ASSESSMENT OF VARIABILITY IN OKRA (*Abelmoschus esculentus* (L.) Moench) GENERATED THROUGH MUTATIONS

SASIPRIYA, S.
PA1TAH088

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE, SHIVAMOGGA
KELADI SHIVAPPA NAYAKA
UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES, SHIVAMOGGA

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DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE, SHIVAMOGGA
KELADI SHIVAPPA NAYAKA
UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES, SHIVAMOGGA

CERTIFICATE

This is to certify that the thesis entitled **'ASSESSMENT OF VARIABILITY IN OKRA (*Abelmoschus esculentus* (L.) Moench) GENERATED THROUGH MUTATIONS'** submitted in partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **GENETICS AND PLANT BREEDING** to the College of Agriculture, Shivamogga, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **SASIPRIYA, S., ID. No. PA1TAH088** (priyaskumar9@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Shivamogga
November, 2021

MAJOR ADIVSOR

APPROVED BY:

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(DUSHYANTHA KUMAR. B. M)

Nominated member: – ONLINE –

(NIRANJANA MURTHY)

Members: **1.** _____

(HARISH BABU. B. N)

2. _____

(GIREESHA T. MOHANNATH)

3. _____

(BASAVARAJ I. HALINGALI)

4. _____

(NAGARAJAPPA ADIVAPPAR)

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(SASIPRIYA, S)

ABSTRACT

The present study was executed in two open-pollinated varieties of okra, namely, Arka Anamika and Arka Abhay, at College of Agriculture, KSNUAHS, Shivamogga, during 2019-2021. The research intended to assess the variability induced through genetic (using gamma radiation) and epigenetic (using two HDAC inhibitors, namely sodium butyrate and trichostatin-A) mutations. Analysis of variance for all the traits in the first and second mutant generations revealed the existence of substantial amount of variability. Remarkable differences in the mean values of most of the traits were observed in response to different doses of gamma radiation and varied doses and incubation times of the chemicals. A spectrum of chlorophyll mutants (chlorina, xantha and viridis), leaf, flower and fruit mutants were noticed in the gamma-irradiated treatments. Noticeable variations for flowers, leaves and fruits, delayed flowering, male and female sterility were observed among the epigenetic treatments. A peculiar flower mutant lacking purple pigmentation on the backside of the petals, induced by sodium butyrate treatment, was found to inherit to the next generation, proving the trans-generational mode of epigenetic inheritance. High estimates of genetic parameters were observed for number of branches and fruits per plant, fruit length, number of internodes and number of seeds per fruit among genetic and epigenetic mutants. The analysis of correlation coefficients indicated that fruit yield per plant had significant positive association with almost all the traits except for days to first flowering and test weight. Number of fruits per plant, fruit weight and number of internodes had exhibited highest positive significant correlation with the yield. The highest positive direct effect on total fruit yield per plant was recorded by number of fruits per plant followed by fruit weight. The mutant lines were evaluated in the second generation and superior lines were selected for early flowering habit, high yield per plant and other important yield attributing traits.

Department of Genetics and Plant Breeding,
College of Agriculture, Shivamogga
KSNUAHS, Shivamogga
November, 2021

Sasipriya S.
(priyaskumar9@gmail.com)

Dushyantha Kumar B. M.
(dushyanth123@yahoo.com)

ಬೆಂಡೆಯಲ್ಲಿ ರೂಪಾಂತರಗಳ ಮೂಲಕ ಉಂಟಾದ ಭಿನ್ನತೆಯ ಮೌಲ್ಯಮಾಪನ

(ಶಶಿಪ್ರಿಯಾ. ಎಸ್)

ಸಾರಾಂಶ

ಪ್ರಸ್ತುತ ಅಧ್ಯಯನವನ್ನು ೨೦೧೮-೨೦೨೧ ಅವಧಿಯಲ್ಲಿ ಕೆ.ಎಸ್.ಎನ್.ಯು.ಎ.ಹೆಚ್.ಎಸ್‌ನ ಕೃಷಿ ಕಾಲೇಜಿನಲ್ಲಿ, ಎರಡು ಮುಕ್ತ ಪರಾಗಸ್ಪರ್ಶದ ಬೆಂಡೆಕಾಯಿ ಪ್ರಬೇಧಗಳಾದ ಅರ್ಕಾ ಅನಾಮಿಕಾ ಮತ್ತು ಅರ್ಕಾ ಅಭಯನಲ್ಲಿ ಕಾರ್ಯಗತಗೊಳಿಸಲಾಗಿದೆ. ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ಅನುವಂಶಿಕ (ಗಾಮಾ ಕಿರಣವನ್ನು ಬಳಸಿ) ಮತ್ತು ಎಪಿಜೆನಿಟಿಕ್ ಎರಡು ಹೆಚ್.ಡಿ.ಪಿಸಿ ಪ್ರತಿರೋಧಕಗಳನ್ನು ಬಳಸಿ), ಅವುಗಳೆಂದರೆ ಸೋಡಿಯಂ ಬ್ಯುಟೈರೇಟ್ ಮತ್ತು ಟ್ರೈಕೋಸ್ಟಾಟಿನ್ – ಎ ರೂಪಾಂತರಗಳ ಮೂಲಕ ಪ್ರೇರಿತವಾದ ಭಿನ್ನತೆಯನ್ನು ನಿರ್ಣಯಿಸಲು ಉದ್ದೇಶಿಸಿದೆ. ಮೊದಲ ಮತ್ತು ಎರಡನೆಯ ರೂಪಾಂತರಿತ ಪೀಳಿಗೆಗಳಲ್ಲಿ ಎಲ್ಲಾ ಗುಣಲಕ್ಷಣಗಳ ಭಿನ್ನತೆಯ ವಿಶ್ಲೇಷಣೆಯು ಗಣನೀಯ ಪ್ರಮಾಣದ ವ್ಯತ್ಯಾಸವನ್ನು ಬಹಿರಂಗಪಡಿಸಿತು. ಗಾಮಾ ವಿಕಿರಣದ ವಿವಿಧ ಪ್ರಮಾಣಗಳಿಗೆ ಪ್ರತಿಕ್ರಿಯೆಯಾಗಿ ವಿವಿಧ ಗುಣಲಕ್ಷಣಗಳ ಸರಾಸರಿ ಮೌಲ್ಯಗಳಲ್ಲಿ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸಗಳನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಇದರೊಂದಿಗೆ ವಿವಿಧ ಪ್ರಮಾಣಗಳ ರಾಸಾಯನಿಕಗಳು ಮತ್ತು ಕಾವು ಸಮಯಗಳನ್ನು ಒಳಗೊಂಡಂತೆ ವ್ಯತ್ಯಾಸ ಕಂಡುಬಂದಿದೆ. ಕ್ಲೋರೋಫಿಲ್ ರೂಪಾಂತರಿಗಳು (ಕ್ಲೋರಿನಾ, ಕ್ಸಾಂಥಾ ಮತ್ತು ವಿರಿಡಿಸ್), ಎಲೆ, ಹೂವು ಮತ್ತು ಹಣ್ಣಿನ ರೂಪಾಂತರಿತ ರೂಪಗಳ ವರ್ಣಪಟಲವನ್ನು ಗಾಮಾ-ವಿಕಿರಣ ಚಿಕಿತ್ಸೆಗಳಲ್ಲಿ ಬಳಸಲಾಗಿದೆ. ಎಪಿಜೆನೆಟಿಕ್ಸ್ ಚಿಕಿತ್ಸೆಗಳಲ್ಲಿ ಹೂವುಗಳು, ಎಲೆಗಳು ಮತ್ತು ಹಣ್ಣುಗಳಿಗೆ ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸಗಳು, ವಿಳಂಬವಾದ ಹೂಬಿಡುವಿಕೆ, ಗಂಡು ಮತ್ತು ಹೆಣ್ಣು ಸಂತಾನಹೀನತೆಯನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಸೋಡಿಯಂ ಬ್ಯುಟೈರೇಟ್ ಚಿಕಿತ್ಸೆಯಿಂದ ಪ್ರೇರೇಪಿಸಲ್ಪಟ್ಟ ದಳಗಳ ಹಿಂಭಾಗದಲ್ಲಿ ನೇರಳೆ ವರ್ಣದ್ರವ್ಯವನ್ನು ಹೊಂದಿರದ ವಿಶಿಷ್ಟವಾದ ಹೂವಿನ ರೂಪಾಂತರವು ಮುಂದಿನ ಪೀಳಿಗೆಗೆ ಅನುವಂಶಿಕವಾಗಿ ಕಂಡುಬರುತ್ತದೆ. ಈ ಒಂದು ಎಪಿಜೆನೆಟಿಕ್ ಅನುವಂಶೀಯತೆಯ ಟ್ರಾನ್ಸ್-ಜನರೇಶನ್ ವಿಧಾನವನ್ನು ಸಾಬೀತುಪಡಿಸುತ್ತದೆ. ಅನುವಂಶಿಕ ಮತ್ತು ಎಪಿಜೆನೆಟಿಕ್ ರೂಪಾಂತರಗಳಲ್ಲಿ ಪ್ರತಿ ಸಸ್ಯದ ಶಾಖೆಗಳು ಮತ್ತು ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆ, ಹಣ್ಣಿನ ಉದ್ದ, ಇಂಟರ್‌ನೋಡ್‌ಗಳ ಸಂಖ್ಯೆ ಮತ್ತು ಪ್ರತಿ ಹಣ್ಣಿನ ಬೀಜಗಳ ಸಂಖ್ಯೆಗೆ ಅನುವಂಶಿಕ ನಿಯತಾಂಕಗಳ ಹೆಚ್ಚಿನ ಅಂದಾಜುಗಳನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಪರಸ್ಪರ ಸಂಬಂಧದ ಗುಣಾಂಕಗಳ ವಿಶ್ಲೇಷಣೆಯಲ್ಲಿ ಪ್ರತಿ ಸಸ್ಯದ ಹಣ್ಣಿನ ಇಳುವರಿಯು ಮೊದಲ ಹೂಬಿಡುವ ಮತ್ತು ಪರೀಕ್ಷಾ ತೂಕದ ದಿನಗಳನ್ನು ಹೊರತುಪಡಿಸಿ ಬಹುತೇಕ ಎಲ್ಲಾ ಗುಣಗಳೊಂದಿಗೆ ಗಮನಾರ್ಹವಾದ ಧನಾತ್ಮಕ ಸಂಬಂಧವನ್ನು ಹೊಂದಿದೆ ಎಂದು ಸೂಚಿಸಿತು. ಪ್ರತಿ ಗಿಡಕ್ಕೆ ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆ, ಹಣ್ಣಿನ ತೂಕ ಮತ್ತು ಇಂಟರ್‌ನೋಡ್‌ಗಳ ಸಂಖ್ಯೆಯು ಇಳುವರಿಯೊಂದಿಗೆ ಅತ್ಯಧಿಕ ಧನಾತ್ಮಕ ಮಹತ್ವದ ಪರಸ್ಪರ ಸಂಬಂಧವನ್ನು ಪ್ರದರ್ಶಿಸಿದೆ. ಪ್ರತಿ ಸಸ್ಯದ ಹಣ್ಣಿನ ಇಳುವರಿ ಮೇಲೆ ಹೆಚ್ಚಿನ ಧನಾತ್ಮಕ ನೇರ ಪರಿಣಾಮವನ್ನು ಪ್ರತಿ ಸಸ್ಯದ ಹಣ್ಣುಗಳ ಸಂಖ್ಯೆಯಿಂದ ನಂತರ ಹಣ್ಣಿನ ತೂಕದಿಂದ ದಾಖಲಿಸಲಾಗಿದೆ. ರೂಪಾಂತರಿತ ಸಾಲುಗಳನ್ನು ಎರಡನೇ ಪೀಳಿಗೆಯಲ್ಲಿ ಮೌಲ್ಯಮಾಪನ ಮಾಡಲಾಯಿತು ಮತ್ತು ಆರಂಭಿಕ ಹೂಬಿಡುವ ಅಭ್ಯಾಸ, ಪ್ರತಿ ಸಸ್ಯಕ್ಕೆ ಹೆಚ್ಚಿನ ಇಳುವರಿ ಹಾಗೂ ಇತರ ಪ್ರಮುಖ ಇಳುವರಿ ಗುಣಲಕ್ಷಣಗಳಿಗಾಗಿ ಉತ್ಕೃಷ್ಟ ಸಾಲುಗಳನ್ನು ಆಯ್ಕೆಮಾಡಲಾಗಿದೆ.

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ನವೆಂಬರ್-೨೦೨೧

ಶಶಿಪ್ರಿಯಾ. ಎಸ್.
(priyaskumar9@gmail.com)

ದುಷ್ಯಂತ್ ಕುಮಾರ್ ಬಿ. ಎಂ.
(dushyanth123@yahoo.com)

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INTRODUCTION

I INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) also familiar as lady's finger or bhindi, is the sixth important vegetable crop grown in tropical, subtropical and Mediterranean regions of the world such as in India, Turkey, Iran, Western Africa and neighbouring countries during spring, summer and rainy seasons (Wammanda *et al*., 2010). The crop belongs to the class Dicotyledonae, order Malvales and Malvaceae family (Schippers, 2000). The genus *Abelmoschus* consists of thirty eight species, among which *A. esculentus* is the widely cultivated and the allopolyploid species (Joshi and Hardas, 1956). The somatic chromosome number of this species has been variously reported as 2n = 130 (Skovsted, 1935) and 2n = 72 (Teshima, 1933) and the cultivated species, *A. esculentus* which is an amphidiploid of *Abelmoschus tuberculatus* (2n = 58) has chromosome number, 2n = 4x = 130. Reports of significant variations in the chromosome numbers and ploidy levels of different species in the genus *Abelmoschus* is available with the lowest number reported in *A. angulosus* (2n = 56) by Ford, 1938 and the highest chromosome number registered is close to 200 for *A. manihot var. caillei* (Singh and Bhatnagar, 1975; Siemonsma, 1982).

The geographical origin of okra is still under consideration, but according to Santos *et al*. (2012), it is believed to have originated from North-Eastern Africa and, Ethiopia is considered to be its secondary origin by Vavilov (1951). India stands first in total okra production globally with an annual production of 6.371 million tonnes from 0.519 m ha area with a productivity of 12.17 tonnes ha^{-1} (Anonymous, 2019). Andhra Pradesh, West Bengal, Bihar, Orissa, Gujarat, Jharkhand, Maharashtra and Assam constitutes 88 per cent of the total okra production in the country (Anonymous, 2018).

Okra is an annual herbaceous crop grown for its tender and immature fruits which is used as vegetables (Chattopadhyay *et al.*, 2011). Fruits are vital source of fat, fibre, calcium, phosphorous, iron, ascorbic acid, carotene, thiamine, riboflavin (Benchasri, 2012) and proteins (20-24%) and their seeds contain 13 to 22 per cent edible oil (Sheikh *et al*., 2013). It is also rich in carbohydrates in the form of mucilage (Kumar and Yadav, 2009) which can be used as a protective food additive in Asian medicine against irritating and inflammatory gastric diseases in humans (Lengsfeld *et al*., 2004). These are also reported to be effective as blood volume expanders and effective to alleviate renal disease, reduce proteinuria and improve renal function (Simon *et al.*, 2013). It is one such vegetable also rich in iodine content besides other nutritional aspects thus, it could be used to control goitre (Purewal and Randhawa, 1947). Okra is a warm-season vegetable crop that is tolerant to high temperatures and drought conditions (Voss and Bell, 2007). It is an often cross-pollinated crop, having an outcrossing rate to the extent of 4 to 19 per cent with a maximum of 42.20 per cent (Kumar, 2006). Okra can be regarded as a multipurpose crop due to various uses of its

fresh leaves, buds, flowers, pods, stems and seeds. Dried stems and roots of okra have been reported to be utilized to clean sugarcane juice from which molasses are prepared. Crude fibre is present in mature pods and stems are utilized by the paper industry. The black or white eyed seeds are sometimes roasted and used as a substitute for coffee in Turkey (Sharma and Prasad 2010).

Despite the importance, the yield of okra has been low in recent times due to various reasons *viz.,* lack of improved varieties to mitigate climate change, abiotic stresses, inadequate use of fertilizers, irrigation and occurrence of various diseases and pests. Among various factors, diseases are one of the major constraints for the low productivity of okra (Das *et al*., 2011). Even though okra is cultivated throughout the year to a larger area in the world, productivity is very low. There is not much variability in okra, especially in the Indian subcontinent, and most of the available varieties are poor yielders and are highly susceptible to many pests and diseases (Jagajanantham *et al*., 2012). Moreover, the presence of chromosomal differences or improper meiotic division tends to act as a barrier to transfer desirable resistant genes from wild relatives to the cultivated lines (Kumar *et al.,* 2019). Variability is a prerequisite for any breeding programme to develop high yielding varieties with other desirable economic traits. In such conditions, induced mutations can be used to generate useful variations for quantitatively inherited characters.

Mutation is the sudden and random heritable change in an organism's genetic constitution, which serves as a process of evolving novel modifications in the genome. Applied mutagenesis helps to create variations for agronomic, pest and disease resistance and post-harvest traits where there is insufficient variability in germplasm available for selection. Induced mutagenesis plays a crucial role in the improvement of crops like okra, where a large part of genetic variability has been eroded due to its continuous cultivation in marginal and sub-marginal land. Physical and chemical mutagens cause genes to mutate at rates over the spontaneous baseline, deliver novel changes in genetic architecture, and widen the genetic diversity of plants (Lagoda, 2007). Radiations were found to be the most efficient mutagen for a higher rate of mutation. Among various physical mutagens, gamma rays are the most commonly used and potent mutagens (Ashadevi *et al.,* 2017) in plants. Ionizing gamma rays are electromagnetic radiations similar to X-rays in physical nature and in mutagenic action (Jadhav *et al.,* 2012). The role of mutation breeding in increasing the genetic variability for desired traits in various crop plants has been proved beyond doubt by many scientists (Tah, 2006; Mostafa, 2011 and Kozgar *et al.,* 2012).

Epigenetic modifications, such as DNA methylation and histone deacetylation provide stable gene silencing mechanisms that regulate gene expression by altering chromatin architecture by regulating vital cellular processes like transcription, replication and DNA repair. Epigenetic mechanisms, leading to changes of gene

functions, are not only mitotically stable but are also meiotically heritable and do not entail a change in DNA sequence (Wu and Morris, 2001). Epiallels are phenotypic variants that are frequently observed in plants and occasionally found to be inherited to the next progeny generation (Martienssen and Colot 2001; Kakutani 2002; Tani *et al.,* 2005). Such epigenetic variants could have significant implications in plant breeding. Most importantly, epigenetic alleles can result from stressful environments and enable plants to tolerate stress (Tsaftaris and Polidoros 2000; Finnegan, 2001; Sherman and Talbert 2002; Steward *et al.,* 2002). Based on the modes of action, chemicals used in plant epigenetics studies can be categorized into three types *viz*., DNA methyltransferase inhibitors, histone deacetylase inhibitors and molecules that disrupt normal methyl supplies for methyl-transferring reactions. The two cytosine analogues, 5-Azacytidine (5-aza) (Yamamoto *et al.,* 2005) and 5-aza 2'-deoxycytidine (aza-dC), (Chang and Pikaard, 2005) and Zebularine (Baubec *et al.,* 2009) are DNA methyltransferases inhibitors whereas, Trichostatin-A (Tanaka *et al.,* 2007) and Sodium butyrate (Chen and Pikaard, 1997) are histone deacetylase inhibitor that has been applied in plant epigenetics studies.

The extent of variability created is measured by the genotypic coefficient of variance (GCV) and phenotypic coefficient of variance (PCV) which indicates about the relative degree of variation in various yield attributing traits. An account of heritability and expected genetic advance together gives an exact idea about the nature of a gene governing a character (Johnson *et al*., 1955). Yield is a complex polygenic trait, a multiplicative product of various yield governing traits, in which direct selection is often misleading. Hence knowledge of the inter-relationship between yield and these characters is of paramount importance for the judicial improvement of the economic yield of a crop. Correlation and path coefficient analyses help in the overall advancement of any crop such as okra in the selection of superior genotypes and in the betterment of any associated trait. The correlation studies simply measure the associations between yield and its attributing traits both at genotypic and phenotypic levels and aids in the direction of selection. The information from the correlation coefficients can be employed in path coefficient analysis to partition them into direct and indirect effects in a cause and effect manner (Kang *et al.,* 1983). Path analysis is a standardized partial regression analysis which deals with a set of variables and splits the total effect of various traits into their direct and indirect contribution.

