) evinced that the instability varied among the states. Instability increased from the Period I to Period II among all the states. During Period III, i.e. post introduction of Bt cotton the instability in the area and production projected mixed trend while, the instability had declined at all India level. But the yield instabilities fluctuated among the states. The highest instability area, production and yield was noticed in Rajasthan during the over-all period due the incidence of pest and diseases (Sharma and Singh 2014).

Components of change

At all India level the production increase was at-

Table 8. Instability in area, production and productivity of cotton crop across selected states in India.

	Maharashtra	Gujarat	Telangana	Karnataka	Andhra Pradesh	Haryana	Madhya Pradesh	Rajasthan	Punjab	India
I Period (1991-92 to 2000-01)										
Area	5.48	4.90	11.42	9.13	11.37	8.28	3.58	25.44	40.36	6.30
Production	26.15	36.97	16.23	11.25	6.62	14.05	21.74	28.98	39.06	13.09
Productivity	26.72	30.23	12.29	7.45	12.45	16.51	21.95	20.50	25.81	9.41
II Period (2001-02 to 2010-11)										
Area	9.23	6.50	16.62	19.93	31.45	8.09	2.98	15.18	57.64	7.40
Production	18.20	22.34	21.13	25.41	20.61	17.91	24.15	31.83	42.31	14.16
Productivity	15.03	22.17	16.70	12.64	14.87	17.58	23.64	23.18	27.29	14.18
III Period (2011-12 to 2020-21)										
Area	4.12	6.71	11.13	18.15	14.36	7.45	8.92	12.53	11.01	5.60
Production	16.43	9.69	19.85	23.62	23.55	23.93	14.48	19.55	18.89	5.96
Productivity	19.36	5.52	24.34	15.91	15.98	23.90	13.28	10.99	14.82	7.71
Overall (1991-92 to 2020-21)										
Area	8.51	10.91	16.48	23.44	28.40	11.63	7.93	29.59	7.35	8.81
Production	23.11	31.07	9.20	40.57	44.92	24.86	27.91	47.52	24.71	20.65
Productivity	23.06	27.06	8.53	23.47	18.59	27.16	27.97	30.53	17.48	18.44

Table 9. Components of change in the average production of cotton in India.

Sources of change		I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	49.28	16.13	54.57
Change in mean area	$\Delta\bar{A}$	50.55	87.23	23.55
Interaction between change in mean area and mean yield	$\Delta\bar{A}$, $\Delta\bar{Y}$	2.22	2.75	21.35
Change in area-yield co-variance	ΔCov (A,Y)	-2.05	-6.11	0.53
Total		100.00	16.13	100.00

tributed by increased acreage in Period I (50.55 %), period II (87.23 %) whereas, for the overall period the increase was due to rise in the yield levels (54.47 %). The area and yield interaction added 21.35% to the production during the overall period but was negligent during Period I and Period II as seen in the (Table 9).

It may be seen in the (Table 10) that the yield variance component caused remarkable change in production by 98.49% in Period I. In Period II it was due change in yield and area covariance (65.48%). The change in production during overall period was due to interaction between changes in area variance and mean yield (39.55 %).

Telangana and its districts

It was noticed that the state had significant compounded annual rates in terms of area, production and productivity as visualized in (Fig. 3). The increase in the annual area by 6.32% caused the production and productivity to rise by 9.88 and 3.27%, respectively. Prior to Bt cotton introduction, the districts of Nalgonda, Karimnagar, Warangal and Khammam had significant growth. After Bt cotton introduction, all the districts had improved growth rates in area, production and productivity except Medak, Mahbubnagar and Rangareddy.

Growth rates in area, production and productivity across different districts of Telangana

The Telangana state was carved out from Andhra Pradesh during 2014 and for the newly formed state the growth rates were enumerated based on the district level data collected from ICRISAT for the 30 years and the results are reported in (Table 11) for the erstwhile districts of Telangana. During the Period III, Nalgonda and Adilabad districts retained significant productivity over other districts. Adilabad was the major contributor to the state with 6.12% of productivity growth while Medak had higher growth rates in area and production followed by Nalgonda and Mahbubnagar. These districts topped as major cotton producing districts of the state. Cotton crop stood as the second major crop of the state with an area of 23.48 lakh hectares during 2020-21 because, larger area under oilseeds, millets and pulses was diverted to cotton as it was the major cash crop. The results were on par with work done by Janaiah *et al*. (2020).

Table 10. Components of change in variance of production of cotton in India.