Under these contexts, the present research entitled "**Assessment of Variability in Okra (*Abelmoschus esculentus* (L.) Moench) Generated through Mutations"** was planned in two open pollinated varieties of okra with the following

objectives:

1. To induce variability through mutations and its assessment
2. To induce variability to create epigenetic variations
3. Assessment of genetic association and path analysis for yield and its contributing traits
4. To identify productive mutant lines

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Plant breeding is the branch of science that deals with the improvement of crop plants by creation, identification, isolation, multiplication and management of genetic variability towards the development of improved cultivars. As most of the crop enhancement programs exploited the natural variability available within the germplasm, which is almost exhausted in nature, mutation breeding plays a novel and powerful role to create genetic variability for further evaluation and selection. Ionizing radiations such as gamma rays and chemical mutagens provide scope for the breeders to induce variability in the crop plants for various yield and quality related quantitative traits. However, the mutations are random events where a breeder has no control to guide it in a favourable way. In okra, there are substantial contribution has been made through induced mutagenesis for enhanced yield, quality, biotic and abiotic resistance.

The relevant literature on different aspects of the present study is reviewed here under the following headings.

2.1 Induce mutations and mutagenesis

2.2 Effectiveness and efficiency of gamma rays

2.3 Mutational response of okra

2.4 Epigenesis and Induction of epigenetic variations

2.5Genetic variability for yield attributing traits

2.6 Correlation coefficient analysis

2.7 Path analysis

2.8 To identify productive mutant lines

2.1 Induce mutations and mutagenesis

Mutation is the sudden and random heritable change in the genetic material of any living cell, not caused by the common phenomena of genetic segregation or genetic recombination. Mutations may occur in nature without intentional human intervention and are spontaneous, which has reduced frequency in occurrence. At the same time, not all the spontaneous changes in the DNA can be considered as favourable and permanent changes. Even if such changes would be permanent, they may not always result in visible or detectable phenotypic effects (Ranel 1989). Although selection for economically beneficial naturally available mutants still takes place with some level of success (Ahloowalia *et al*., 2004; Wilde *et al.*, 2012), the purposeful induction of a specifically targeted mutation with a specific mutagen and ideal dose in selected genotype with an efficient screening method will be more rewarding towards the goal.

2.1.1Artificial mutagens

A physical or chemical agent that alters the genetic information at an organism's gene level and thus increases the number of mutations above the natural background level is called a mutagen. De Vries (1905) suggested the application of radiations to induce mutations. The discovery that X-ray induced mutations in *Drosophila melanogaster* (Muller, 1927) and in *Hordeum vulgare* (Stadler, 1928) led plant breeders and geneticists to use the radiation-induced mutations for changing the plant characters. In 1946, Auerbach and Robson have attempted to use chemicals such as mustard gas to induce mutations. Since then, several agents have been discovered that can increase the frequency of artificially induced mutations. The main physical mutagens available for induction of mutations include UV radiation, electromagnetic waves such as X-rays, γ-rays and cosmic rays; fast-moving particles such as α-particles, β-particles and neutrons. There are several chemical agents to impart mutations in organisms such as alkylating agents, acridines, azides, hydroxyl amides *etc*. In general, ionizing radiations such as X-rays and γ-rays are preferred over chemical mutagens because of their ease of application, good penetration, reproducibility, high mutation frequency and less disposal problems.

2.1.2 Relative efficiency of mutagens

Different types of mutagens are useful in inducing variability and have become potential tools in plant breeding programs. While ionizing radiation still remains a tour de force in generating genetic variability, a number of chemicals have been found to be equally efficient and effective mutagens. Both physical and chemical mutagens can induce mutations in organisms in different and specific ways (Smith, 1961). Ionizing radiations had the advantages of a precise dosimeter, good penetrance, ease of application and capacity to induce a wide spectrum of mutations. The choice of mutagens (physical and or chemical) for a particular type of genetic change would depend upon many factors *viz.*, crop species, the material to be treated, treatment duration and metabolic state of the organism (Nilan, 1972). Many scientists have compared the relative efficiency and effectiveness of physical and chemical mutagens in various crop plants. Gregory *et al.* (1965a) showed that radiations could induce micro-mutations affecting quantitative characters in crop plants and that phenotypic selection could accumulate favourable mutations to get better strains.

2.1.3 Gamma rays

A gamma ray or gamma radiation is a penetrating form of electromagnetic radiation arising from the radioactive decay of atomic nuclei like nuclear ^{60}Co or ^{139}Cs. It consists of the shortest wavelength electromagnetic waves of 0.001 to 0.1 Å and imparts the highest photon energy. Gamma-ray has high penetration power into the cells and tissues and the direct effect of gamma-rays is due to the photons

hitting the orbital electron of the atom in its path; thus, all the photon energy is transferred to the electron in the form of kinetic energy. The indirect effect is mediated by the production of free radicals which can transfer their energy to other molecules at random. Genetic consequences of gamma rays on DNA includes disruption of the continuity of one or both strands, cross-linking of DNA or DNA and histone proteins, removal or chemical alteration of a base which changes its pairing properties *etc.* (Cassarett, 1968). The final effect of irradiation treatment on the organisms is influenced by the modifying effect of various internal as well as external factors, which could act as protective or sensitizing agents (IAEA, 1977).

2.1.4 The rate of application of mutagens

The utility of a mutagenic agent in plant breeding depends on two factors, *i.e.,* mutagenic effectiveness and mutagenic efficiency. The former refers to the frequency of a given mutagen employed at a given dose, indicated as the ratio factor mutation/ dose. The latter explains the desirable changes free from associated undesirable changes, *i.e.,* the ratio factor mutation/ biological damage. When there is no published information on mutation dose in a particular crop, it often resorts to LD_{50} (Lethal Dose-50), a standard parameter to decide the effective doses of both physical and chemical mutagens (Albokari *et al*. 2012). Thus, LD_{50} is a dose, which results in 50 per cent mortality of treated seeds (Roychowdhury, 2011). With ionizing radiations, a dose that restricts survival to 50 per cent (LD_{50}) or growth to 50 per cent (GR_{50}) is a good treatment. Various research studies have reported the optimum dose of gamma radiation to be ranged from 40 to 80 kR (Yashvir, 1975 and Jambhale and Nerkar, 1982) and as 10 to 100 kR (Abraham and Bhatia, 1984).

2.2 Effectiveness and efficiency of gamma rays

Singh and Singh (2001) studied the mutagenic effectiveness and efficiency of gamma rays and their combination with EMS using two green gram varieties (T-44, PDM 22). Mutagenic effectiveness was noticed to be decreased with an increase in doses for both the mutagens. They found that, among combination treatments, 40 kR gamma rays + 0.02 M EMS were found to be the most efficient dose for inducing mutations.

Jayakumar and Selvaraj (2003) used gamma rays (5, 10, 15 and 20 kR) and EMS (0.05, 0.1, 0.15, 0.2 %) to treat sunflower seeds of variety ‘Modern’ (*Helianthus annuus* L.) to analyze the mutagenic effectiveness and efficiency. It was observed that the effectiveness of mutagens decreased with an increase in concentrations.

An experiment was conducted to study the response of okra to gamma rays at 20, 30 and 40 kR and EMS at doses 0.1, 0.2 and 0.3 per cent and its various combinations by Dalve *et al*., 2010. They observed that the combination treatments yielded higher mutation rates compared to the individual mutagen alone. Some of the

best treatments were 40 kR gamma + 0.1 per cent EMS followed by 30 kR gamma + 0.1 per cent EMS to induce valuable mutations.

Seeds of musk okra (*Abelmoschus moschatus*) were exposed to varying concentrations of sodium azide (NaN3) in the range 0.05 to 0.20 per cent and gamma rays of doses in the range 20 to 80 kR and were analyzed for the relative efficacy of the two mutagens by Warghat *et al.* (2011). The study revealed that, gamma ray was more effective and efficient mutagen for producing useful mutants in *A. moschatus*.

A study was conducted by Jadhav *et al*. (2012) in okra variety Parbhani Kranti irradiated with gamma rays at 15, 30, 45 and 60 kR doses and also mutated with EMS.Significant differences between the treatments were observed for all the characters in the M_2 generation. The lower doses of mutagens were found less lethal compared to higher doses of gamma rays.

Elangovan and Pavadai (2015) irradiated the okra variety Arka Anamika with gamma rays at 10, 20, 30, 40, 50, and 60 KR levels to know the mutagenic effects. They observed that, high doses of gamma irradiation (40 and 50 KR) produce moderate to high mutation effects on the crop.

Maryam and Kasimu (2016) selected three varieties of okra, Jokoso, NHAe47-4 and Beru and were irradiated with 20, 40, 60, 80 and 100 kR doses of gamma rays then soaked in 2.0 mM and 3.0 mM of sodium azide for 2hours to determine the effects of the combined mutagens on their morphology. The results showed the differences in their response to gamma rays and sodium azide solutions. The seeds treated with the highest dose of combined mutagens showed the highest mutation efficiency.

An investigation was carried out by Amir *et al.* (2018) to evaluate the effect of different doses of gamma rays (100, 200, 300, 400, 500 Gy and zero doses as control) on *Abelmoschus esculentus*. A comparison of the results of different doses with control showed that, gamma irradiation has a significant role in producing mutations in the okra crop. The mutagenic effectiveness and efficiency decreased with an increase in the dose of mutagen.

Asare *et al.* (2017) conducted a research with the okra genotype, UCCC6, irradiated with 400 Gy to 1000 Gy of gamma rays and evaluated the mutational efficacy. They concluded that, optimum mutational effects were induced by 400 Gy, but the higher doses had growth retardation effects.

Suneeta *et al.* (2018) investigated the mutagenic effect of gamma rays on musk okra seeds at different doses like 100, 200, 300, 400, 500 and 600 Gy. The study reported gamma rays as a potent mutagen to create variations and obtained a higher frequency of mutation at an optimum dose of 500 Gy, below and above which were less in comparison.

A research was conducted using gamma radiation and EMS on okra seeds by Ashadevi *et al.* (2019) and observed a higher frequency of mutants in gamma rays than using EMS. Total mutation frequency was highest in the gamma irradiation treatment than EMS. The 300 and 400 Gy doses of gamma irradiation and the 0.1 per cent EMS produced high mutagenic efficiency. The treatments 100 kR gamma rays and 0.2 per cent EMS were found to be highly diverse from the rest of the treatments.

Seeds of okra (*Abelmoschus esculentus* L.) variety P-8 were treated with gamma rays (35 kR, 40 kR, 45 kR, 50 kR, 55 kR, 60 kR, 65 kR, 70 kR, 75 kR, 80 kR and 85 kR) and EMS (0.2 %, 0.4 %, 0.6 %, 0.7 %, 0.8 %, 0.9 %, 1.0 %, 1.1 %, 1.2 %, 1.4 % and 1.6 %) and their combination treatments to assess the mutagenic efficiency of physical and chemical mutagens (Gupta and Sood, 2019). They observed a high rate of mutation and lethals in treatments with higher rate of mutagens in combination like 75 kR +1.4 % EMS and 85 kR + 1.4 % EMS.

A study was conducted to know the efficacy and to determine the doses of mutagens in bhendi cv. Arka Anamika by Ruban *et al.* (2019). The seeds were exposed to gamma irradiation treatment of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 kR. Ten concentrations of EMS and DES *viz.*, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 per cent were also used. The results revealed that the dose of 40 kR gamma in combination with 0.3, 0.4 and 0.5 per cent of EMS had higher mutagenic effects compared to the single treatments.

Hazra *et al*. (2021) has conducted a study using okra seeds wherein the seed germination/seedling emergence and seedling growth were evaluated under laboratory and field conditions by imposing 300 to 1000 Gy gamma radiations. The results indicated that more than 80 per cent of the seed exposed to the LD_{50} dose of gamma radiation in the laboratory did not emerge under field conditions and the gamma radiation dose between 350 Gy and 450 Gy was optimum to create desirable mutants in okra.

2.3 Mutational response of okra

Where there is an insufficient variation for a specific trait, or inaccessibility of available variation due to hybridization barriers, mutagenesis can be employed for the genesis of novel variations. Mutants have been obtained in okra either naturally or induced through physical or chemical mutagens to acquire lethal, chlorophyll deficiencies, plants with improved stature, growth habit, branching pattern, leaf, flower, stem, fruit traits, fruit yield, seed yield and days to first flowering. Chlorophyll mutations give a standout amongst the most frequent and authentic records for the assessment of the genetic effects of mutagen treatments in various crop species. It is the most commonly occurring mutagenic effect that appears in the plant kingdom.

The frequency of chlorophyll mutants in M_1 and M_2 generation is basically considered as a reliable measure of genetic deviations induced by mutagens (Nilan and Konzak, 1961).

2.3.1 Macro-mutation

Rao (1991) conducted an experiment in okra using gamma rays to analyze the induction of macro-mutations in the mutant population. A number of macro mutants (viable mutations) with various morphological and physiological changes were observed in both M_2 and M_3 generations. Leaves with cup shape, mutants with very long fruits, dwarf and very early mutants, tall mutant with long stout fruits and bold seeds, mutants with short fruit and blunt tip were some of the types obtained.

Kolar *et al. (*2011) studied the phenotypic response of *Delphinium malabaricum* to chemical mutagens (EMS and SA) and physical mutagen (gamma rays). Eleven different types of chlorophyll mutants namely albina, albina-green, xantha, aurea, chlorina, viridis, yellow viridis, tigrina, striata, maculata and variegated types were identified in the treated populations. It was observed that, frequency of viridis mutants was highest, followed by xantha and other types in all the treatments.

Seeds of cowpea were treated with gamma rays and EMS of variable doses by Sadashiv and Kondiram (2012) to observe the macro- mutants. Mutations affecting morphological changes in plant habit, leaf and pod morphology and maturity were observed. Fourteen stable mutants such as gigas, tall, dwarf, semi-dwarf, bushy, compact *etc*., were isolated from the mutant population.

Ramchandar *et al.* (2017) conducted an experiment on black gram (*Vigna mungo* (L) Hepper) varieties, VBN 4 and ACM 07002, which were exposed to gamma rays doses at 200, 250, 300 and 350 Gy and EMS doses at 20, 30 and 40 mM. Wide range of chlorophyll mutants and viable leaf mutants were isolated in M_2 generation.

Okra seeds were used to irradiate with gamma rays of different doses to study its mutagenic effect on morphological traits by Surendran and Udayan (2017). Some of the morphological changes observed were for plant height, leaf morphology, flower arrangements, flowers with more than five petals, flower without stigma, more than one fruit from single node and fruits with sterile seeds.

An investigation using okra seeds and gamma rays was conducted by Suneetha *et al.* (2018) to identify the macro- mutations including chlorophyll mutations. The observations indicated that the mutagenic treatments had resulted in different types of chlorophyll mutants.

Ashadevi *et al.* (2019) conducted an experiment using okra seeds treated with gamma rays and EMS to identify variable mutations induced. The lower doses of EMS and gamma rays produced more chlorophyll mutant plants than higher concentrations owing to less damage at lower concentrations. The viable and non-viable chlorophyll mutants were identified and the number of non-viable mutants increased as the dose of mutagen increased.

Okra seeds were irradiated with different doses of gamma rays to detect macro mutations induced (Gupta and Sood, 2019). Morphological changes in growth habit, leaf, flower, pod, seed size and maturity *etc.*, were scored as viable mutants. Different types of okra viable leaf mutants such as rosette, lobed and round were also observed.

Mohite and Gurav (2019) studied the effect of different doses of gamma rays on the morphological traits of okra. The study revealed the presence of different chlorophyll mutants such as yellow viridis, striata, albina green and chlorina, with some leaf morphological variations. The numbers of chlorophyll mutants were increased along with an increased dose of gamma rays.

2.3.2 Micro-mutation

Mutations that are not readily visible and which affecting quantitative traits of an organism are referred to as micro-mutation. Baur (1924) emphasized the importance of small mutations in evolution and the idea was later analyzed and accepted by Stebbins (1950) and Dobzhansky (1951). Knapp (1950) presented a clear suggestion on the utilization of micro mutations in plant breeding. Gual and Mittelstenscheld (1961), Brock and Latter (1961), Bhatia and Swaminathan (1962), Gregory (1965b), Brock (1965), Scocciroli (1965) and Ehrenberg *et al.* (1965) published systematic approaches and efficient techniques for the systematicselection of micro mutations generated through induced mutations. They noticed that the availability of micro-mutation would contribute to the total variability of the traits with or without affecting the mean performances. This suggests the need to assess the mean and variability of the treated populations in M_2 and later segregating generations to get an idea of the nature and magnitude of induced variability to know the scope of improvement through selection.

Sherif *et al*. (2011) identified the micro- mutations in some of the vegetative and yield contributing characters such as number of fruits per plant, fresh and dry weight of calyx per plant, plant height, number of branches per plant, main root length per plant, number of roots per plant, fresh and dry weight of leaves and stems and roots per plant in *Hibiscus* sp. using gamma rays. They concluded that the gamma rays are potent to create variations.

Jadhav *et al.* (2012) observed for traits like germination, pollen sterility, mortality, days to first flower initiation, days to 50 per cent flowering, number of

fruits per plant, average fruit length, yield per plant and number of seeds per fruit in okra plants after treating with gamma rays and EMS. It was observed that higher doses of gamma rays and ethyl methane sulphonate had deleterious effects on seed germination, pollen fertility, plant survival and other morphological traits.

A study was conducted in two okra varieties, Parbhani Kranti and Arka Anamika using varied doses of gamma rays and EMS to know the effect of mutagens on the pod length by Kashid and Kulthe (2014). It was observed that both the varieties showed marginal differences in their pod length pertaining to the dosage of mutagens. Other traits like plant height, nodes per plant, number of fruits per plant, green fruit yield per plant, per plot and hectare were decreased with an increase in the mutagenic doses.

Pushparajan *et al.* (2014) used the okra variety, Anakomban which was irradiated with different doses of gamma rays to know the extent of micro- mutations induced. Various yield attributing characters such as plant height, internode length, number of leaves per plant, pollen sterility, number of fruits per plant and fruit characters such as length, girth, weight, number of seeds per fruit and weight of 100 seeds were studied and concluded the variation occurred in the traits.

Reddy and Dhaduk (2014) carried out an investigation to study the extent of genetic variability induced through physical and chemical mutagens in okra using two popular okra varieties *viz.* GO-2 and GJO-3, treated with 20 kR, 30 kR and 40 kR of gamma rays and 0.15 % and 0.25 % EMS. Traits like fruit yield, fruit weight per plant, fruit length and fruit width were some of the characters showing variation with respect to the change in dosage of mutagens.

Ullah *et al.* (2014) studied the amount of micro- mutations in two okra varieties, Puhja and Nutech after treating with different doses of gamma rays. The results revealed that the two varieties of okra responded differently to radiation doses for some of the plant characters like plant height, number of leaves per plant, number of pods per plant, length of the pods, 1000 seed weight and number of seeds per plant.

The effect of gamma rays on some of the temporal, morphological and biochemical parameters of okra was studied by Amir *et al.* (2018). Days to germination, germination percentage, flower initiation, fruit initiation, days to fruit maturation, number of fruits per plant and plant height were some of the traits which showed significant changes pertaining to the changes in doses of mutagen.

An investigation for understanding the morphological mutations in okra using gamma rays was conducted by Surendran and Udayan (2017). In the M_2 generation, they observed that the 400 Gy irradiated plants showed different growth inducing morphological changes and yield attributing characters such as plant height, internodal length, number of leaves per plant, number of fruits per plant and fruit

characteristics such as length, girth, weight, number of seeds per fruits and weight of 100 seeds.

Mohite and Gurav (2019) induced mutation in okra seeds using gamma rays and observed for different agro- morphological traits. They identified significant changes in characters of okra, including shoot length, root length, number of secondary branches, fruits per plant, seeds per fruit and 100 seed weight both in M_1 and M_2 generations.

With the objective of increasing yield and resistance to YVM disease in okra, mutation has been induced using six doses of gamma irradiations (Pushparajan *et al*., 2021). The effect of gamma radiations on fruit length and other yield attributing traits were studied in M_1, M_2 and M_3 generations, among which 400 Gy irradiation was found to increase fruit length and other yield attributing traits.

2.4 Epigenesis and epigenetic mutagens

Cytosine methylation represents a major molecular mechanism that provides critical genomic information and contributes to understand the molecular basis of phenotypic variation based on epigenetic modification in eukaryotic organisms, though the levels and patterns of cytosine DNA methylation appear to vary drastically among different organisms (Avramidou *et al.,* 2015; Okano *et al.,* 1999). Cytosine-5-methylation is the most common DNA modification, which transfers a methyl group from S-adenosyl-L-methionine to the fifth carbon of cytosine residues, extensively occurring in eukaryote genomes (Finnegan *et al.,* 2000). In plants, DNA methylation generally refers to three different nucleotide sequence contexts: CG, CHG and CHH methylation (where H = C, T or A) (Gruenbaum *et al.*, 1981; Law and Jacobsen, 2010). Many studies have showed that, DNA methylation might play indispensable roles in regulating diverse physiological processes during plant growth and development, including coordination of gene expression to adapt to environmental changes (Zhang *et al.,* 2016), involvement in chromatin organization (Chinnusamy and Zhu, 2009), and maintenance of genomic integrity (Wang *et al*., 2016).

DNA methylation variations can generate new phenotypic variants that could be targeted by selection (Cubas *et al*., 1999; Kalisz and Purugganan. 2004). It is therefore essential to explore the consequences of DNA methylation on species diversity and evolution. Recent studies have showed that environmental stimuli (including biotic and abiotic stresses) could induce changes in genomic DNA methylation (Dowen *et al.,* 2012; Garg *et al.,* 2015), and such environmentally induced methylation can be heritable, which may result in a re-shaping of phenotypes in next generations (Herman and Sultan, 2016). Particularly, the combination of genotype-specific environmental sensitivity, DNA methylation and trans-generational

stability, and phenotypic impacts might be a primary candidate mechanism for adaptive evolution in plants (Alsdurf *et al*., 2013; Herman and Sultan, 2016; Zhang *et al.,* 2013). Investigation of the inherent relationships of phenotypic and DNA methylation variations might be a good way to dissect this potential mechanism for plant adaptive evolution and understanding the acquiring of new characters in plant species.

2.4.1Epigenetic modifications in plants

Comparative assessment of genetic and epigenetic variation among regenerants of potato derived from long-term nodal tissue culture and cell selection was conducted by Dann and Wilson (2011). The results indicated that the long-term tissue culture clone lines exhibited genetic and epigenetic differences between them which were significant and were positively correlated with the resistance towards common scab disease.

Dowen *et al.* (2012) reported an unexpected role for DNA methylation in the regulation of the *Arabidopsis thaliana* immune system. Profiling the DNA methylomes of plants exposed to bacterial pathogen, a virulent bacteria or salicylic acid (SA) hormone revealed numerous stress-induced differentially methylated regions, many of which were intimately associated with differentially expressed genes. It was further confirmed that, dynamic DNA methylation changes within repetitive sequences or transposons which can regulate neighbouring genes in response to SA stress.

Durand *et al.* (2012) conducted a study in natural populations of *Arabidopsis thaliana* to understand the role of epimutations in governing genetic incompatibility. The results suggested that the rearranged gene copy triggers de novo DNA methylation and silencing of the unlinked native gene by RNA-directed DNA methylation leading to in compatibility reactions in *Arabidopsis.* This natural, strain-specific epiallele was stable over numerous generations even after removing the duplicated, rearranged gene copy through crosses.

Chen *et al*. (2013) investigated DNA cytosine methylation alterations in the young panicles of PTGMS line, PA64S of rice under two different photoperiod and temperature conditions. The results were compared the DNA methylation level of PA64S under lower temperatures and SD conditions (fertility) was low while higher methylation was observed in PA64S (sterility). These results suggested that DNA methylation may be involved in the sterility–fertility transition of PA64S under two different environmental conditions.

Seven resistant and sensitive chickpea genotypes were inoculated with *Fusarium oxysporum f. sp. Ciceris* and analysed for DNA methylation patterns and changes in leaves, stems and roots by Mohammadi *et al.* (2015). It was found an

extensive cytosine methylation alterations in the pathogen-treated genotypes compared with the corresponding control, including hypermethylation and demethylation as well as the potential conversion of methylation types. For all genotypes, the percentage of demethylated sites was more than methylated sites in infected plants than the corresponding control plants, which may seem to provide the plants with resistance against the pathogen.

DNA methylation was compared between the leaves of banana inoculated with *Fusarium oxysporum f. sp. Cubense* race, Foc TR4 and the mock-inoculated leaves at different pathogenic stages by Jing- Yao *et al.* (2016). From the study, it was clear that, DNA hypermethylation and hypomethylation were induced by pathogen infection during all pathogenic stages. The results suggest that DNA methylation plays an essential role in the pathogenic response to Foc TR4 for banana.

Li *et al.* (2016) analyzed the variations in DNA methylation of mature chrysanthemum leaves during the floral transition induced by short-day (SD) treatment. The results clearly showed that the DNA methylation percentage of chrysanthemum leaves decreased significantly during floral development following the treatment. The decline in DNA methylation was elevated in the early-flowering cultivar compared with the late-flowering cultivar.

More *et al.* (2016) studied the effect of transgene induced DNA methylation patterns in SbDREB2A overexpressed tobacco transgenic lines. These transgenic lines contained DREB (Dehydration-responsive element binding) transcription factor (TF) which plays a vital role in providing stress tolerance in an ABA-independent manner by regulating downstream genes in plants. It was observed that an increase in percent methylation in the transgenic lines as compared to wild type and plants transformed with vector alone.

Analysis of DNA methylation patterns associated with drought stress response in faba bean (*Vicia faba* L.) was conducted by Abid *et al.* (2017). The drought-tolerant Bachar genotype in comparison with the drought-sensitive F177 genotype was analyzed and the results showed an overall decrease in methylation on exposure of drought in both genotypes. The resistant genotype showed a higher rate of decrease in methylation compared to the susceptible genotype and it clearly indicated their possible role in drought stress tolerance in case of faba bean.

Hoang *et al.* (2018) concluded from their studies associated with epigenetic modifications in rice that, DNA methylation directly regulates the expression of Xa21G, a Xa21- like protein that might participate in the ETI resistance pathway. They also revealed potential epigenetic factors that might regulate the defense response in rice by analyzing available microarray data.

Liegard *et al.* (2018) tested the possibility ofheritable differences in DNA methylation, the trans-generational epigenetic variations using the well characterized quantitative resistance of *Arabidopsis* to clubroot, a major disease caused by *Plasmodiophora brassicae.* Epigenetic recombinant inbred lines (epi-RIL) were derived and the studies revealed a complex model in which a combination of allelic and epiallelic variations which interacts with the environment to lead to variation in clubroot quantitative resistance.

2.4.2 Induction of epigenetic variations

The effects of n-sodium butyrate on cell division, DNA synthesis, RNA synthesis and protein synthesis in synchronously dividing explant cultures of Jerusalem artichoke (*Helianthus tuberosus* L.) tuber tissue were investigated by Pederson and Minocha (1988). The study revealed that the addition of butyrate after the initiation of the S phase resulted in a rapid decline in the rates of DNA synthesis to background levels. The effects of butyrate on RNA and protein synthesis were found to be more ambiguous as butyrate substantially inhibited the incorporation of ^{3}H-uridine and ^{3}H-Ieucine into RNA and proteins respectively, which also caused reductions in the uptake of these precursors.

A DNA demethylating agent, 5-azacytidine was used to study its effect on a short day plant, *Perilla frutescens var. crispa* by Konda *et al.* (2006). The results showed that the chemical, 5-azacytidine treatment had induced the short day plant to produce flowers under long days. Flowers were formed even at the lower nodes, which had not been directly treated with 5-azacytidine. A slight suppression of vegetative growth was also observed but had no apparent effect was found on any other phenotypes. The results suggested that DNA demethylation induced flowering by inducing the production of a transmissible flowering stimulus in *P. frutescens*.

Iwase *et al.* (2009) studied the dwarfing and flowering induction properties of two epigens, 5-azacytidine and Zebularine in *Pharbitis nil*, a short duration plant. The investigation indicated that the DNA demethylating reagents induced flowering under non-inductive long-day (LD) conditions and also caused dwarfism. These results suggest that the flowering related genes were activated by DNA demethylation agents.

An investigation on inhibition of histone deacetylase using HDAC inhibitor and Trichostatin-A was conducted by Izawa *et al.* (2009) to know its effect on appressorium formation in the rice blast fungus *Magnaporthe oryza*. The study indicated that the treatment of chemicals has significantly reduced the formation of appressorium and the rate of asexual reproduction rate of the fungus. It clearly indicated that the regulation of acetylation of histones has an important role in the asexual differentiation of *M. oryzae.*

Bossdor *et al.* (2010) conducted a greenhouse experiment in which a set of natural genotypes of *Arabidopsis thaliana* was treated with the demethylating agent 5-azacytidine and examined for the consequences of this treatment for plant traits and their phenotypic plasticity. The experimental results indicated that the demethylation strongly reduced the growth and fitness of plants and delayed their flowering, altered the phenology like plant height but the degree of this response varied significantly among genotypes.

Hu *et al.* (2011) treated maize with the HDAC inhibitor Trichostatin-A (TSA) under cold stress conditions to know its effect in response to cold. It was found from the study that TSA has strongly inhibited the induction of the maize cold-responsive genes ZmDREB1 and ZmCOR413. The time course of TSA effects on the expression of ZmDREB1 and ZmCOR413 genes indicates that, HDACs appear to directly activate the ZmDREB1 gene, which in turn modulates ZmCOR413 expression. The findings also indicated that the HDACs had positively regulated the expression of the cold-induced ZmDREB1 gene through histone modification and chromatin conformational changes and that this activation is both gene and site selective.

The role of DNA methylation was investigated by Kanchanaketu and Hongtrakul (2015) in the development of *Jatropha curcas* L. using the DNA demethylating agent, 5-azacytidine (AzaC). The results showed that treated plants responded to AzaC by both accelerating and inhibiting growth and development. Some of the plants exhibited observable morphological abnormalities, such as stem bending, reduced plant height and increased stem branching. The most severe effect in the treated plants was noticed as the significant failure of root development, which was lethal.

Zhang *et al.* (2016) used sodium butyrate (NaB), a histone deacetylase (HDAC) inhibitor that can cause a significant increase in histone acetylation in both mammals and plant genomes, was applied to treat maize seedlings. The results showed that NaB had substantial inhibition effects on different root zones at the tissue level and caused cell cycle arrest at pre-prophase in the root meristem zones. This effect was accompanied by a dramatic increase in the total level of acetylated lysine 9 on histone H3 (H3K9ac) and acetylated lysine 5 on histone H4 (H4K5ac).

Arabidopsis thaliana seedlings were treated with two non-methylable cytosine analogues, 5-azacytidine and Zebularine by Griffin *et al.* (2016), to construct maps of DNA methylation with single base-pair resolution using whole-genome bisulfite sequencing. The results showed that both inhibitor treatments result in nearly indistinguishable patterns of genome-wide DNA methylation and that 5-azacytidine had a slightly greater demethylating effect at higher concentrations across the genome.

Jiang *et al.* (2017) studied the role of Trichostatin-A (TSA) in inducing microsporederived embryos in wheat.A significant increase in the efficiency of DH production was observed in both cultivated varieties and F_1 hybrids. From the study they advocated the chemical agents such as Trichostatin-A (TSA) to assist in the optimization of doubled haploidy for rapid improvements in wheat germplasm and addressing recalcitrance issues in cell culture responses.

Wójcikowska *et al.* (2018) conducted a study using Trichostatin-A (TSA) in *Arabidopsis thaliana* and found that the TSA-treated explants generated somatic embryos that developed efficiently on the adaxial side of the cotyledons, which are the parts of an explant that are involved in auxin-induced somatic embryogenesis. A substantial reduction in the activity of histone deacetylase (HDAC) was observed in the TSA-treated explants, thus confirming the histone acetylationrelated mechanism of the TSA-promoted embryogenic response.

Finnegan *et al.* (2019) investigated the role of DNA methylation in regulating spikelet number and flowering time by treating semi-spring wheat with the demethylating agent, Zebularine. From the study, they identified three lines with a heritable increase in spikelet number which showed non-Mendelian inheritance, suggesting an epigenetic basis. Delayed flowering was associated with a deletion of the floral promoter, FT-B1, which delayed the transition to reproductive growth, extended the duration of spike development and increased spikelet number under different temperature regimes and photoperiod.

The effect of 5-azacytidine (5A) induced DNA hypomethylation on the growth and abiotic stress tolerance of *Arabidopsis thaliana* were analyzed by Ogneva *et al.* (2019). Growth analysis revealed that, 5A treatment did not affect the fresh and dry biomass accumulation but led to a higher percentage of flowering in *A. thaliana* plants. 5A eliminated the stimulatory effect of the heat and drought stresses on the transcriptional levels of a number of stress-inducible genes, such as DREB1, LEA, SOS1 or RD29A. The data indicated that, DNA methylation is an important mechanism regulating plant abiotic stress resistance.

An investigation with the aim to understand the novel signatures of seed germination in *Medicago truncatula,* using histone deacetylase inhibitor sodium butyrate (NaB) was conducted by Pagano *et al.* (2019). The analysis revealed the influence of NaB on seed nucleotide, amino acid, lipid and carbohydrate metabolism. Up-regulation of antioxidant and polyamine biosynthesis genes occurred in response to NaB and DNA damage was evidenced. They concluded that the observed changes in seed metabolism could provide novel potential metabolic hallmarks of germination.

Pagano *et al.* (2020) studied the genotoxic effect of different doses of sodium butyrate (NaB, 1 mM and 5 mM) in seeds of *Petunia hybrida* as a stress agent and

applied under different light/dark conditions throughout a time period of 10 days.The results indicated that sodium butyrate applied to *Petunia hybrida* seeds under a long-day photoperiod has a negative impact (reduced seedling length, decreased production of photosynthetic pigments and accumulation of DNA damage) on early seedling development, whereas its administration under dark/light conditions bypasses some of the adverse effects.

2.5 Genetic variability for yield attributing traits

The existence of a sufficient level of genetic variability is a prerequisite for any breeding programme aims at variety development, hence detailed appraisal of the accessions for different morphological, agronomical and quality traits is necessary to identify useful traits either for direct use or to pave the way for hybridization programs. The availability of genetic variability, its collection, evaluation, characterization, documentation, maintenance and use for improvement in economic traits are necessary and very useful in crop breeding programmes.

Hazra and Basu (2000) revealed the presence of a wide range of variations in okra for plant height (80.80 cm), leaves per plant (28.90), nodes per plant (14.90), days to first flower (49.90), fruit weight (15 g), fruits per plant (10), seeds per fruit (53.3), fruit yield per plant (155.7g), moderate variations for primary branches per plant (2.9) and fruit length (12.9 cm) and lesser variations for node at first flower (4.8) and ridges per fruit (5.1). Primary branches per plant showed a moderate range of variation and also recorded the highest genotypic coefficient of variation. However, traits like plant height, leaves per plant, fruit weight, fruits per plant, seeds per fruit and fruit yield per plant showed a moderate GCV.

Dhankar and Dhankar (2002) found that traits like fruit yield, number of fruits per plant and plant height showed high to moderate heritability in genotypes of okra. The genetic advance was found medium to low for all traits which indicated that, there is limited scope for improvement of these characters through simple selection procedures.

Gandhi *et al.* (2002) studied 44 okra genotypes for 13 traits, in which branches per plant, fruit yield per plant and height at first fruit set showed high GCV and PCV estimates. Vast differences between GCV and PCV were observed for branches per plant and seed yield per plant, indicating the role of the environment in the expression of these characters.

Singh and Singh (2002) treated seeds of three okra cultivars *viz.,* Parbhani Kranti, Hisar Unnat and Satdhari with gamma rays and EMS. High heritability and GAMwere observed for yield per plant, plant heightandnumber of seeds per fruit in M_2 and M_3 generations, indicating the presence of additive genes which can be further improved by simple selection processes.

Bendale *et al.* (2003) recorded a medium to high GAM and high heritability for yield andyield-contributing characters *viz.,* first flowering node, days to first harvest, fruitlength, fruit weight, plant height, nodes per plant, internodal length, branchesper plant, the moisture content in fruit, fruiting period, seeds per fruit, 100 seed weight,yield per plant and fruits per plant.

The genetic variability was studied in 22 diverse genotypes of okra for fruit yield and its component traits in okra by Mehta *et al.* (2006). The research revealed that the values of PCV were higher than that of GCV values for all the seven traits indicating the influence of environmental effects in the expression of these traits. The GCV, heritability and genetic advance as percentage of mean were higher for fruit yield, average fruit weight, plant height and fruit length, which might be attributed to additive gene action resulting in their inheritance.

Sharma and Mishra (2007) irradiated the okra variety, ANKUR-40 with 15, 30, 45 and 60 and 75 kR doses of gamma rays. This study revealed that, plant population differed significantly under 15, 30 and 45 kR for fruits per plant and fruit length whereas, fruit yield was significantly varied in 30 kR treatment. 30 kR gamma-rays was proposed as the best treatment for the improvement in fruit yield in okra from the study.

An investigation including 51 F_1 hybrids, 17 lines and checks of okra was carried out to understand the genetic variability in fifteen yield contributing characters. From the study, Solankey and Singh (2009) had concluded that the amount of PCV was higher in magnitude than GCV for all the traits. Higher GCV was estimated for number of branches per plant, fruit yield per plant, internodal length and number of nodes per plant. High heritability was obtained for all traits, especially for number of ridges per fruit, number of branches per plant, number of fruits per plant, number of seeds per fruit, number of nodes per plant, fruit yield per plant and single fruit weight.

Shanthakumar and Salimath (2010) observed high heritability and genetic advance for the characters such as days to first flowering, plant height, number of primary branches per plant, number of internodes per plant, number of fruits per plant, fruit weight, number of seeds per fruits and fruit yield per plant in the early segregating populations of okra. The study indicated the involvement of additive type of gene action in controlling these characters hence, selection could be proposed for further improvement.

Twenty-nine okra accessions from different agro-ecological regions in Nigeria were grown and assessed to determine their genetic variability, heritability and genetic advance from eight yield related characters. From the study, Nwangburuka *et al.* (2012) recorded a high GCV, broad-sense heritability and genetic advance for

traits such as plant height, fresh pod length, fresh pod width, mature pod length, branching per plant and pod weight per plant, suggesting the effect of additive genes and reliability of selection based on the phenotype of these traits for crop improvement.

Katagi *et al*. (2013) recorded higher values of PCV than corresponding GCV values for all the twelve characters in segregating populations of okra, indicating the influence of environmental effects on the expression of these characters. The GCV was found higher for plant height, fruit yield per plant, fruit weight and days to 50 per cent flowering indicating the predominance of additive gene action.

Koudinya *et al.* (2013) selected 40 genotypes of okra to study the PCV, GCV, broad sense heritability (h^2) and expected genetic advance in the population. The results showed that, majority of the characters except first fruiting node, branches per plant and seeds per fruit recorded smaller differences between PCV and GCV values as they were less influenced by the environment. The estimates were moderate for plant height, internodal length, branches per plant, fruits per plant, seeds per fruit, test weight and fruit yield per plant. High heritability estimates were found for the majority of the characters, *viz.* plant height, stem diameter, internodal length, days to first flowering, days to 50 per cent flowering and fruits per plant.

Nine commercial cultivars of okra were evaluated for a number of agro-botanical traits by Bashar *et al.* (2014). The analysis of variance for all the traits showed highly significant variations among the genotypes. The phenotypic coefficient of variation (PCV) was found higher than the genotypic coefficient of variation (GCV) for all characters. Maximum GCV and PCV were observed for branches per plant (42.54 and 42.60) and leaves per plant (27.93 and 27.99, respectively). Heritability, as well as genetic advance, was found high and maximum was recorded for branches per plant (99.72 and 87.50, respectively).

Eight genotypes of okra including two checks collected from different parts of India, were evaluated for nine yield and its attributing characters by Barche *et al.* (2014). High significant difference due to genotypes was observed for all the traits studied indicating sufficient genetic variability among the genotypes. The estimates of PCV and GCV was observed for traits like yield per plot and number of fruit per plant. High heritability values coupled with a high percentage of genetic advance were recorded for weight of fruit per plant and plant height.

Pushparajan *et al.* (2014) reported that, plant height decreased from lower to higher dose except for 400Gy exposure. The same trend of decrease in plant height was also noticed in 30, 60 and 90 days after planting. The height of the plant, derived from 400 Gy treated seeds exceeded to that of control also.

Reddy and Dhaduk (2014) observed an increase in GCV, heritability and the genetic advance in M_2 generation, under different mutagenic treatments for most of the traits studied among the varieties of okra, GO-2 and GJO-3. In GO-2, high heritability and the genetic advance was observed for some critical yield contributing characters like fruit length at 40 kR; fruit weight at 20 kR and 40 kR; and fruit yield per plant at 20, 30 and 40 kR. Similarly, in GJO-3, high heritability coupled with high genetic advance was observed for fruit length at 30 kR and fruit yield per plant at 20 kR.

An investigation was undertaken by Umrao *et al.* (2014) to assess the genetic diversity of 50 genotypes based on 11 traits. Asignificant variation was noticed for all the traits. High heritability estimates were observed for all the traits except the thickness of the fruit. In general phenotypic coefficients of variability were found to be greater than their corresponding genotypic coefficients of variations. High estimates of heritability coupled with high genetic advance and moderate to high GCV were observed for plant height up to 1st fruiting node (cm), number of first fruiting nodes per plant, number of branches per plant and number of fruits per plant.