Sources of change	Symbol	I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	0.94	-4.01	13.23
Change in mean area	$\Delta\bar{A}$	1.05	-17.14	26.52
Change in yield variance	ΔV(Y)	98.49	4.74	-8.30
Change in area variance	ΔV(A)	-2.48	23.90	15.01
Interaction between changes in mean area and mean yield	$\Delta\bar{Y}$, $\Delta\bar{A}$	0.00	-0.24	-0.16
Change in yield and area covariance	ΔCov (A,Y)	-5.91	65.48	12.39
Interaction between changes in yield variance and mean area	$\Delta\bar{A}$, ΔV(Y)	11.20	1.75	-7.77
Interaction between changes in area variance and mean yield	$\Delta\bar{Y}$, ΔV(A)	-0.22	1.53	39.55
Interaction between changes in mean yield and area and change in area-yield covariance	$\Delta\bar{A}$, $\Delta\bar{Y}$, ΔCov (A,Y)	-0.60	13.61	20.57
Change in residual	ΔR	-2.49	10.38	-11.05
Total		100.00	100.00	100.00

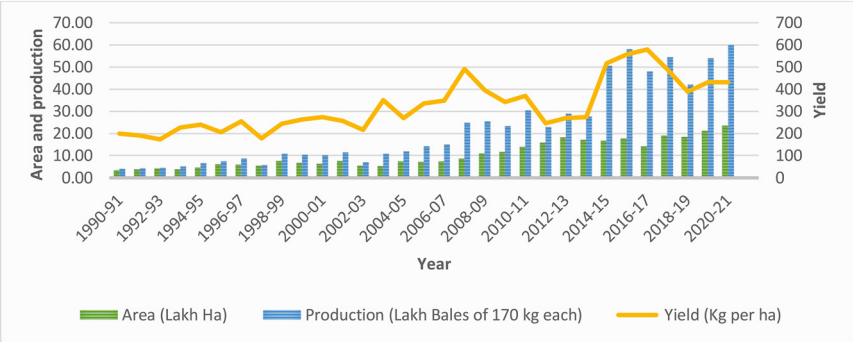

Fig. 3. Area, production and productivity of cotton in Telangana.

Instability in area, production and productivity across different districts of Telangana

The instability analysis (Table 12) carried out for the Telangana state inferred that, the instability in area was higher with 16.32% in comparison to production and productivity. Period II witnessed increased variability in area and production over Period I. Declining variability was observed in area (5.49 %) and production (1.28 %) during Period III. The wider adoption of Bt cotton across the regions reduced instabilities in some districts over period of time. During the overall period instability was differing. The increased instability was a variable of concern because, it negatively affected the shock absorbing ability of the crop during uncertainties.

Components of change

Telangana state witnessed higher production due to increased yield by 44.87% in period I. Also mean area change by 40.31% increased the production during period I. But the growth in area led to significant rise in production in period II (83.20 %) and the overall period (86.82%). There was negative co-variance

Table 11. Growth rates in area, production and productivity of cotton crop across different districts of Telangana.

	Adilabad	Warangal	Karimnagar	Khammam	Mahbubnagar	Medak	Nalgonda	Nizamabad	Rangareddy	Telangana
I Period (1991-92 to 2000-01)										
Area	0.14	13.16***	12.92***	11.06***	7.66	5.19	20***	-1.25	0.44	4.63***
Production	2.74	18.20***	15.89***	10.63***	5.67	8.88	18.26***	2.39	-1.07	11.82***
Productivity	2.59	4.46**	2.63	-0.39	-1.85	3.5**	-1.44	3.70**	-1.51	2.74*
II Period (2001-02 to 2010-11)										
Area	8.38***	4.35**	18.07***	6.82***	13.63***	29.72***	7.58***	5.74*	5.99**	6.31***
Production	15.16***	12.06***	25.81***	18.85***	15.81***	28.8***	16.34***	20.01**	6.65**	13.29***
Productivity	6.25***	7.39***	6.5 5***	3.77**	1.92	-0.71	8.14***	13.53**	0.58	5.83***
III Period (2011-12 to 2020-21)										
Area	1.83	1.30	-8.82***	-2.31	6.23**	11.88***	5.60***	1.18	18.82***	3.22**
Production	10.46***	2.85***	-0.47	2.69	10.42*	16.16*	12.6*	9.36	23.62	9.12***
Productivity	8.47***	1.53	9.16	5.11	3.94	3.82	6.63***	8.08	4.15	6.15**
Overall (1991-92 to 2020-21)										
Area	3.89***	5.47***	6.32***	4.80***	8.34***	13.10***	10.35***	0.61	7.5***	6.32***
Production	10.26***	7.83***	8.38***	7.89***	11.12***	16.75***	13.54***	3.65***	9.95***	9.88***
Productivity	6.12***	2.25***	1.94***	2.84***	2.57***	3.22***	2.89***	3.02***	2.32***	3.27***

Note: *** Significant at 1% level, ** Significant at 5% level and *Significant at 1% level of significance.

Table 12. Instability in area, production and productivity of cotton crop across different districts of Telangana.