Elangovan *et al.* (2015**)** studied the effect of gamma irradiation treatment at doses, 10, 20, 30, 40, 50 and 60 kR levels on okra variety, Arka Anamika. Agronomic traits were analyzed such as days of first flower, the height of plants, number of fruits per plant, fruit length, seed yield per plant, fresh weight per plant, dry weight per plant and 100 seed weight, and the results indicated a positive shift in concerned parameters.

Four biparental and F_2, F_3 populations of okra, were evaluated to ascertain genetic parameters of variability for growth and yield parameters by Hallur *et al.* (2015). The study showed that the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the characters studied. The plants showed less difference between GCV and PCV for plant height, number of branches, number of fruits, fruit length, fruit diameter, fruit weight, fruit yield per plant and seed yield per plant indicating ample scope for improvement. All the characters exhibited high heritability with high GAM indicating the predominance of additive gene components.

Mishra *et al.* (2015) observed wide variability for different traits in okra. Invariably, higher values were observed for the phenotypic coefficient of variation and corresponding genotypic coefficient of variation, indicating the impact of environmental factors towards trait expression. The presence of moderate to high heritability coupled with moderate genetic advance was recorded for fruit weight, days to 50 per cent flowering, fruits per plant as well as fruit yield per plant, indicated their possibility of improvement with a simple selection procedure.

Sharma and Prasad (2015) investigated the PCV and GCV in various agro- morphological traits in okra and found that and phenotypic variance was higher than their respective coefficient of genetic variation. The differences between genetic coefficients of variation and phenotypic coefficient of variation were high for fruit diameter followed by number of branches per plant, days to 50 per cent flowering, fruit weight and days to first harvest indicating the vulnerability of traits to environmental influences.

Twenty one accessions of okra were assessed by Sravanthi (2016) for variability for 12 morphological characters. Highly significant differences were observed among the accessions. High phenotypic and genotypic coefficient of variation was observed for per cent incidence of YVMV, yield per plant, fruit weight, and number of fruits per plant and high heritability accompanied with high genetic advance was noticed for yield per plant, fruit weight and number of fruits per plant.

Thulasiram *et al.* (2017) used thirty genotypes of okra to work out the variability and heritability. Analysis of variance showed that there was high significant variation for all of the studied traits between genotypes. The genotypic coefficients of variation (GCV) and phenotypic coefficient of variation (PCV) were highest for the character leaf area, diameter of fruit and number of primary branches per plant. High heritability, as well as high values of genetic advance, was observed in the characters leaves per plant and yield per plant; thus, there is ample scope for improving character through direct selection.

Alake (2019) assessed the variability of agro-morpho-nutritional traits in okra landraces sourced from five agro-ecological zones in Nigeria. Differences existed for all evaluated traits among landraces, and relatively low broad-sense heritabilityand the genetic advance was recorded for pod yield and pod width, which limits potential for improvement. Estimates of phenotypic variance were greater than that of genotypic, environmental and interaction variances, indicating environment that influenced this broad genetic population of okra landraces.

Genetic variability, heritability and genetic advance as per cent of mean of 12 quantitative characters in F_2 segregating population of okra were studied by Rathod *et al.* (2019). Significant differences among the F_2 population were observed for all the characters under study. The characters *viz.,* number of branches per plant at final harvest, internodal length, fruit yield per plant, number of fruits per plant and plant height at final harvest showed high PCV and GCV. High heritability coupled with high genetic advance as per cent of mean was recorded for plant height at final harvest, number of branches per plant at final harvest, number of fruits per plant and fruit yield per plant.

A study was initiated by Melaku *et al.* (2020) with the objectives of estimating variability, heritability and genetic advance for indigenous okra collections and exotic commercial varieties for yield and yield related traits. The phenotypic and genotypic coefficients of variations ranged from 7.00 to 35.27 and 5.69 to 33.31 per cent, respectively. Heritability in broad sense ranged from 36.4 per cent (days to maturity) to 99.30per cent (leaf width) while the genetic advance as per cent of mean ranged from 7.7 (days to emergence) to 65.15 per cent (tender fruits mucilage content), respectively. Heritability and genetic advance as percent of mean values were high and moderate for all traits except for days to emergence.

2.6 Correlation coefficient analysis

Correlation studies are of considerable importance in plant breeding. The coefficient of correlation describes the degree and amount of association between two different variables. The correlation between yield and its component traits gives an idea for opting optimum selection pressure, which could profitably be exercised to achieve an increase in yield. As such, it is necessary to estimate the correlation coefficients, as it aids in estimating the true relationships between various traits due to genetic causes. A brief review related to this aspect in relation to okra breeding is reviewed as follows:

Hazra and Basu (2000) observed okra germplasm for yield related traits and reported that the fruit yield per plant was significantly and positively associated with plant height, whereas, days to first flowering showed anegative association with number of fruits per plant.

Gandhi *et al.* (2002) from the study on okra genotypes noticed that the dry fruit yield of okra was highly and significantly dependent on characters like the number of nodes per plant, internodal length, number of fruits per plant and yield per plant.

Niranjan and Mishra (2003) reported that in okra, fruit yield was positively correlated with edibility period of fruits, fruits per plant, fruit length, seeds per fruit, fruit weight, plant height and branches per plant at both genotypic and phenotypic levels. Associations were significant at the genotypic level only between edibility period of fruits and number of branches per plant. All characters expressed positive association with each other at both levels.

Jaiprakashnarayan and Mulge (2004) studied the character correlations between yield attributing traits in okra and reported a positive association of yield per plant with fruit weight, number of nodes per plant, number of fruits per plant, fruit length, plant height (at 60 and 100 DAS) and number of leaves (at 45 and 100 DAS).

NH47-4 variety of okra, *Abelmoschus esculentus* (L.) Moench, was grown and studied by Akinyele and Osekita (2006) for correlations between the yield attributing

traits and found that the trait seed yield per plant showed a significant positive correlation with number of pods per plant, height at flowering, pod width and weight of hundred seeds. The significant genotypic and phenotypic correlation found between days to flowering and days to maturity, though negative, can be used as a criterion for selecting lines with a short life span.

Verma *et al.*(2007) revealed that yield per plant in okra had exhibited positive correlation with fruits per plant, fruit weight, fruit length and girth while, a negative association was observed with 100 seed weight, days to first flowering and days to 50 percent flowering.

Fifty okra (*Abelmoschus esculentus* L.) accessions were studied with an objective of knowing the agro- morphological traits and their interrelation effects on the yield of green pods by Alam and Hossain (2008). Correlation coefficient between yield and growth contributing parameters indicated that yield of green pod had highly significant positive association with the number of nodes per plant.

Balakrishnan and Sreenivasan (2010) carried out the correlation and path analysis in fifteen diverse genotypes of okra for fruit yield and its component traits. The study revealed that fruit yield was positively associated with number of fruits, internode number, fruit weight and fruit length.

An experiment comprising of 163 genotypes including 43 parents and 120 crosses of okra to determine the genetic variability, nature of association among different yield attributes was conducted by Adiger *et al.* (2011). The fruit yield was found significantly and positively correlated with plant height, number of branches per plant, internodal length, fruit length, fruit weight and number of fruits per plant at both genotypic and phenotypic level, indicating mutual association of these traits.

Kumar *et al.* (2012) revealed that the values of correlations at genotypic level were higher than the phenotypic correlations indicating, strong inherent association between the various characters studied in okra genotypes. Yield per plant showed positive association with number of flowers per plant, fruits per plant, length of fruit and weight at genotypic and phenotypic levels. This indicated that fruit yield could be improved by making selection on the basis of flowers per plant, fruit per branch, fruits per plant and length of fruits.

Sharma and Prasad (2010) reported from the study on okra agro- morphological traits that apositive significant correlation for days to 50per cent flowering with days to first harvest, number of pods per plant with pod yield per plant, pod yield per plant with pod yield per plot was observed. While, a negative correlation was observed for pod weight withnumber of pods per plant.

Das *et al.* (2012) studied 18 genotypes of okra and revealed that the numbers of fruit per plant and fruit weight wassignificantlyand positively correlated with each

other. Results further indicated that numbers of node on main stem, fruit length, fruit diameter, fruit weight, numbers of fruit per plant, numbers of seed per fruit, ascorbic acid content and crude protein content not only exhibited highly positive correlation coefficient with green fruit yield per plant but they were also positively and significantly inter-related to each other.

From a study on okra germplasm, Nwangburuka *et al.* (2012) expressed a positive and significant correlation between plant height at maturity, seeds per pod, fresh pod width and pods per plant, branches per plant with seed weight per plant and pod weight per plant, suggests that selection based on these phenotype of these characters will lead to high seed and pod yield in okra.

Thirty accessions of okra (*Abelmoschus spp*. (L.) Moench) germplasm were collected by Ahiakpa *et al.* (2013) to understand the correlation between the various traits. The study revealed a strong positive correlation between total fruit production and first fruit producing node (r = 0.76); first fruit producing node and first flowering node (r = 0.79); and number of fruits per plant and stem diameter at base (r = 0.88).

Twenty F_1 progenies of okra derived from diallele crossing including parents were used to study the correlation by Dhankar *et al.* (2013). The study showed that the fruit yield per plant showed significant positive correlation with number of fruits per plant and branches per plant where a negative correlation was found with days to first flowering and plant height.

Reddy *et al.* (2013) evaluated one hundred germplasm lines of okra (*Abelmoschus esculentus* (L.) Moench) and revealed that plant height, fruit length, fruit width, fruit weight, total number of fruits per plant, number of marketable fruits per plant and total yield per plant had significant positive correlation, while number of branches per plant, internodal length, days to first flowering, first flowering node and first fruiting node had significant negative correlation with marketable yield per plant.

A field study was conducted in okra crop by Simon *et al.* (2013) to evaluate the extend of variability and character association in some selected quantitative traits. The pod yield was found significantlyand positively correlated with pod length and pod weight phenotypically, indicating that selection based on these traits could significantly improve total yield in this cultivar. It was also observed that seed yield and pod yield had a significant negative phenotypic correlation with days to flowering.

Nirosha *et al.* (2014) studied 49 genotypes including 42 crosses of okra to determine nature of association among different yield attributes. The fruit yield showed significant positive correlation with characters like plant height, number of branches per plant, inter nodal length, fruit length, fruit weight, number of fruits per

plant, marketable yield per plant both at genotypic and phenotypic level, indicating mutual association of these traits.

Sawant *et al.* (2014) revealed from the study on okra that, plant height, number of nodes per plant, number of fruits per plant, length of fruits, weight of fruit, chlorophyll content of leaves and total yield per plant had significant positive correlation with the total marketable yield of fruits, while node at which first fruit appears, diameter of fruit had significant negative correlation with economical yield.

Yonas *et al.* (2014) studied 25 okra accessions based on quantitative morphological characters and found that fruit yield had positive and highly significant genotypic correlation with traits like fruit length, average fruit weight, fruit diameter, seed per pod, hundred seed weight and number of pod per plant.

A study was undertaken to analyze the correlation for growth and fruit characteristics in 57 okra lines by Ahmed *et al.* (2015). Highest positive correlation was observed between number of fruits per plant and yield per plantand between number of fruits per plant and 100-seed weight. The results also showed that significant positive correlation were between 100-seed weight and yield per plant, 100-seed weight and leaf length, 100-seed weight and leaf diameter, number of leaves per plant and 100-seed weight, 100-seed weight and plant height, 100-seed weight and fruit length. Significant positive correlations were also observed for plant height and number of fruits per plant, number of leaves per plant and yield per plant.

Gogineni *et al*. (2015) studied the correlation analysis in ten different okra hybrids for fruit yield and its component traits. The correlation analysis indicated that, fruit yield was significantly associated with fruit length, fruit girth, fruit weight, number of fruits per plant and plant height at both genotypic and phenotypic level, indicating mutual association of these traits.

Saryam *et al.* (2015) from a study of 60 genotypes reported that yield per plant had highly significant positive phenotypic correlation with traits *viz.,* number of fruits per plant (0.803), fruit diameter (0.376), fruit length (0.349), number of seeds per fruit,days to maturity, fruit weight, leaf blade width, 100 seed weight, flower diameter, fruiting span, petiole lengthand stem diameter. The highly negative non-significant association was observed with incidence of YVMV (-0.389), days to 50 per cent flowering (-0.319) and node at first flower appears (-0.307).

Kumar and Reddy (2016) evaluated 24 entries of okra and the correlation coefficient analyses revealed that, total number of fruits per plant and total yield per plant had positive significant association with marketable pod yield per plant. The genotypic correlation coefficient of plant height, number of branches per plant, intermodal length, fruit length, fruit weight and number of marketable fruits per plant.

Thirty two genotypes of okra were analyzed by Deepanshu and Shamad (2017) to estimate the correlation coefficients of various characters. The study showed that, number of branches per plant, number of leaves per plant, fruit length, fruit girth, fresh weight of fruit, number of seed per fruit and number of fruit per plant showed positive correlation at both genotypic and phenotypic level proved their genetic worth for selection and improvement of okra.

An investigation was conducted to estimate correlations and path coefficients from 52 okra genotypes by Kerure *et al.* (2017). The study showed that fruit yield per plant had positive association with stem girth, number of branches per plant, plant height, first fruit producing node, fruit length, fruit diameter, average fruit weight, number of fruits per plant, number of seeds per fruit and 100 seed weight while, negative association with days to 50 per cent flowering, number of locules per fruit and days to 80 per cent maturity.

Prasath *et al.* (2017) studied character association in 30 genotypes of okra and found that, plant height, number of fruits per plant, internodal length, last harvest, fruit length, fruit girth, fruit weight, number of fruits per plant, number of seeds per fruit, 100 seed weight, number of pickings and iodine content had significant and positive correlation with fruit yield per plant. It was observed that with an increase in plant height and less internodal length, there were corresponding increases in fruit yield per hectare.

Singh *et al.* (2017**)** reported that among 180 genotypes of okra, the fruit yield has significant positive correlation with number of fruits per plant, plant height, average fruit weight, number of seeds per fruit, fruit length, first flower producing node, first fruit producing node, 50 per cent flowering and stem diameter, indicating mutual association of these traits.

Correlation coefficient in okra was studied using parents, their F_1 and F_2 generations by Raval *et al*. (2018) on thirteen characters. Among them, fruit yield per plant exhibited positive and highly significant correlation with number of fruits per plant, plant height at final harvest, fruit weight, number of branches per plant, fruit girth, number of seeds per fruit, internodal length and 100 seed weight.

Kumar *et al.* (2019) evaluated sixty eight okra accessions for the character association and the analysis of pooled data revealed that, pod yield per plant showed positive correlation with plant height, number of fruits per plant, fruit width, number of branches per plant, number of nodes per plant and number of first fruiting node at both genotypic and phenotype levels, respectively. The highest positive correlation on pod yield per plant was exhibited by number of fruits per plant, plant height, fruit width, number of branches per plant and number of nodes per plant at phenotypic levels.

Thirty one hybrids of okra were evaluated by Kumari *et al.* (2019) to study the correlation between various yield attributing traits. Phenotypic correlation analysis revealed that, yield per plant showed highly significant and positive association with fruit length, fruit width, average fruit weight and number of fruits per plant while, it showed highly significant and negative association with internodal length and number of nodes. Fruit width, fruit weight, fruit length, number of fruits per plant and number of nodes per plant is positively and significantly correlated with yield per plant while, plant height, days to 50 per cent flowering and intermodal length were negatively and significantly correlated with yield per plant at genotypic level.

The experiment comprising 142 F_2 plants of okra (*Abelmoschus esculentus*) were grown and analyzed for yield and its attributing traits by Rathod *et al.* (2019). Correlation analysis of 12 quantitative characters indicated that fruit yield per plant exhibited positive and highly significant correlation with number of fruits per plant, plant height at final harvest, internodal length, number of branches per plant and fruit length suggesting that these characters are the primary yield determinants in okra and selection criteria based on these characters would be beneficial for improvement of fruit yield per plant.

An experiment was carried out in selected genotypes of okra by Ashraf *et al.* (2020) to understand the correlation between various traits. The results indicated that, fruits per plant and fruit weight of different genotypes had a high degree of significant positive association with fruit yield. The days to first flowering and days to first fruit harvest showed a significant positive correlation with picking duration both genotypic and phenotypic levels. The Picking duration showed a highly significant positive genotypic correlation with fruit diameter and fruit length. At the final harvest, plant height showed a highly significant positive genotypic correlation with fruit length and fruit weight at the genotypic level.

2.7 Path analysis

Asthe number of factors involved in correlation studies increase, their association becomes more complex and confusing. Under such circumstances, path coefficient analysis helps in removing the complication by partitioning the total effect of the independent variable in to direct and indirect effects on dependent variable, by partitioning the correlation coefficients. It also indicates the real determinant of yield and helps in genetic improvement of crops. There are abundant records of path coefficient studies in okra as described some of them below.

Ariyo *et al.* (1986) reported that edible pod weight had the greatest positive direct effect on pod yield and an indirect effect through reduction in edible pod width. Pod width had a negative direct effect on pod yield. Pod weight had large indirect effects through a reduced flowering and reduced number of pods per plant and

reduction in number of days. It indicated that only number of branches per plant, edible pod length and weight of 100 seeds would be useful for indirect selection for pod yield.

Mandal and Dana (1994) from a study on different yield contributing characters of okra, reported that number of fruits per plant and fruit length had highest direct positive effect on total fruit yield per plant. Negative direct effect was exhibited by days to 50 per cent flowering. The results suggests that, number of fruits per plant can be the most reliable and effective character to select for when high yield as the objective.

Sarkar *et al.* (2004) investigated path coefficient analysis in okra genotypes and revealed that number of fruits per plant and fruit weight had positive and high direct effect on fruit yield, indicating their importance as reliable selection criteria for improvement of yield in Okra.

Akinyele and Osekita (2006) in path coefficient analysis of okra, indicated that number of fruits per plant and height at flowering had the highest direct effect on seed yield. This suggested that the fruit yield in okra could be improved by selecting for these two attributes, fruits per plant and height at flowering which are indicated as the primary determinants for seed yield per plant.

An investigation carried out by Verma *et al.* (2007) on okra revealed that, number of fruits per plant had highest positive direct effect on yield per plant followed by number of nodes to first flower. The indirect effects of most the components towards yield were negligible in magnitude. However, nodes to the first flower *via* plant height and fruit length and days to first flowering *via* days to 50 per cent flowering and days to 50 per cent flowering through fruit length showed high indirect effects on yield per plant.

Magar and madrap (2009) observed 41 genotypes of okra for yield and contributing traits and the path coefficient study revealed that the number of fruits per plant had the maximum direct contribution towards total yield followed by fruit weight, plant height and days to first flowering. These important traits may be viewed in selection programme for the further improvement of okra.

A study was conducted to evaluate the okra germplasm for character association and direct and indirect effects of various traits by Balakrishnan and Sreenivasan (2010) and proposed that, plant height, fruit length and marketable fruit yield showed a positive direct effect on yield. Other characters like days to first flowering, internodal length, leaf number and number of ridges on fruits showed negative direct effect on yield.

A study consisted of 121 okra genotypes were analysed by Saifullah and Rabbani (2010) for character association and path coefficient. Results showed

that, plant height showed medium direct positive effect on fruit yield per plant. This trait also had indirect positive effect with number of fruits per plant and number of seeds per plant. Primary branches per plant had negative direct effect on yield and indirect positive effect with plant height, length of fruit, diameter of fruit, number of fruits per plant, fruit weight, number of seeds per fruit and fruit yield per plant. Number of internodes per plant also showed direct negative effect on fruit yield.

Adiger *et al.* (2011) reported a high and positive direct contribution of fruit weight towards fruit yield followed by number of fruits per plant, plant height and number of branches per plant. Days to 50 per cent flowering exhibited highest negative direct effect followed by test weight and fruit diameter.

Findings of Akinyele and Osekita (2011) from studies on NH 47-4 variety of okra revealed that, plant height at flowering, final plant height and number of seeds per fruit showed positive direct genotypic effect on fruit yield per plant. Number of fruits per plant and seeds per fruit showed a very high direct genotypic effect on yield. Thus, fruit per plant was the prime character contributing to fruit yield.

Reddy *et al.* (2013) revealed that fruit weight, total number of fruits per plant and number of marketable fruits per plant had a positive high direct effect on marketable pod yield per plant. Fruit weight, total number of fruits per plant and number of marketable fruits per plant were regarded as the primary determinants of marketable pod yield per plant and the improvement in marketable pod yield per plant will be efficient if the selection is based on these traits.

Inter-character correlations and path coefficient analyses of yield related characters were evaluated in some quantitative traits of okra by Adekoya *et al.* (2014). The path coefficient study revealed that, weight of matured pods per plant had the largest direct effect on seed yield perplant, branch length and stem height at flowering. The residual effects was recorded as 0.16, which is low in nature.

Balai *et al.* (2014) studied a group of genotypes of okra and observed that average weight of edible pod (0.943 g) had highest positive direct effect on total yield followed by traits like number of pods (0.372 plant^{-1}) and number of leaves (0.125 plant^{-1}). The study further suggested that plant height, length of pod, average weight of edible pod and number of seeds per pod are essential traits which should be used as selection criteria to develop high yielding varieties in okra.

Sawant *et al.* (2014) evaluated twenty germplasm lines of okra for character association and trait contribution for fourteen morphological characters and revealed that, number of leaves per plant, internodal length, number of fruits per plant,diameter of fruit and weight of fruit had a positive high direct effect on yield per plant. If the selection is made based on these characters then improvement in yield will be efficient.

Forty five okra genotypes were evaluated for twenty morphological characters by Prajna *et al*. (2015) and found that fruit yield per plant showed indirect positive effect *via* plant height at 45 days after sowing (DAS) and internodal length for plant height at 90 DAS. Fruit yield per plant showed significant and negative indirect effect *via* number of fruits per plant and number of leaves per plant at 45 DAS.

The study on direct and indirect effects of seventeen different growth, physiological and fruit related traits on yield of okra were conducted by Rajkumar and Sundaram (2015). Results revealed the presence of very high direct positive effect of fruit number on yield per plant. The traits *viz.*, number of fruits per plant, plant height and fruit weight were identified as the important yield determinants followed by leaf area index and stem diameter through path coefficient analysis. The indirect effect of fruit length and fruit girth on yield through fruit weight was found to be positive.

Sreenivas *et al.* (2015) found that number of fruits per plant had the maximum direct contribution (0.698) towards total yield followed by fruit weight (0.467), fruit girth (0.075) and plant height (0.014) from an investigation carried out in okra. However, days to first flowering and fruit length exhibited negative direct effect towards economical yield. Hence, selection should be practiced for those characters which have positive direct effectsin order to isolate superior plant types for improvement of fruit yield.

Correlation and path coefficient studies were conducted in okra genotype by Sharma and Prasad (2015) and reported that number of fruits per plant and fruit weight contributed major direct positive effect to fruit yield per plot. Traits like number of branches per plant and days to first harvest showed highest negative direct effect on yield component. The estimated residual effect found was 0.0118 indicated about 98.82 per cent of variability in fruit yield was contributed by yield affecting characters studied.

Aminu *et al.* (2016) indicated that the number of pods per plant in okra exhibited positive and direct effect on the pod yield. The indirect influence of other yield components through number of pods per plantwas found to enhance the pod yield n okra. Days to 50 per cent flowering, plant height, pod length, number of pods per plant, pod diameter, fresh weight per pod are other traits that can be used for the selection and development of high pod-yielding varieties in okra.

Twenty-eight germplasm lines of okra (*Abelmoschus esculentus* (L.) Moench) were evaluated by Pithiya *et al*. (2017) for various traits. Path coefficient analysis on various yield contributing characters revealed that number of fruits per plant, number of seeds per fruit, plant height, fruit length, 100-seed weight and number of branches showed direct positive effect towards yield. The improvement in pod yield per plant

will be efficient, if the selection is based on number of fruits per plant, number of seeds per fruit, plant height, fruit length, 100-seed weight and number of branches.

Prasath*et al.*(2017) studied thirty okra genotypes and revealed that, plant height, internodal length, days to 50 per cent flowering, fruit length, fruit width, fruit weight, number of fruits per plant, number of seeds per fruit, 100 seed weight and iodine content had positive direct effect on fruit yield. These characters played a significant role in recombination breeding and suggested that direct selection based on these traits will be rewarding for crop improvement of okra.

Singh *et al.* (2017) conducted path analysis and observed that, fruit width in okra followed by number of fruits per plant, first fruit producing node and average fruit weight had direct effect for fruit yield. 100 seed weight followed by first flower producing node, 50 per cent flowering and intermodal length plant height at 45 days after sowing and days to first flowering showed negative direct effect. These important traits may be viewed in selection programme for the further improvement of okra yield.

Rathava *et al.* (2019) conducted a study on 31 genotypes of okra to determine the nature of association among different yield attributes and their direct and indirect contribution towards yield. Path coefficient analysis revealed that, number of fruit per plant had maximum direct contribution towards fruit yield followed by average fruit weight, average fruit diameter and plant height. However, average fruit length had the higher negative direct effect on fruit yield per plant followed by days to 50 per cent flowering, number of branches, internodal length and fibre content.

Thirty six okra genotypes were evaluated for different agro- morphological and biochemical traits by Mohammed *et al.* (2020). Path coefficient analysis indicated that fresh fruit mass and seed yield per hectare had positive direct effects on fruit yield per hectare at phenotypic and genotypic levels. These traits also exerted high to low positive indirect effects through other traits on fruit yield at phenotypic and genotypic levels

An experiment was conducted by Rana *et al.* (2020) to assess the genetic variability, correlation and path analysis for yield and yield contributing characters in seventeen genotypes of okra. Phenotypic path coefficient analysis showed positive and direct effect of average fruit weight, number of fruits per plant, number of leaves per plant at 45 and 90 DAS, fruit length, plant height at 45 DAS and 90 DAS, internodal length, days to 50 per cent flowering, leaf area on fruit yield per plant and therefore, selection of these traits would be beneficial for improvement in okra.

Rynjah *et al.* (2020) studied correlation and path coefficient analysis in thirty six okra genotypes for fourteen traits. A high positive direct effect on yield plant was found to be contributed by fruit girth followed by plant height, fruit weight, fruit

length and number of branches per plant. Hence, improvement in yield will be efficient if selection is based on fruit girth, fruit length, number of fruits per plant, plant height and fruit weight and short flowering period.

2.8 Identification of productive mutant lines

Mutation techniques have been widely applied to improve crop yield, quality, disease and pest resistance and produced more germplasm with novel, desired traits (Maluszynski *et al.,* 1995). Many mutants were developed and released worldwide in many crop plants (Ahloowalia *et al.,* 2004). Isolation and selection of new and valuable superior mutants, for instance by screening for spontaneous mutants and induced mutants is equally important. Multi-location trial, as the last step of phenotypic evaluation of plant varieties to be released, is needed to select superior and stable promising mutant lines and to understand the effect of genotype and environment. Notably, the significant interaction between promising mutant lines and environments would be valuable to indicate the superior varieties selected (Atta *et al.,* 2009).

Hussain *et al.* (2001) treated one locule bulk: F_1seed derivative of cross between interspecific mutant strain NIAB-313 (*Gossypium barbadense* L. × *Gossypium hirsutum* L.) with exotic (Reba P-288) was done at 20, 25 and 30 kR gamma radiation doses. Radiation treatment at 30 kR dose proved to be successful for creating valuable genetic variability. Nine promising high yielding superior fibre quality mutant lines that do not support virus accumulation and high yielding were identified from the segregating populations.

Kumar and Udaykumar (2004) developed a mutant population in tomato variety Arka Vikas using ethyl methane sulphonate (EMS) and gamma irradiation. The M_o population was screened for thermo-tolerance and M_1 progenies were developed from M_o-tolerant plants. The mean performance of the M_1 progenies in terms of thermo-tolerance of the selected Mo-tolerant lines was found superior to the original population. The results indicated that significant genetic variation could be created by physical and chemical mutagens and efficient selection of superior lines are possible.

Manju and Gopimony (2006) has induced mutations in F_1 seeds obtained by interspecific hybridization between *A. esculentus* var. Kiran and *A. manihot* using gamma irradiation (100 200, 300 and 400 Gray) for selecting high yielding YVM resistant types from the generations segregating until F_6 M_6 . Cultivar AE18 was found out yielded the others and was released as “Anjitha” during 2006, for cultivation in the Thiruvananthapuram District of Kerala.

Attempts were made by George *et al.* (2008) to induce mutations for low lectin content in the Soybean cultivar MACS 450 by subjecting to combination

treatments of γ-rays and ethyl methane sulphonate (EMS).In M_2, 72 plants were identified for low lectin content and were carried up to M_5 generation and was compared with the nine true breeding lines identified having low lectin content. Three mutants from M_6 generation found to possess very low lectin content and superior in quality compared to parent cultivar.

A dwarf-type mutant (S-20–1) in bermuda grass that exhibited slower vertical growth and shorter internodes and leaf length was selected from the gamma-ray irradiated seeds of a bermuda grass cultivar Sundevil II (S-CK) by Chen *et al.* (2009). The mutant line, S-20–1 had slower turf coverage than parent line, S-CK. The mutant line also showed an enhanced drought resistance in greenhouse and field tests compared to other lines and check variety.

Muthuswamy and Jayabalan (2011) irradiated immature ovule of cotton seeds with 10 to 50 Gy gamma rays and treated with 1 to 5 mM EMS and SA to investigate the stimulatory effects of mutagenic treatments. The M_2 and the subsequent generations of plants derived from irradiated/treated ovules were grown to analyze their performance with reference to control. Among the 19 different mutant lines isolated from the study, a mutant line, M_7 showed superior variations in terms of yield characters such as plant height, number of bolls, yield of seed cotton, ginning percent and fibre characters so that it is identified as a potent mutant line.

Three diverse sesame genotypes namely Rama, SI 1666 and IC 21706 were treated with both physical (γ-rays of doses 200 Gy, 400 Gy and 600 Gy) and chemical (EMS of concentrations 0.5 %, 1.0 %, 1.5 % and 2.0 %) mutagens, separately by Begum *et al.* (2012).Based on seed yield, oil content and fatty acid composition nineteen superior M4 lines were selected for multilocation trials to assess the stability of desirable variation. Apart from higher seed yield three superior mutant lines also possessed high oil percentage with relatively more PUFA content than the control.

An investigation was carried out with multicut forage sorghum variety SSG 59-3 and its 15 mutants derived from gamma irradiation to identify the superior mutant genotypes for high fodder yield and quality in sorghum by Singh and Chaudhary (2015). The mutant genotype SSG 226 was the best performer for both quality and fodder yield and, another two mutant genotypes SSG 231 and SSG 222 was also good for fodder yield and quality. The genotype SSG 226 produced highest green fodder yield and dry fodder yield with crude protein (8.18) along with desirable lowest crude fibre (30.60) and highest ash content (8.39) at first cut.

Yuliasti and Reflinur (2015) conducted a research to evaluate the yield performance of mungbean mutant lines that showed tolerance to drought stress. Five mutant lines and two parental lines were tested for yield and drought tolerance under two environments. The results showed that three mutant lines, including PsJ30, PsJ31,

PsJ32 produced the highest grain compared to the other mutant lines and the parents. Of those mutant lines, PSJ31 was the most tolerant to drought and PSJ31 has now been officially released as a new variety named as Muri which was identified to have high yield and tolerant to drought.

Shen *et al.* (2016) inoculated of tobacco mutant lines with tobacco viruses in a greenhouse identify mutants resistant to tobacco mosaic virus (TMV) and cucumber mosaic virus (CMV). A total of 4000 second generation segregating (M_2) mutants of tobacco cultivar Zhongyan 100 were screened and in the M_3 generation, there were seven mutants with hereditary high resistance. Two hereditary immune M_4 mutants, one of which was a male sterile line, were identified and evaluated in the glasshouse and in the field. For CMV, seven highly resistant plants were selected from the M_2 generation.

Hordeum vulgare mutant lines were developed from the cultivar UNALM 96, following irradiation with gamma rays at 200 and 300 Gray doses. Mutant lines were selected in the M_8 generation with higher agronomic performance and nutritive quality. They were found adapted to the highlands with grain yield over the value of the parental material and showed improved contents of P (131 mg/g dry weight-DW), Zn (66 mg/g DW), Mn (55 mg / g DW), Fe (57 mg / g DW) and Cu (63 µg / g DW). Gomez *et al.,* 2017).

An experiment was conducted by Sreekantappa *et al.* (2018) by irradiating seeds of okra variety Arka Anamika with gamma rays at 80 kR of dose to screen the mutant population for sucking pest resistance. The study revealed some appreciable variations identified based on the field tolerance. On further screening in *in vitro*, two mutant lines have been identified with tolerance to sucking pests.

A research project was conducted by Sarkar *et al.* (2019) out to evaluate the genotypic variability among the salt tolerant mutant lines of wheat genotypes to select superior lines based on yield performance on non-saline soil. The performance of mutant wheat lines was carried out using a check variety, 'Prodip', a high yielding variety, developed by Bangladesh Agriculture Research Institute (BARI). Thirty-seven wheat mutant lines, which perform better than 'Prodip' were selected based on yield contributing characters and can be used for our further screening process in salt affected areas for selecting the best salt tolerant genotypes.

Pushparajan *et al.* (2021) treated seeds of Anakomban okra variety with six doses of gamma irradiations the objective of increasing yield and resistance to yellow vein mosaic disease in okra. The effect of gamma radiations on fruit length and other yield attributing traits were studied in M_1, M_2 and M_3 generations. A mutant in M_3 generation was identified which produced fruits up to 57cm (22.30 inch) long and it is identified as fruit length mutant SKBH 2756, reported for the first time.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present investigation was conducted at the College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences Shivamogga during 2019-2021. The research was further subdivided into two experiments. The experiment I was to analyze the variability induced by gamma radiation in okra and the second study intended to examine the epigenetic mutations induced in okra through chemicals such as Trichostatin-A and Sodium butyrate. The details of material and methods adopted during research entitled "Assessment of variability in okra (*Abelmoschus esculentus* (L.) Moench) generated through mutations" are described as follows.

3.1 EXPERIMENT 1: Gamma radiation induced mutations in Okra

3.1.1 Experimental site

The experiment on "Assessment of variability in okra generated through gamma radiation induced mutations" (experiment I) was conducted in the experimental plot of College of Agriculture, ZARHS, KSN University of Agricultural and Horticultural Sciences, Shivamogga, which is geographically located between 13º 27' to 14º 39' N latitude and 74º 37' to 75º 52' E longitude with an altitude of 650 meters above the MSL. The experimental site is under the Southern Transition Zone of Karnataka (Zone 7). The soil of the experimental site was clay loam and was medium-high to high in fertility level.

3.1.2 Experimental material

Two cultivated open-pollinated okra varieties namely, Arka Anamika and Arka Abhay, were selected for the research. The seeds were obtained from the Indian Institute of Horticultural Research (ICAR- IIHR), Bangalore.

3.1.3 Mutation treatment

The potent physical mutagen, gamma rays was selected for inducing mutations. Three doses, 30 kR, 50 kR and 80 kR, were finalized as treatments based on the LD_{50} value obtained from other research articles. Thousand seeds for each treatment were used for the irradiation. The irradiation was carried out at ICAR- IIHR, Bangalore.

3.2 M_1 generation

3.2.1 Field experiment

Gamma irradiated seeds of both the varieties were sown in the experimental site with a spacing of 60 × 45 cm in a four meter row in an augmented design during August 2019 to raise M_1 generation. In every block, untreated Arka Anamika, Arka Abhay, Parbhani Kranti (YVM resistant) and Pusa Sawani (YVM susceptible) were

sown as checks for respective treatments. The General field view of the M_1 generation is shown in Plate 1. The recommended package of practices like fertilization, weeding and plant protection were ensured during the crop period till harvest. Observations on the following characters were recorded from 40 randomly selected plants in each treatment and averaged to get the mean value of each character.

3.2.2 Observations recorded

The traits considered and the procedure adopted for recording the observations for different traits is given below**.**

3.2.2.1 Quantitative traits

The quantitative characters studied and techniques adapted to record these observations are given below.

3.2.2.1.1 Plant height (cm)

Height of the plant was measured in centimetres at the time of harvest from ground level to the tip of the main stem.

3.2.2.1.2 Days to first flowering

Number of days taken from the date of sowing to the time of the first flower opening in each plant was recorded separately.

3.2.2.1.3 Number of branches

Total number of branches on each plant was recorded individually at the time of harvest.

3.2.2.1.4 Number of internodes on the main stem

Number of internodes on the main stem was counted after 75 days after sowing.

3.2.2.1.5 Fruit length (cm)

The average length of tender fruits per plant was measured in centimetres from the base of the calyx to the tip of the fruits.

3.2.2.1.6 Fruit width (mm)

The average fruit diameter of the tender fruits per plant was measured in millimetres at the centre of the fruit by using vernier calipers.

3.2.2.1.7 Number of ridges per fruit

The number of ridges of fruit was counted on the tender fruits after harvest to identify fruit mutants.

Plate 1: General Field view of M_1 generation

3.2.2.1.8 Single fruit weight (g)

Single fruit weight was calculated by adding the weight of the fruits at third picking and divided by the total number of fruits and expressed as grams per fruit.

3.2.2.1.9 Number of fruits per plant

Number of fruits per plant was computed by adding the number of fruits of all the pickings from each plant.

3.2.2.1.10 Number of seeds per fruit

The number of seeds in each fruit was counted and the average was calculated**.**

3.2.2.1.11 Weight of seeds per fruit (g)

The total seeds per individual fruit were weighed and the average weight was expressed in grams.

3.2.2.1.12 Test weight (g)

Hundred counted seeds are weighed to determine the test weight in grams.

3.2.2.1.13 Total fruit yield per plant (g)

Total fruit yield per plant was computed by adding the fruit weight of all the pickings and expressed in grams per plant.

3.2.2.2 Qualitative traits

Observations on different qualitative traits among M_1 plants of okra were recorded. The characters studied and techniques adopted to record the remarks are given below.

3.2.2.2.1 Fruit pubescence

Fruit pubescence was judged by moving the fingers on the fruit surface and categorized into smooth (S), rough (R) and prickly (P)

3.2.2.2.2 Fruit colour

The colour of the fruit was recorded at the edible maturity stage based on visual appearance as light green (L), yellow-green (Y), green (G), dark green (D) and red (R).

3.2.2.2.3 Stem colour

The colour of the stem was recorded at the maturity stage based on visual appearance as green (G), dark green (D) and red (R).

3.2.2.3 Observation on macro- mutations

3.2.2.3.1Chlorophyll mutations

Different chlorophyll mutants were scored daily from 10th to 31st day after sowing. The identification and classification procedure as proposed by Gustafson (1940) was followed. A short description about chlorophyll mutation is given below.

Albino: white, lethal, no chlorophyll or carotenoids are formed.

Xantha: Yellow to yellowish-white in colour, lethal to plants, carotenoids are present but chlorophyll is absent.

Chlorina: Uniform green colour of the leaves with white patches on tips, viable mutations.

Viridis: Uniform light yellow-green colour of leaves, viable in nature.

Striata: Longitudinal strips of different colours on the leaves.

Virescent: Chlorophyll deficient leaflets are yellow in colour and did not survive beyond the seedling stage.

3.2.2.3.2 Morphological mutations

Each plant in the M_2 family of all treatments was closely examined during the entire growth period for the identification of viable mutations affecting various morphological attributes. The identification and description of different morphological mutants proposed by Blixt (1961) were followed. Each of these mutants is described below.

Plant mutants

Dwarf: Reduced size of plant parts like flowers and leaves. Height measures up to 20 to 35 cm.

Tall: At maturity, plants were taller than control due to the increased length of internodes up to 60 to 95 cm.

Leaf mutants

Different types of okra leaf shape mutants were observed and classified as **rosette, lobed** and **round.**

Flower mutants

The plants examined for the mutation like flowers with multiple stigmata, presence of extra ovary with elongated stigma, flowers with more than five petals, malformed androecium or gynoecium.

Pod mutants

Variations in length of pods, multiple fruits from a single node and fruits with many locules, fruit with different sized seeds and seedless fruits were scored.

3.3 M_2 generation

3.3.1 Field experiment

Selfed seeds of healthy, disease-free individual plants of M_1 generation of Arka Anamika and Arka Abhay were harvested separately from 100 individual plants from each of the three treatments. Plant to row progeny (each plant as a line) was sown to raise, M_2 generation along with the four checks. General field view of M_2 generation is given Plate 2. The sowing was undertaken on 2nd January 2020 on the fertile and well levelled piece of land at the experimental plot of College of Agriculture, ZARHS, KSN University of Agricultural and Horticultural Sciences, Shivamogga. Recommended doses of manures and fertilizers were applied. All intercultural operations and plant protection measures were taken up to raise a successful crop. Need based control measures were also applied to obtain a healthy crop. The other experimental details are as below.