	Adilabad	Warangal	Karimnagar	Khammam	Mahbubnagar	Medak	Nalgonda	Nizamabad	Rangareddy	Telangana
I Period (1991-92 to 2000-01)										
Area	5.45	10.81	16.13	12.05	36.58	37.38	27.08	30.00	30.58	11.42
Production	31.33	20.59	21.63	21.66	36.94	37.68	21.86	31.37	29.66	16.23
Productivity	31.22	17.45	12.72	27.69	30.06	13.13	12.44	11.67	17.22	12.29
II Period (2001-02 to 2010-11)										
Area	14.68	14.47	20.93	11.16	33.03	39.00	23.52	26.64	22.50	16.62
Production	21.88	12.53	21.21	18.71	43.73	38.80	18.91	66.60	22.73	21.13
Productivity	22.24	13.41	18.36	13.70	21.72	37.35	19.18	45.69	12.37	16.70
III Period (2011-12 to 2020-21)										
Area	12.29	7.99	9.17	9.40	22.15	14.00	10.93	24.59	16.08	11.13
Production	14.33	11.17	24.42	24.47	49.37	39.91	27.17	42.34	36.28	19.85
Productivity	12.94	12.12	17.02	24.35	35.46	29.19	19.48	33.66	26.79	24.34
Overall (1991-92 to 2020-21)										
Area	16.82	15.25	33.47	17.05	39.96	51.81	23.78	32.82	63.67	16.48
Production	24.93	19.83	32.71	22.95	52.65	55.33	24.94	59.26	67.65	9.20
Productivity	24.13	16.32	24.99	24.26	31.42	31.36	22.69	40.80	14.52	8.53

between the area and yield in all the periods of study. The results are put forward in (Table 13).

It is evident from the (Table 14) that change in variance in production was majorly due to interaction between the yield and area variance (92.98 %) followed by change in yield variance (89.57 %), change in mean yield (75.35 %) and mean area (36.41 %) during Period I. In Period II, variance in area contributed to 69.74% production increase whereas

Table 13. Components of change in the average production of cotton in Telangana.

Sources of change		I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	44.87	12.91	8.16
Change in mean area	$\Delta\bar{A}$	40.31	83.20	86.82
Interaction between change in mean area and mean yield	$\Delta\bar{A}, \Delta\bar{Y}$	16.34	4.88	15.24
Change in area-yield co-variance	ΔCov (A,Y)	-1.51	-0.98	-10.23
Total		100.00	100.00	100.00

Table 14. Components of change in variance of production of cotton in Telangana.

Sources of change	Symbol	I Period	II Period	Overall
Change in mean yield	$\Delta\bar{Y}$	75.35	-296.79	134.36
Change in mean area	$\Delta\bar{A}$	36.41	-5.15	-5033.33
Change in yield variance	ΔV(Y)	89.57	5.12	-825.18
Change in area variance	ΔV(A)	-21.72	69.74	315.32
Interaction between changes in mean area and mean yield	$\Delta\bar{Y}, \Delta\bar{A}$	5.45	-3.01	7.27
Change in yield and area covariance	ΔCov (A,Y)	6.19	-2.45	-16.24
Interaction between changes in yield variance and mean area	$\Delta\bar{A}, \Delta$V(Y)	92.98	6.41	-5964.27
Interaction between changes in area variance and mean yield	$\Delta\bar{Y}, \Delta$V(A)	-17.58	8.81	120.44
Interaction between changes in mean yield and area and change in area-yield covariance	$\Delta\bar{A}, \Delta\bar{Y}, \Delta$Cov (A,Y)	-75.09	29.21	-469.07
Change in residual	ΔR	-91.55	288.11	11830.69
Total		100.00	100.00	100.00

the change in mean yield had the stabilizing effect on production. The overall period had its major change component as change in residual.

CONCLUSION

At global level there was deceleration in the acreage growth, but the production and productivity were increasing due to adoption of genetically modified varieties and cutting edge technologies. Brazil and India witnessed higher growth rates and the instabilities during the overall study period. The major component of change in average production at world level was mean yield. India as well as its major states saw significant growth in area, production and productivity during the Period II due to Bt introduction. Further there was also higher growth visible in the overall period. Rajasthan had inclining instabilities during all the periods of study. The variability in average production in India was due to both change in yield and acreage. Telangana state again spiked production due to Bt introduction and had considerable growth rates during all the periods. Also, the districts viz., Adilabad, Nalgonda, Medak and Mahbubnagar underwent the same phenomenon. The level of instability was higher in production and productivity than in area in all the districts. Change in mean area was the major source of average production change for the state and change in mean yield was the source of growth during Period I. In Period II it was area variance, while for the overall period it was residuals. Thus, introduction of Bt cotton has empowered Telangana and India to be the net exporters from importers, thus meeting the global demand. However, despite higher production the country's productivity level is lower than the world average. Also, stagnation in the yield has begun in recent years. Hence, there is a need to focus on rising the crop yields through intensive cultivation techniques, development of new traits to offer resistance against pests and better marketing infrastructure. Promotion of Bt varieties over Bt hybrids among the farmers need to be done.

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