Design	:	Augmented RCBD
Treatments	:	6 (3 from each variety: 30 kR, 50 kR, 80 kR)
Total number of blocks	:	24 (12 for each variety)
Blocks per treatment	:	4
No. of plants per treatment.	:	100
Block length	:	5 m
No of plants per row	:	10
Spacing	:	60× 45 cm

3.3.2 Observation on micro- mutations

Hundred normal looking plants excluding the macro-mutants were randomly tagged from each treatment to analyze the direction and spectrum of micro-mutations induced by different doses of gamma rays. Observations on aforesaid quantitative traits like days to first flowering, plant height, number of branches, fruit length, fruit width, number of internodes, number of fruits, fruit yield per plant, average fruit

weight, weight of seed per fruit, test seed weight and average yield per plant were recorded on selected normal healthy plants as described in M_1 generation.

3.4 Statistical analysis for M_1 and M_2 generations

The mean values recorded for the above characters for each mutant line in all the blocks were subjected to statistical analysis in type 2 modified augmented design (You *et al*., 2016) for both M_1 and M_2 generations. The details of the different statistical procedures were followed in different generations are presented below.

3.4.1 Analysis of Variance (ANOVA)

The total variation for each of the character was partitioned into variations due to blocks and non-assignable causes (error). The significance of difference among treatments in the M_1 generation of both the varieties was tested using Duncan's multiple range test (DMRT) method (Duncan, 1955). Critical difference (CD) at P= 0.05 was calculated for comparison of effect of mutagenic treatments with control.

Table 1: Analysis of variance for gamma irradiated treatments

Source of variation	Degree of freedom (d.f)	Sum of squares (SS)	Mean sum of squares (M.S.S)	Variance ratio (F)
Blocks	b-1	bSS	bMS	bMS/EMS
Entries	e-1	eSS	eMS	eMS/EMS
Checks	c-1	cSS	cMS	cMS/EMS
Varieties	v-1	vSS	vMS	vMS/EMS
Checks vs Varieties	1	cvSS	cvMS	cvMS/EMS
Error	(c-1)(b-1)	ESS	EMS	-
Total	N-1	TSS	-	-

Where, b = Blocks e = Entries c = Checks v = Varieties bMS, eMS, cMS, vMS, cvMS and EMS are Mean sum of squares due to Blocks, Entries, Checks, Varieties, Checks Vs varieties and Error.

Plate 2: General Field view of M_2 generation

GCF (General correction factor) = GT2 /N

$$bSS = \sum_{i=1}^{b} b^2 \text{ i } (c + nj) - \text{ GCF}$$

$$\text{TSS} = \sum_{i=1}^{c} \sum_{j=1}^{b} \text{cij}^2 + \sum_{j}^{v} v_i - \text{GCF}$$

cCF = (Check correction factor) = Tc^2 /bc

$$cSS = \sum_{i=1}^{c} (Tc_i /b) - cCF$$

eMS = eSS/c-1

$$\text{eSS} = (m \times GT) + \left(\sum_1^b b_{j\,Tb_i}\right) + \left(\sum_1^c Tc_{j\,i}\right) + \left(\sum_1^b b_{j\,Tb_j}\right) + \left(\sum_1^v v_{j\,v_j}\right) - \sum_1^b T^2 b_j \ (c + n_j)$$

3.4.2 Mean

The mean values of the different characters were calculated from the data recorded in the M_1 generation.

$$\text{Mean} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Where

X_i= i^{th} observation of a population

n = number of observations

3.4.3 Range

The range was the minimum and maximum values of the observations in a sample of genotypes.

3.4.4 Standard error (SE)

It is the measure of uncontrolled variation present in a sample which was estimated by dividing the standard deviation (SD) by the square root of number of observations (n) in the sample and was denoted by SE.

$$\text{SE} = \frac{\text{SD}}{\sqrt{n}}$$

3.4.5 Variance

Variance is defined as the average of the squared deviation to find individual observation from the mean. It is expressed as the sum of squares of the deviations of

all observations of a sample from its mean and divided by (n-1), where n is the number of observations. It is estimated by the following the formula given below.

$$\text{Variance}(\sigma^2) = \frac{\sum x^2 - \frac{(\sum(x))^2}{n}}{n-1}$$

Where,

Xi = i^{th} observation of a population

n = Number of observations

3.4.6 Standard deviation (SD)

Standard deviation is a measure of the dispersion of a set of data from its mean. Standard deviation is calculated as the square root of variance.

$$SD = \sqrt{\text{Variance}}$$

3.4.7 Estimation of genetic parameters

Genotypic and phenotypic variances were estimated using the formula given by Weber and Moorthy (1952).

3.4.7.1 Genotypic and phenotypic variances

The genotypic and phenotypic variances were computed based on the expected mean sum of squares from the ANOVA table as follows:

$$\text{Genotypic variance } \sigma_g^2 = \frac{\text{MSS (genotype)} - \text{MSS (error)}}{\text{Number of blocks}}$$

$$\text{Phenotypic variance } \sigma_p^2 = \sigma_g^2 + \sigma_e^2$$

Environmental variance (σ_e^2) = Me

3.4.7.2 Coefficients of variations

Genotypic and phenotypic coefficients of variations were computed according to Burton and Devane (1953) based on the estimate of genotypic and phenotypic variances as follows.

3.4.7.3 Genotypic coefficient of variation (GCV)

$$GCV = \frac{\sigma_g}{\bar{X}} \times 10$$

3.4.7.4 Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sigma_p}{\bar{X}} \text{ x } 100$$

Where,

X = General mean

σ_g = Genotypic standard deviation

σ_p = Phenotypic standard deviation

GCV and PCV were classified as suggested by Shivasubramanian and Menon (1973).

0 to 10 %	:	Low
11 to 20 %	:	Moderate
21 % and above	:	High

3.4.7.5 Heritability

Broad-sense heritability was estimated as the ratio of genotypic variance to the phenotypic variation and expressed in percentage (Falconer, 1981).

$$h^2 = \frac{\sigma_g^2}{\sigma_p^2}$$

Where,

σ_g^2 = Genotypic variance

σ_p^2= Phenotypic variance

Heritability percentage was categorized as demonstrated by Robinson *et al.* (1949).

0 to 30 %	:	Low
31 to 60 %	:	Moderate
61 % and above	:	High

3.4.7.6 Genetic advance (GA)

Genetic advance (GA) was computed using the formula given by Robinson *et al.* (1949).

$GA = k \times h^2 \times \sigma_p$

Where,

k = Selection differential (2.06) at 5 per cent selection intensity

σ_p = Phenotypic standard deviations

h^2 = Heritability at broad sense

3.4.7.7 Genetic advance as percentage over mean (GAM)

Genetic advance as percentage over mean was worked out as suggested by Johnson *et al.* (1955).

$$\text{GAM} = \frac{\text{GA}}{\overline{\text{X}}} \times 100$$

Where,

GA = Genetic advance

$\overline{\text{X}}$ = General mean of the character

The GAM was categorized as suggested by Johnson *et al.* (1955).

0 to 10 %	:	Low
11 to 20 %	:	Moderate
21 % and above	:	High

3.4.8 Correlation coefficient

To determine the degree of association of characters with yield and also among the yield components, the correlation coefficients were calculated. Phenotypic coefficients of correlation between two characters were determined by using variance and covariance components as suggested by Al- Jibouri *et al*. (1958).

$$\text{rp}\,(\text{x},\text{y}) = \frac{\text{Cov}_\text{p}(\text{x}.\text{y})}{(\sqrt{\text{Var}_\text{x}}) \times (\sqrt{\text{Var}_\text{y}})}$$

Where,

rp (xy) is the phenotypic correlation coefficient.

Cov_p is the phenotypic co-variances of x and y.

Var_x and Var_y are the phenotypic variance of x and y.

The calculated value of 'r' was compared with 't' table value with n-2 degree of freedom at 5 per cent and 1 per cent level of significance where ' n' refers to the number of pairs of observations.

3.4.9 Path coefficient analysis

Path co-efficient analysis suggested by Wright (1921) and Dewey and Lu (1959) was carried out to know the direct and indirect effect of the morphological traits on fruit yield. The following set of simultaneous equations were formed and solved for estimating various direct and indirect effects.

r1y = a + r12b + r13c + ……....+ r1Ii

r2y = a + r21a + b + r23c + ……..+ r2Ii

r3y = r31a + r32b + c + ……..+ r3Ii

r1y = r11a + r12b + r13c + ……..+ I

Where,

r1y to 11y = r value between causal factors 1 to I with dependent characters y.

r12 to r1I = Co-efficient of correlation among causal factors

a, b, c…i = Direct effects of characters 'a' to 'I' on the dependent character 'y.'

Residual effect (R) was computed as follows.

$$\text{Residual effect (R)} = 1 - \sqrt{a2 + b2 + c2 + \cdots i2 + 2abr12 + 2acr13 + \cdots}$$

Lenka and Mishra (1973) have suggested scales for path coefficients analysis.

0.00-0.09	:	Negligible
0.10-0.19	:	Low
0.20-0.29	:	Moderate
0.30-0.99	:	High
> 1.00	:	Very high

3.5 EXPERIMENT 2: Induced epigenetic mutations in Okra

3.5.1 Experimental sites

The investigation was carried out during 2020-2021 at College of Agriculture, Navile, Shivamoga. It is geographically situated between 130 27' to 140 39' N latitude and 740 37' to 750 52' E longitude with an altitude of 650 m above the MSL. The soil of the experimental site was clay loam with medium-high to high levels of fertility.

3.5.2 Experimental material

Dry, healthy and genetically pure seed material of two okra varieties namely Arka Anamika and Arka Abhay were used in the present investigation. Fresh seeds were obtained from the Indian Institute of Horticultural Research, Hesaraghatta, Bangalore. Two epigenetic mutagens *viz.*, Sodium butyrate and Trichostatin-A were selected for the induction of epigenetic mutations in okra seeds.

3.5.3 Preparation of mutagenic solution

Freshly prepared solutions of Sodium butyrate and Trichostatin-A were used to induce mutations. A stock solution of 100 mM Sodium butyrate (Molecular weight 110.1g, Sigma-Aldrich CAT No: 303410) was prepared by dissolving 1.101 g in 100 ml of sterile water. The clear stock solution obtained was filter sterilized and then

diluted to the required final concentrations of 50 µM and 150 µM using sterile distilled water inside a laminar flow hood.

Similarly, 3.31mM Trichostatin-A stock (Molecular weight 302.37g Sigma-Aldrich CAT No: T8552) was prepared by dissolving 1 mg of Trichostatin-A in 1ml of DMSO. The required final concentrations of 0.4 µM and 1.2 µM were prepared by diluting with sterile distilled water.

The working solutions of both Sodium butyrate and Trichostatin-A were prepared from the stock solution using the formula,

$$\mathbf{M_1V_1 = M_2V_2}$$

Where,

M_1 = Strength of stock solution V_1= Volume of stock solution

M_2= Strength of desired solution V_2= Volume of desired solution

3.5.4 Mutagen treatment

Pure and healthy seeds of two okra varieties, Arka Anamika and Arka Abhay were selected and pre-soaked for one hour in double distilled water as it allows the cells to reach active metabolic state when they are relatively more sensitive to mutagenic action. The control seeds were also immersed in distilled water for the same duration but seeds were not treated with the mutagen.

Two sets of 100 seeds each of Arka Anamika and Arka Abhay were treated with 50µM and 150 µM of sodium butyrate. A set treated with 50 µM and 150 µM were incubated for 3 days and another set treated was incubated for 5 days in the dark (Plate 3). Similarly, two sets of 100 seeds each of Arka Anamika and Arka Abhay were treated with 0.4 µM and 1.2 µM of Trichostatin-A. One set treated with 0.4 µM and 1.2 µM were incubated for 3 days and another set treated was incubated for 5 days in the dark conditions (Plate 4). A control plate was maintained for each treatment. The control set is treated with DMSO for the Trichostatin-A treatment. The details of the treatments are given in Table 2.

Table 2: Descriptions of epigenetic mutagen treatments

Treatment	Varieties	Chemical	Description of the treatments
T_1	Arka Anamika	Control	Control: Pre-soaking for 1 hour in distilled water
T_2	Arka Anamika	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 3 days incubation in 50 µM SB.
T_3	Arka Anamika	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 5 days incubation in 50 µM SB.
T_4	Arka Anamika	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 3 days incubation in 150 µM SB.
T_5	Arka Anamika	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 5 days incubation in 150 µM SB.
T_6	Arka Abhay	Control	Control: Pre-soaking for 1 hour in distilled water
T_7	Arka Abhay	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 3 days incubation in 50 µM SB.
T_8	Arka Abhay	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 5 days incubation in 50 µM SB.
T_9	Arka Abhay	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 3 days incubation in 150 µM SB.
T_{10}	Arka Abhay	Sodium butyrate (SB)	Pre-soaking for 1 hour followed by 5 days incubation in 150 µM SB.
T_{11}	Arka Anamika	Control	Control: Pre-soaking and incubation in DMSO
T_{12}	Arka Anamika	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 3 days incubation in 0.4 µM TSA.
T_{13}	Arka Anamika	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 5 days incubation in 0.4 µM TSA.
T_{14}	Arka Anamika	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 3 days incubation in 1.2 µM TSA.
T_{15}	Arka Anamika	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 5 days incubation in 1.2 µM TSA.
T_{16}	Arka Abhay	Control	Control: Pre-soaking and incubation in DMSO
T_{17}	Arka Abhay	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 3 days incubation in 0.4 µM TSA.
T_{18}	Arka Abhay	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 5 days incubation in 0.4 µM TSA.
T_{19}	Arka Abhay	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 3 days incubation in 1.2 µM TSA.
T_{20}	Arka Abhay	Trichostatin-A (TSA)	Pre-soaking for 1 hour followed by 5 days incubation in 1.2 µM TSA.

3.6 S_1 and TS_1 generation

3.6.1 Field experiment

Mutagen treated seeds of both the varieties were sown in the experimental site with a spacing of 60 × 45 cm in an augmented design during December 2020 to raise first generation. Untreated control seeds of Arka Anamika, Arka Abhay, Parbhani Kranti (YVM resistant) and Pusa Sawani (YVM susceptible) were sown as checks for respective treatments. The recommended package of practices like fertilization, weeding and plant protection wereensured during the crop period till harvest. Observations on the following characters were recorded from selected plants in each treatment.

3.6.2 Observations recorded in S_1 and TS_1 generation

The traits considered and the procedure adopted for recording the observations for different traits is given below**.**

3.6.2.1 Quantitative traits

The quantitative characters studied and techniques adapted to record these observations are given below.

3.6.2.1.1 Plant height (cm)

Height of the plant was measured in centimetres at the time of harvest from ground level to the tip of the main stem.

3.6.2.1.2 Days to first flowering

Number of days taken from the date of sowing to time of first flower opening in each plant was recorded separately.

3.6.2.1.3 Number of branches

Total number of branches on each plant was recorded individually at the time of harvest.

3.6.2.1.4 Number of internodes on the main stem

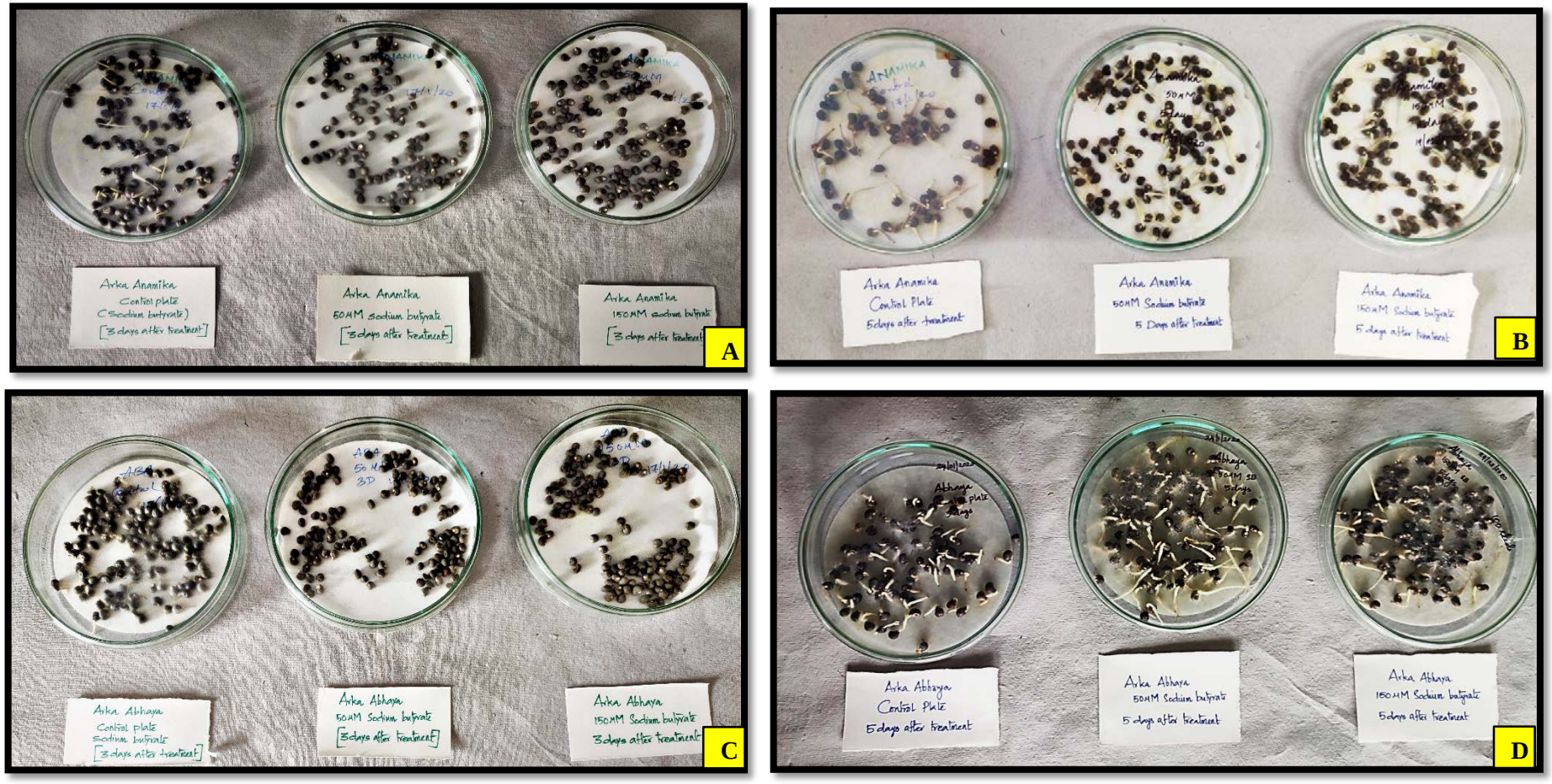
Number of internodes on the main stem was counted after 75 days after sowing.

3.6.2.1.5 Fruit length (cm)

Average length of tender fruits per plant was measured in centimetres from the base of calyx to the tip of fruits.

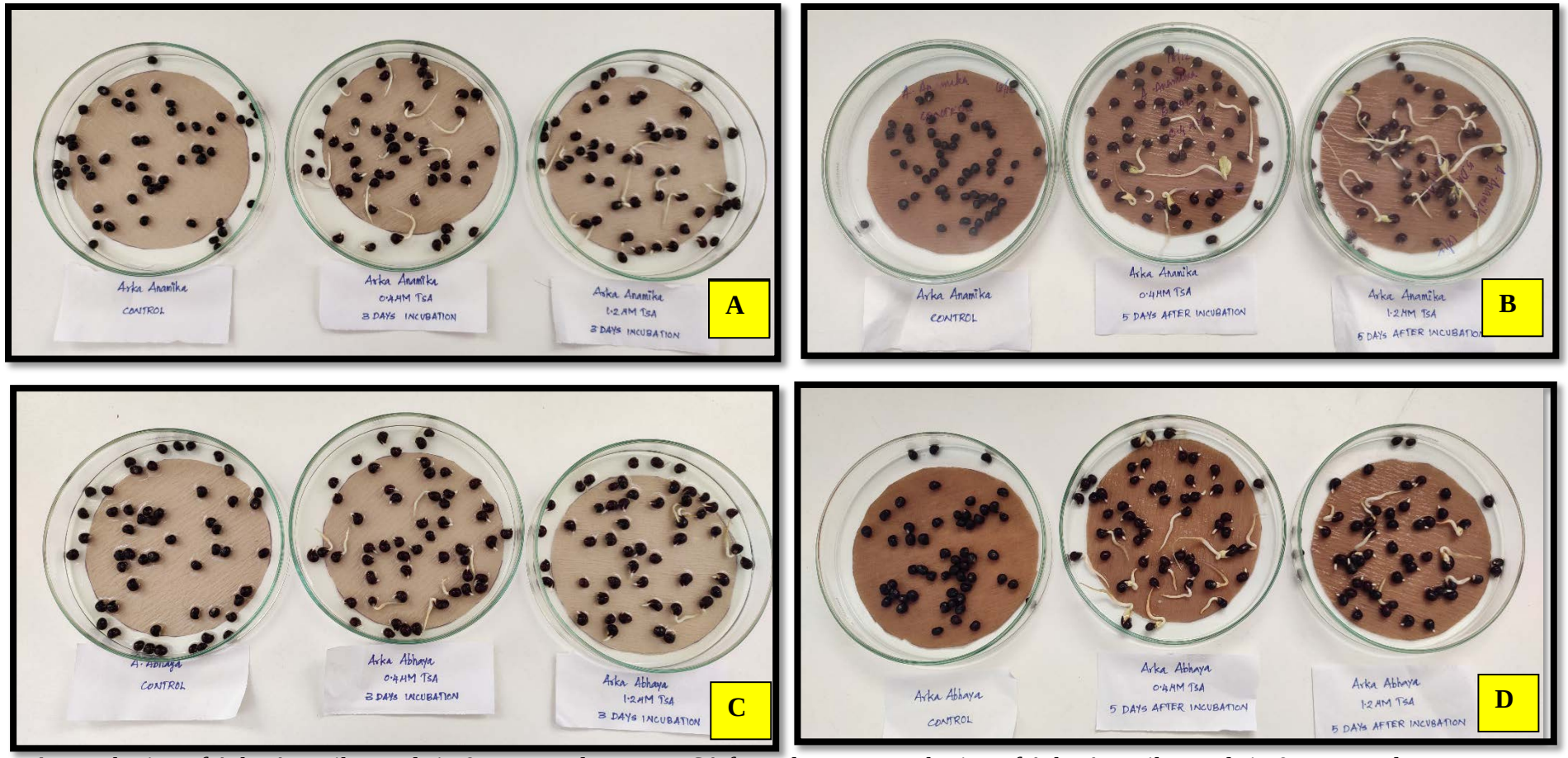
3.6.2.1.6 Fruit width (mm)

The average fruit diameter of the tender fruits per plant was measured in millimetres at the centre of fruit by using vernier calipers.



***A**: Incubation of Arka Anamika seeds in 50 µM and 150 µM SB for 3 days, **B**: Incubation of Arka Anamika seeds in 50 µM and 150 µM SB for 5 days, **C**: Incubation of Arka Abhay seeds in 50 µM and 150 µM SB for 3 days, **D**: Incubation of Arka Abhay seeds in 50 µM and 150 µM SB for 5 days*

Plate 3: Experimental setup for Sodium butyrate (SB) treatment



***A**: Incubation of Arka Anamika seeds in 0.4 µM and 1.2 µM TSA for 3 days, **B**: Incubation of Arka Anamika seeds in 0.4 µM and 1.2 µM TSA for 5 days, **C**: Incubation of Arka Abhay seeds in 0.4 µM and 1.2 µM TSA for 3 days, **D**: Incubation of Arka Abhay seeds in 0.4 µM and 1.2 µM TSA for 5 days*

Plate 4: Experimental setup for Trichostatin-A (TSA) treatment

3.6.2.1.7 Number of ridges of fruit

The number of ridges of fruit was counted on the tender fruits after harvest to identify fruit mutants.

3.6.2.1.8 Number of locules of fruit

The number of locules of the fruit was counted on the tender fruits after harvest to identify fruit mutants.

3.6.2.1.9 Single fruit weight (g)

Single fruit weight was calculated by adding the weight of the fruits at third picking and divided by the total number of fruits and expressed as grams per fruit.

3.6.2.1.10 Number of fruits per plant

Number of fruits per plant was computed by adding the number of fruits of all the pickings from each plant.

3.6.2.1.11 Number of seeds per fruit

The number of seeds in each fruit was counted and the average was calculated**.**

3.6.2.1.12 Weight of seeds per fruit (g)

The weight of seeds per fruits is weighed and average weight was expressed in grams.

3.6.2.1.13 Test weight (g)

Hundred counted seeds are weighed to determine the test weight in grams.

3.6.2.1.14 Total fruit yield per plant (g)

Total fruit yield per plant was computed by adding the fruit weight of all the pickings and expressed in grams per plant.

3.6.2.2 Qualitative traits

Observations on different qualitative traits among M_1 plants of okra were recorded. The characters studied, and techniques adopted to record the remarksare given below.

3.6.2.2.1 Fruit pubescence

Fruit pubescence was judged by moving the fingers on fruit surface and categorized into smooth (S), rough (R) and prickly (P)

3.6.2.2.2 Fruit colour

The colour of the fruit was recorded at edible maturity stage based on visual appearance as light green (L), yellow green (Y), green (G), dark green (D) and red (R).

3.6.2.2.3 Stem colour

The colour of the stem was recorded at maturity stage based on visual appearance as green (G), dark green (D) and red (R).

3.6.2.3 Observation on macro- mutations

3.6.2.3.1 Chlorophyll mutations

Different chlorophyll mutants were scored daily from 10^{th} to 31^{st} day after sowing. The identification and classification procedure as proposed by Gustafson (1940) was followed.

3.6.2.3.2 Morphological mutations

Each plant in the M_2 family of all treatments was closely examined during the entire growth period for the identification of viable mutation affecting various morphological attributes. The identification and description of different morphological mutants proposed by Blixt (1961) were followed. Each of these mutants is described below.

Plant mutants

Dwarf: Reduced size of plant parts like flower and leaves. Height measures up to 20-35 cm.

Tall: At maturity, plants were taller than control due to increased length of internodes up to 60-95 cm

Leaf mutants

Different types of okra leaf shape mutants were observed and classified as **rosette, lobed** and **round.** Leaves pedicel without purple pigmentation and green leaf venation was observed.

Flower mutants

The plants examined for the mutation like flowers with multiple stigmata, presence of extra ovary with elongated stigma, flowers with more than five petals, less than five petals, malformed androecium or gynoecium, petals without purple pigmentations, pigmented calyx *etc*.

Pod mutants

Variations in length and colour of pods, multiple fruits from a single node, and fruits with many locules, fruit with different sized seeds and seedless fruits were scored.

3.7 S_2 and TS_2 generation

3.7.1 Field experiment

Selfed seeds of healthy, disease-free individual plants from the first generation of Arka Anamika and Arka Abhay of all the treatments were harvested separately from selected individual plants. Plant to progeny row progeny (each plant as a line) was sown to raise, M_2 generation along with the four checks. The sowing was undertaken in Augmented RCBD design on the fertile and well levelled piece of land at experimental plot of College of Agriculture, ZARHS, KSN University of Agricultural and Horticultural Sciences, Shivamogga. Recommended doses of manures and fertilizers were applied. All intercultural operations and plant protection measures were taken up to raise a successful crop. Need based control measures were also applied to obtain a healthy crop.

3.7.2 Observation on micro- mutations

Individual normal looking plants excluding the macro-mutants were randomly tagged from each treatment to analyze the direction and spectrum of micro-mutations induced by different concentrations of sodium butyrate and Trichostatin-A. Observations were made on aforesaid quantitative traits like days to first flowering, plant height, number of branches, fruit length, fruit width, number of internodes, number of fruits, fruit yield per plant, average fruit weight, weight of seed per fruit, number of ridges per fruit, number of locules per fruit, 100 seed weight and average yield per plant.

3.8 Statistical analysis S_2 and TS_2 generation

The mean values recorded for the above characters for each mutant line in all the blocks were subjected to statistical analysis in type 2 modified augmented design (You *et al.*, 2016) for both first and second generations. The details of the different statistical procedures followed in different generations are presented below.

3.8.1 Analysis of Variance (ANOVA)

The total variation for each of the character was partitioned into variation due to blocks and non-assignable causes (error). Significance of difference among treatments in the S_1 generation of both the varieties was tested using Duncan's multiple range test (DMRT) method (Duncan, 1955). Critical difference (CD) at P= 0.05 was calculated for comparison of effect of mutagenic treatments with control.

Table 3: Analysis of variance for epigenetic mutagen treatments

Source of variation	Degree of freedom (d.f)	Sum of squares (SS)	Mean sum of squares (M.S.S)	Variance ratio (F)
Blocks	b-1	bSS	bMS	bMS/EMS
Entries	e-1	eSS	eMS	eMS/EMS
Checks	c-1	cSS	cMS	cMS/EMS
Varieties	v-1	vSS	vMS	vMS/EMS
Checks vs Varieties	1	cvSS	cvMS	cvMS/EMS
Error	(c-1)(b-1)	ESS	EMS	-
Total	N-1	TSS	-	-

Where, b = Blocks e = Entries c = Checks v = Varieties bMS, eMS, cMS, vMS, cvMS and EMS are Mean sum of squares due to Blocks, Entries, Checks, Varieties, Checks Vs varieties and Error.

GCF (General correction factor) = GT2 /N

$$bSS = \sum_{i=1}^{b} b^2 \text{ i } (\text{c} + \text{nj}) - \text{ GCF}$$

$$\text{TSS} = \sum_{\text{i}=1}^{\text{c}} \sum_{\text{j}=1}^{\text{b}} \text{cij}^2 + \sum_{\text{j}}^{\text{v}} \text{v}_\text{i} - \text{GCF}$$

cCF = (Check correction factor) = Tc^2 /bc

$$cSS = \sum_{i=1}^{c} (Tc_i /b) - cCF$$

eMS = eSS/c-1

$$eSS = (m \times GT) + \left(\sum_{1}^{b} b_{j\,Tb_i} \right) + \left(\sum_{1}^{c} Tc_{j\,i} \right) + \left(\sum_{1}^{b} b_{j\,Tb_j} \right) + \left(\sum_{1}^{v} v_{j\,v_j} \right) - \sum_{1}^{b} T^2 b_j \ (c + n_j)$$

3.8.2 Mean

The mean values of the different characters were calculated from the data recorded in M_1 generation.

$$Mean = \frac{\sum_{i=1}^{n} X_i}{n}$$

Where

X_i = i^{th} observation of a population

n = number of observations

3.8.3 Range

The range was the minimum and maximum values of the observations in a sample of genotypes.

3.8.4 Standard error (SE)

It is the measure of uncontrolled variation present in a sample which was estimated by dividing the standard deviation (SD) by the square root of number of observations (n) in the sample and was denoted by SE.

$$SE = \frac{SD}{\sqrt{n}}$$

3.8.5 Variance

Variance is defined as the average of the squared deviation so find individual observation from the mean. It is expressed as the sum of squares of the deviations of all observations of a sample from its mean and divided by (n-1), where n is the number of observations. It is estimated by the following the formula given below.

$$\text{Variance}(\sigma^2) = \frac{\sum x^2 - \frac{(\sum(x))^2}{n}}{n-1}$$

Where,

Xi = i^{th} observation of a population

n = Number of observations

3.8.6 Standard deviation (SD)

Standard deviation is a measure of the dispersion of a set of data from its mean. Standard deviation is calculated as the square root of variance.

$$SD = \sqrt{\text{Variance}}$$

3.8.7 Estimation of genetic parameters

Genotypic and phenotypic variances were estimated using the formula given by Weber and Moorthy (1952).

3.8.7.1 Genotypic and phenotypic variances

The genotypic and phenotypic variances were computed based on the expected mean sum of squares from ANOVA table as follows:

$$\text{Phenotypic variance } (\sigma_p^2) = \sigma_g^2 + \sigma_e^2$$

$$\text{Environmental variance } (\sigma_e^2) = \text{Me}$$

3.8.7.2 Coefficients of variations

Genotypic and phenotypic coefficients of variations were computed according to Burton and Devane (1953) based on the estimate of genotypic and phenotypic variances as follows.

3.8.7.3 Genotypic coefficient of variation (GCV)

$$\text{GCV} = \frac{\sigma_g}{\overline{X}} \times 100$$

3.8.7.4 Phenotypic coefficient of variation (PCV)

$$\text{PCV} = \frac{\sigma_p}{\overline{X}} \text{ x } 100$$

Where,

$\overline{X}$ = General mean

σ_g = Genotypic standard deviation

σ_p = Phenotypic standard deviation

GCV and PCV were classified as suggested by Shivasubramanian and Menon (1973).

0 to 10 %	:	Low
11 to 20 %	:	Moderate
21 % and above	:	High

3.8.7.5 Heritability

Broad-sense heritability was estimated as the ratio of genotypic variance to the phenotypic variation and expressed in percentage (Falconer, 1981).

$$h^2 = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Where,

σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

Heritability percentage was categorized as demonstrated by Robinson *et al.* (1949).

0 to 30 %	:	Low
31 to 60 %	:	Moderate
61 % and above	:	High

3.8.7.6Genetic advance (GA)

Genetic advance (GA) was computed using the formula given by Robinson *et al.* (1949).

$GA = k \times h^2 \times \sigma_p$

Where,

k = Selection differential (2.06) at 5 per cent selection intensity

σ_p = Phenotypic standard deviations

h^2 = Heritability at broad sense

3.8.7.7 Genetic advance as percentage over mean (GAM)

Genetic advance as percentage over mean was worked out as suggested by Johnson *et al.* (1955).

$$GAM = \frac{GA}{\overline{X}} \times 100$$

Where,

GA = Genetic advance

$\overline{X}$ = General mean of the character

The GAM was categorized as suggested by Johnson *et al.* (1955).

0 to 10 %	:	Low
11 to 20 %	:	Moderate
21 % and above	:	High

3.8.8 Correlation coefficient

To determine the degree of association of characters with yield and also among the yield components, the correlation coefficients were calculated. Phenotypic

coefficients of correlation between two characters were determined by using variance and covariance components as suggested by Al- Jibouri *et al*. (1958).

$$rp\ (x,y) = \frac{\mathrm{Cov}_p(\mathrm{x.y})}{(\sqrt{\mathrm{Varx}_x}) \times\ (\sqrt{\mathrm{Vary}_y})}$$

Where,

rp (xy) is the phenotypic correlation coefficient.

Cov_p is the phenotypic co-variances of x and y.

Var_x and Var_y are the phenotypic variance of x and y.

The calculated value of 'r' was compared with 't' table value with n-2 degree of freedom at 5 per cent and 1 per cent level of significance where ' n' refers to number of pairs of observations.

3.8.9 Path coefficient analysis

Path co-efficient analysis suggested by Wright (1921) and Dewey and Lu (1959) was carried out to know the direct and indirect effect of the morphological traits on fruit yield. The following set of simultaneous equations were formed and solved for estimating various direct and indirect effects.

r1y = a + r12b + r13c + ……....+ r1Ii

r2y = a + r21a + b + r23c + ……..+ r2Ii

r3y = r31a + r32b + c + ……..+ r3Ii

r1y = r11a + r12b + r13c + ……..+ I

Where, r1y to 11y = Coefficient of correlation between causal factors i to 1 with dependent characters y.

r12 to r1I = Co-efficient of correlation among causal factors

a, b, c…i = Direct effects of characters 'a' to 'I' on the dependent character 'y.'

Residual effect (R) was computed as follows.

$$\text{Residual effect (R)} = 1 - \sqrt{a2 + b2 + c2 + \cdots i2 + 2abr12 + 2acr13 + \cdots}$$

Lenka and Mishra (1973) have suggested scales for path coefficients analysis.

0.00-0.09	:	Negligible
0.10-0.19	:	Low
0.20-0.29	:	Moderate
0.30-0.99	:	High
> 1.00	:	Very high

EXPERMENTAL RESULTS AND DISCUSSION

IV EXPERIMENTAL RESULTS AND DISCUSSION

There are ample research evidence indicating the importance of induced mutations in various crop species for creating novel and useful variations, both for qualitative as well as quantitative characters which may enhance the crop improvement programmes. The present investigation entitled "**Assessment of Variability in Okra (*Abelmoschus esculentus* (L.) Moench) Generated through Mutations"** was planned in two open- pollinated varieties of okra to evaluate the effectiveness and efficiency of different mutagens in generating genetic and epigenetic variability for yield and its component traits.

Two different experiments, one for analysing the genetic variations induced by gamma irradiation and the other using chemical mutagens to induce epigenetic mutations were conducted in two okra varieties, namely Arka Anamika and Arka Abhay. The investigation results obtained in the two experiments are discussed in detail under the subtitles given below.

4.1 Experimental studies in okra using gamma radiation

4.1.1 Observation in M_1 generation

4.1.2 Observation in M_2 generation

4.2 Experimental studies in okra using epigenetic mutagen, Sodium butyrate (SB)

4.2.1 Observation in S_1 generation (First mutant generation) of Sodium butyrate

4.2.2 Observation in S_2 generation (Second mutant generation) of Sodium butyrate

4.3 Experimental studies in okra using epigenetic mutagen, Trichostatin-A (TSA)

4.3.1 Observation in TS_1 generation (First mutant generation) of Trichostatin-A

4.3.2 Observation in TS_2 generation (Second mutant generation) of Trichostatin-A

4.1 Experimental Studies in okra using gamma radiation

4.1.1 Observation in M_1 generation

The immediate micro and macro effects of gamma radiation treatment on M_1 plants were estimated on the basis of its effect on parameters like days to first flowering, plant height (cm), number of branches, number of internodes on the main stem, number of fruits per plant, fruit length (cm), fruit width (mm), number of ridges per fruit, single fruit weight (g), number of seeds per fruit, weight of seeds per fruit (g), seed index and fruit yield per plant (g).

4.1.1.1 Morphological mutations

The range of various chlorophyll mutants and other macro-mutations observed in the M_1 generation of Arka Anamika and Arka Abhay are summarized in Table 4.

Various chlorophyll mutants such as chlorina, xantha, albina green, albino and viridis were observed in the plants, following the irradiation with gamma radiation. Similar results were also reported by Kolar *et al.* (2011) in *Delphinium malabaricum* and Mohite *et al.* (2019) in okra. Chlorophyll mutations such as albino and viridis induced by gamma radiation in common bean (Ulukapi and Ozmen, 2017) and musk okra (Warghat *et al*., 2011) were also reported which emphasize the efficiency of gamma rays in the induction of chlorophyll mutations. The number of chlorina type of mutants was higher followed by xantha and viridis type. The reason for the appearance of greater number of chlorina, xantha and viridis types may be attributed to the involvement of polygenes in the chlorophyll formation (Gaul, 1964). The various types of other mutants such as early and late-flowering types, dwarf statured and tall plants, leaf mutants such as rosette, round and lobed types were also observed (Plate 3). A similar type of leaf mutants was also observed in *Lablab purpureus* (Monica and Seetharaman, 2017) and in okra (Surendran and Udayan, 2017; Gupta and Sood, 2019).

Flower mutants with six and more number of petals and altered aestivation were noticed at higher doses of gamma radiation. These types of flower mutants were also obtained in the study of Surendran and Udayan (2017) in okra. The length and width of the pods also found varied along with an increased number of ridges. Pods with sterile seeds were also identified in the study, as reported by Surendran and Udayan (2017).The total number of visible mutations followed a trend of increasing frequency with the increase of the dose of the mutagen. A maximum number of viable and morphological mutations were obtained at a moderate dose in the study. Mohite *et al.* (2019) also opinioned the same about the increase in total lethal mutations as increase in doses.

Chlorophyll mutations can be used as dependable indices for analyzing the efficiency of various physical and chemical mutagens in inducing genetic variability for crop improvement. The occurrence of different chlorophyll mutations after treatments with mutagens have been reported in several crops (Gustafson, 1940; Sharma and Sharma, 1981; Mitra and Bhowmik, 1999; Solanki, 2005 and Gupta and Sood, 2019).

4.1.1.2 Analysis of variance (ANOVA) for characters in M_1 generation.

Analysis of variance for the yield and its eleven contributing parameters in the M_1 generation of Arka Anamika and Arka Abhay are performed and presented in Table 5 and Table 6, respectively. The ANOVA for both the varieties showed that mean sum of squares within blocks (eliminating treatments), within the treatments (eliminating blocks) and mutants vs checks were significant for all the traits except fruit length such as days to first flowering, plant height (cm), number of branches, number of internodes on the main stem, number of fruits per plant, fruit length (cm),

Table 4: Spectrum of induced visible mutations by different doses of gamma radiation in M_1 generation

Type of mutation	Arka Anamika					Arka Abhay				
Chlorophyll mutants	**Control**	**30 kR**	**50 kR**	**80 kR**	**Total**	**Control**	**30 kR**	**50 kR**	**80 kR**	**Total**
Chlorina	-	1	2	4	7	-	1	3	3	7
Xantha	-	1	2	3	6		0	2	3	5
Viridis	-	0	0	3	3	-	0	1	3	4
Albina green	-	0	0	3	3	-	0	0	3	3
Albino	-	0	0	1	1	-	0	0	0	0
Dwarf	-	1	1	8	10	-	0	0	8	8
Tall	-	1	3	0	4	-	0	4	0	4
Early flowering	-	0	3	0	3	-	1	5	0	6
Late flowering	-	1	1	5	7	-	1	2	6	9
Leaf mutants	-	3	2	4	9	-	2	3	6	11
Flower mutants	-	0	0	2	2	-	0	0	1	1
Pod mutants (Increased ridge number)	-	4	6	15	25	-	6	7	12	25

fruit width (mm), average fruit weight (g), number of seeds per fruit, weight of seeds per fruit (g), seed index and fruit yield per plant (g) showing significant differences among the mutant lines of different doses in different blocks. This has indicated the existence of significant differences for the major yield governing traits in the mutant lines of two okra varieties, Arka Anamika and Arka Abhay. The results are in accordance with that of Warghat *et al*. (2011),) Khajuria *et al*. (2015), Ashadevi *et al.* (2017), Maryam (2017), Amir *et al.* (2018) and Mohite and Gurav (2019) for different traits in gamma radiation- induced mutants in okra.

Significant differences among mutagenic doses of gamma rays among the M_1 population of Arka Anamika and Arka Abhay was tested using Duncan Multiple Range Test (Table 7), and it was evident from the test that, means of important yield governing traits varied significantly among different treatments.

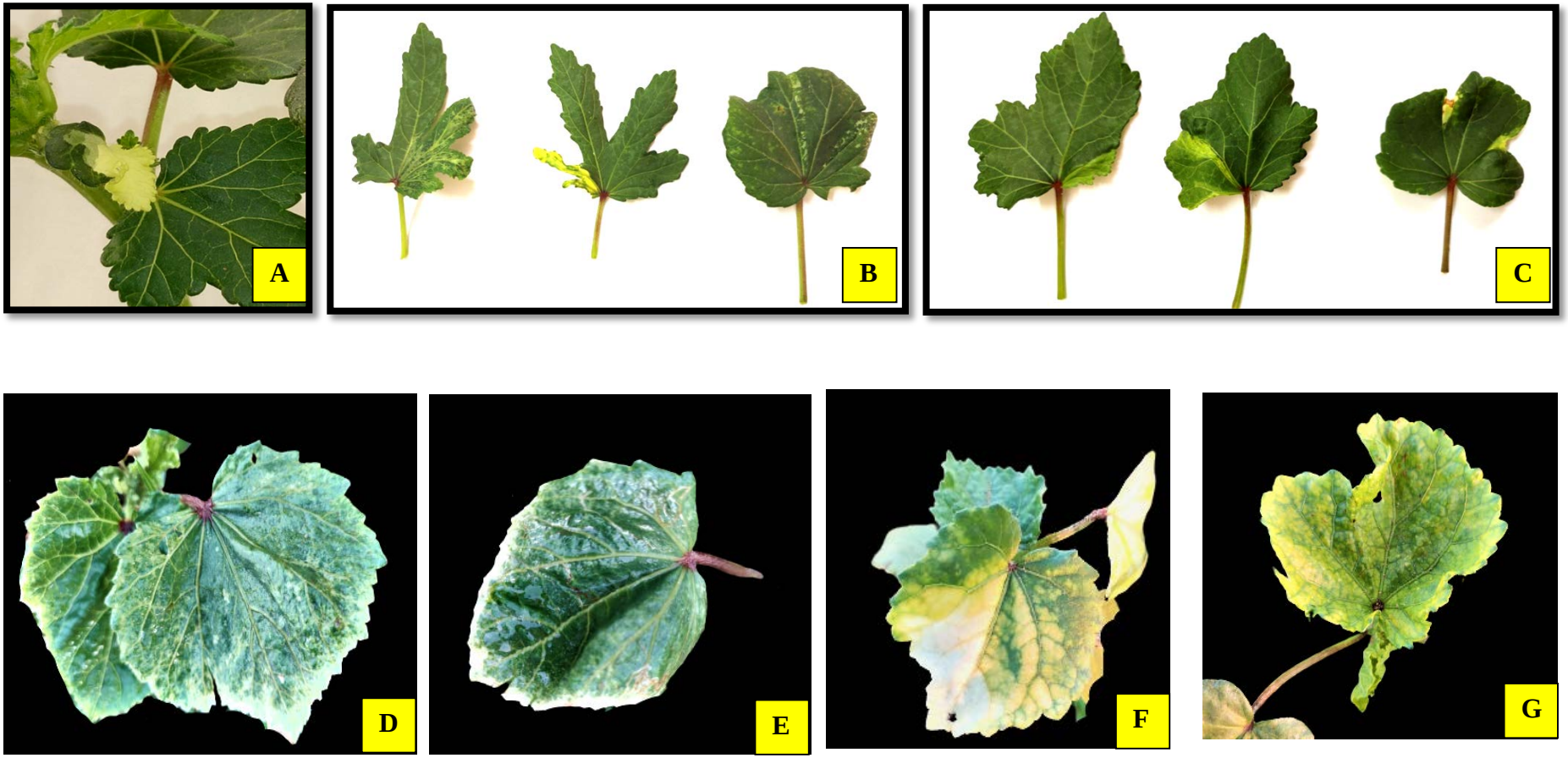
4.1.1.2.1 Effect of gamma irradiation on different characters

Significant differences in the mean values of most of the traits were observed for mutant lines of both Arka Anamika and Arka Abhay in response to varying doses of gamma radiation (Table 7).

At a lower dose of gamma radiation (30 kR), the effects on most of the traits such as plant height and days to first flowering and total fruit yield were comparable with that of the control treatment. At lower doses of gamma radiation, the mean value of characters such as plant height, number of fruits per plant, fruit length, number of seeds per fruit and total yield were on par with that of the respective parents as noticed by Warghat *et al.* (2011). Similarly, Dalve *et al*. (2010) reported a comparable mean performance of control plants and mutagen treated plants at lower doses in okra.

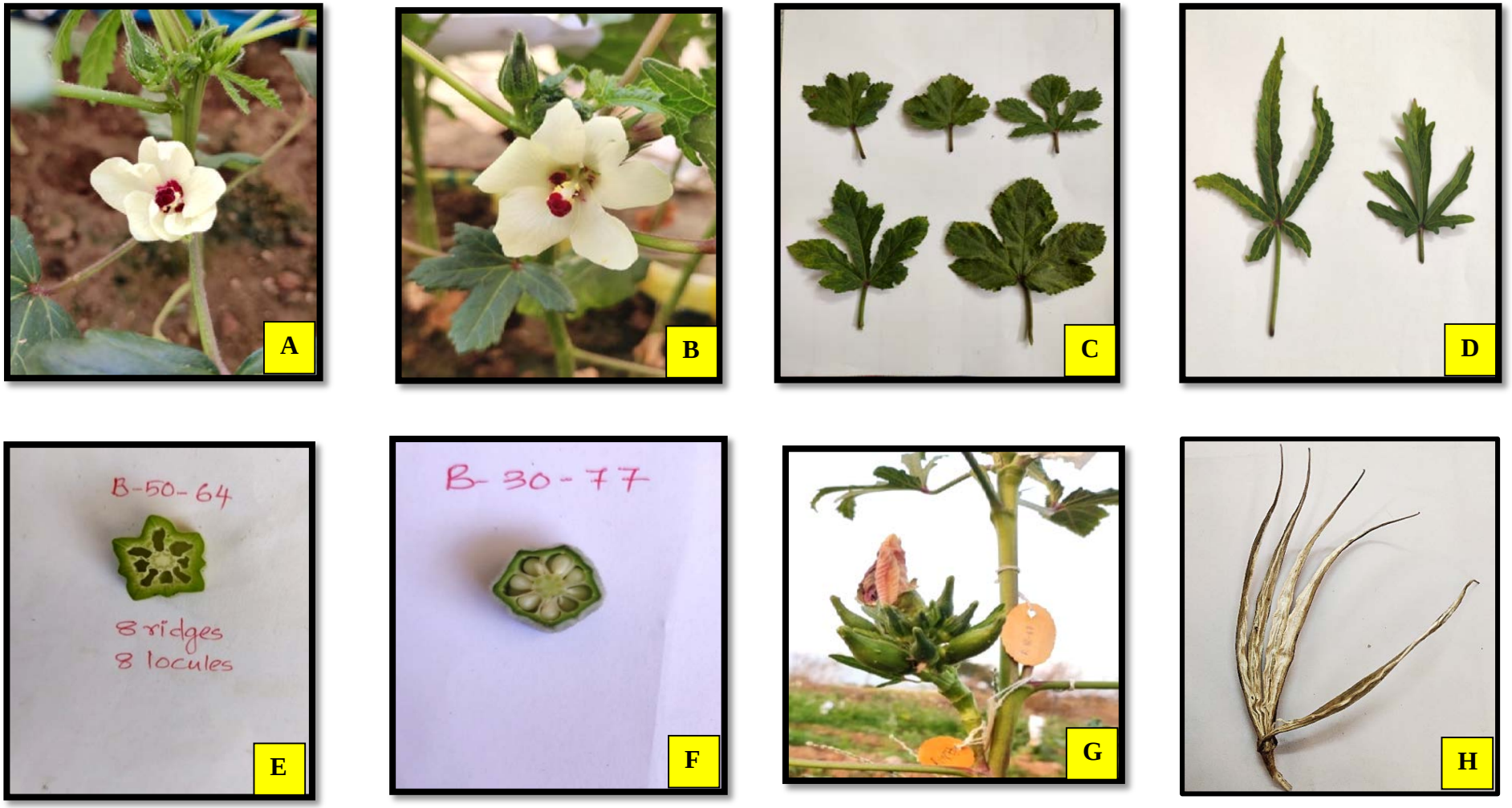
The treatment with 50 kR of gamma radiation enhanced some of the important traits governing yield among both the mutant population. Traits such as plant height, number of fruits per plant, fruit length, single fruit weight, number of seeds per plant and total fruit yield per plant were observed to be significantly higher in 50 kR treatment compared to other treatments and control in case of mutants of Arka Anamika and Arka Abhay. Other traits such as seed weight per fruit and test weight were also higher and were comparable to the control. The observation was in accordance with that of Norfadzrin *et al.* (2007), Hegazi and Hamideldin (2010), Jadhav *et al.* (2012), Warghat *et al.* (2011), Pushparajan *et al.* (2014), Kashid and Kulthe (2014), Elangovan and Pavadai (2015) and Gupta and Sood (2019) in okra.

In general, it was clear that, a higher dose (80 kR) had detrimental effects on most of the traits such as plant height, number of fruits per plant, fruit length and width, single fruit weight, number of seeds per plant, seed weight per fruit, test weight and total fruit yield. Remarkable increase in the number of days to first flowering was



A: Albino, B and C: Chlorina, D and E: Albina green, F: Xantha, G: Viridis

Plate 5: Chlorophyll mutations induced by gamma radiation in the M_1 generation



A and B: Increased number of petals, C: Round leaves, D: Rosette leaves, E and F: Pod mutants with increased number of ridges and locules, G: Multiple flower buds in a bunch, H: Fruit with sterile seed

Plate 6: Visible mutations induced by gamma radiation in the M_1 generation

Table 5: Analysis of variance for growth and yield parameters in mutant families (M_1) of Arka Anamika variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	5	26.57 **	351.14 **	7.31 **	18.7 **	101.72 **	1.18 **	55.22 **	174.49 **	478.29 **	3.82 **	10.49**	15710.90 **
Treatment (eliminating Blocks)	123	1.34 **	55.6 **	2.65 **	6.8 **	7.18*	3.07 **	8.78 **	19.88 **	217.04 **	2.09 **	2.83 **	1340.08 **
Checks	3	17.15 **	42.52 **	5.59 **	7.88 **	14.98**	0.01	0.13 *	2.78	2.76 *	0.64 **	5.9 **	1173.82 **
Mutants	119	1.86 **	70.92 **	2.81 **	6.55 **	11.19**	0.51 **	11.39 **	27.27 **	243.15 **	2.3 **	2.57 **	1976.44 **
Mutants vs Check	1	23.87 **	25.03 **	10.73 **	125.75 **	0.69	21.92 **	0.26 *	54.18 **	138.08 **	0.5 **	20.85 **	3730.09 **
Residuals	15	0.28	0.83	0.05	0.03	2.73	0.05	0.04	0.9	0.77	0.03	0.33	55.39
CV		1.06	1.92	4.94	2.74	11.65	4.27	2.19	7.70	1.72	5.02	7.88	10.12
CD (5%) (Mutant v/s Control)		1.35	2.34	0.57	0.42	4.26	0.56	0.5	2.44	2.26	0.47	1.48	19.16
CD (5%) Two Mutants (Different Blocks)		1.77	3.07	0.75	0.55	5.57	0.73	0.65	3.2	2.96	0.62	1.93	25.08

** at 1% level of significance, * at 5 % level of significance

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 6: Analysis of variance for growth and yield parameters in mutant families (M_1) of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	5	38.11 **	497.56 **	0.52 **	11.3 **	69.84**	1.21**	16.86 **	117.13 **	697.16 **	6.53 **	11.54 **	6680.28 **
Treatment (eliminating Blocks)	123	2.35 **	57.22 **	1.5 **	3.48 **	8.02**	3.13**	8.49 **	15.53 **	165.97 **	2.03 **	3.75 **	616.99 **
Check	3	17.15 **	42.52 **	5.59 **	7.88 **	14.76**	0.02	0.13 *	2.78	2.76 *	0.64 **	5.9 **	946.96 **
Mutants	119	2.43 **	76.57 **	1.43 **	3.83 **	10.73**	0.63 **	9.14 **	20.62 **	200.23 **	2.35 **	4.08 **	831.68 **
Mutants vs Check	1	137.9 **	284.07 **	0.01	4.82 **	0.39	18.64**	40.83 **	23.62 **	57.97 **	0.53**	8.87 **	1272.68 **
Residuals	15	0.28	0.83	0.05	0.03	2.60	0.05	0.04	0.9	0.77	0.03	0.33	45.88
CV		1.04	2.02	5.76	3.82	11.58	11.72	1.91	8.00	1.75	4.88	7.57	14.45
CD (5%) (Mutant v/s Control)		1.29	2.35	0.56	0.42	4.15	0.55	0.51	2.47	2.26	0.46	1.50	17.43
CD (5%) Two Mutants (Different Blocks)		1.75	3.10	0.75	0.55	5.44	0.72	0.65	3.2	3.04	0.71	1.95	22.83

** at 1% level of significance, * at 5 % level of significance

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 7: DMRT results for different treatments and characters among Arka Anamika and Arka Abhay mutant lines

Variety	Treatment	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TWT	YLD
ARKA ANAMIKA	30 kR	48.25^{C}	47.17^{AB}	3.82^{BC}	7.32^{B}	14.89^{AB}	7.05^{C}	13.90^{B}	52.67^{AB}	3.68^{A}	7.04^{A}	114.27^{B}
	50 kR	49.35^{B}	51.15^{A}	4.92^{AB}	15.47^{A}	17.05^{A}	9.12^{B}	17.39^{A}	55.10^{A}	4.00^{A}	7.35^{A}	231.80^{A}
	80 kR	51.32^{A}	43.10^{B}	5.05^{A}	4.27^{C}	11.76^{C}	10.27^{A}	7.55^{C}	46.40^{B}	3.24^{A}	7.05^{A}	89.95^{C}
	Control	48.76^{BC}	47.01^{AB}	3.62^{C}	7.20^{BC}	15.32^{AB}	8.75^{B}	11.66^{B}	48.23^{B}	3.64^{A}	7.40^{A}	102.48^{B}
	Mean	49.59	47.13	4.55	9.02	14.28	8.81	12.88	51.24	3.64	7.09	145.34
	CD (5%)	1.35	2.34	0.57	0.42	2.26	0.50	2.44	2.25	0.77	1.48	19.16
ARKA ABHAY	30 kR	49.27^{c}	44.40^{ab}	3.70^{b}	8.57^{ab}	14.25^{ab}	9.12^{b}	13.00^{a}	53.02^{ab}	4.00^{a}	7.44^{a}	105.72^{b}
	50 kR	51.37^{b}	50.47^{a}	4.35^{b}	13.90^{a}	16.60^{a}	10.97^{a}	15.40^{ab}	55.80^{a}	4.17^{a}	7.74^{a}	166.27^{a}
	80 kR	56.50^{a}	38.62^{b}	6.05^{a}	3.39^{b}	12.16^{c}	10.98^{a}	8.82^{c}	44.90^{b}	3.16^{a}	7.43^{a}	72.70^{c}
	Control	49.41^{c}	47.01^{a}	3.62^{b}	7.37^{ab}	15.32^{ab}	8.75^{c}	10.00^{bc}	48.23^{b}	3.64^{a}	7.40^{a}	92.70^{b}
	Mean	51.01	44.61	4.64	8.62	14.04	10.28	12.29	51.09	3.77	7.53	114.89
	CD (5%)	1.29	2.35	0.56	0.42	2.14	0.51	2.47	2.26	0.86	1.50	17.43

Mean with same superscript within a column do not differ at 5% level of significance.

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
NS: No. of Seeds
INT: No. of Internodes
SFW: Single Fruit Weight
YLD: Total Yield
SWT: Seed weight
TWT: Test Weight

also observed at a higher dose in both the varieties. Similar findings were also reported by Warghat *et al.* (2011) for number of fruits per plant, Jadhav *et al.* (2012) for plant height, fruit length, average fruit weight and total fruit yield and Hegazi and Hamideldin (2010) for number of seeds per plant, seed weight per fruit and test weight. Maryam and Kasimu (2016) also observed late flowering and maturity in okra as the doses of gamma radiation increase. On the other hand, traits such as number of branches per plant and number of internodes on the main stem were found more in the extreme dose of 80 kR. Hegazi and Hamideldin (2010) also noticed a similar trend in okra.

4.1.1.3 Genetic parameters of variability

Selection of elite mutant lines from a large base population is the most critical and challenging aspect of a plant improvement programme. The quality of the selection is mainly dependent upon the existence of genetic variability present within the mutant population under the selection. Comprehensive knowledge of the magnitude and direction of genetic variability and the range of heritability is essential to exercise the selection because the phenotypic selection is largely dependent upon the range of genetic diversity present in the population. The genetic advance (GA) and genetic gain (GG) are other principal selection parameters, which measures the differences between the mean genotypic values of the selected lines with that of its base population from which these were selected. Mean, range and other genetic parameters estimated for Arka Anamika and Arka Abhay are given in Tables 8 and 9, respectively.

4.1.1.3.1 Days to first flowering (DFF)

The number of days to first flowering in Arka Anamika mutant population has ranged from 45 to 53 days with an overall mean of 49.53 days, indicating significant variation present for the trait. Among the 120 mutant lines, the line AN-30-2 exhibited the early flowering (45 days) and the line AN-80-34 recorded the late flowering (53 days) compared to the parent, Anamika (46.80 days). The trait scored low phenotypic (2.75) and genotypic (2.54) coefficient of variations combined with high a heritability of 85.17 per cent and the genetic advance as per cent of mean scored was low (4.84).

Similarly, the Arka Abhay mutants scored a mean value of 51.02 days of first flowering with a range of 47 and 54 days. The parent Abhay has scored an average days of flowering of 49.42 days which is significantly low compared to the mean value of 120 mutant lines. The lines AB-30-8 and AB-80-27 has recorded the lowest and the highest number of days to first flowering which is 47 days and 54 days respectively. The amount of genotypic (2.87) and the phenotypic (3.05) coefficient of variation were very low, associated with a high value of broad sense heritability (88.63 %) and a low value of genetic advance as per cent of mean (5.58).

Table 8: Mean, range and genetic variability parameters for growth and yield traits in mutant families (M_1) of Arka Anamika

Trait	Arka Anamika Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	46.80	49.53	45.00	53.00	2.54	2.75	85.17	2.40	4.84
PH	50.23	47.19	31.13	78.98	11.67	19.85	58.83	7.73	16.38
NB	4.78	4.58	2.00	10.00	11.87	12.26	94.26	0.98	21.39
NF	8.57	9.29	2.00	14.00	40.64	40.73	91.59	7.77	83.63
FL	15.43	14.22	6.94	23.74	15.19	23.83	40.66	2.84	19.97
FW	17.20	17.30	14.10	25.60	2.82	8.86	32.15	0.75	4.33
INT	8.87	8.82	3.00	20.00	7.92	8.14	93.27	1.58	17.91
SFW	11.00	12.56	3.35	31.31	40.90	41.59	96.69	10.42	82.96
NS	49.62	51.31	21.00	105.00	30.34	30.39	59.68	14.07	27.42
SWT	3.42	3.65	1.63	9.85	41.21	41.51	98.52	1.08	29.58
TWT	7.13	7.24	2.40	12.14	21.00	22.48	87.23	2.93	40.47
YLD	102.92	145.94	9.04	229.3	30.21	38.27	79.67	28.33	19.41

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 9: Mean, range and genetic variability parameters for growth and yield traits in mutant families (M_1) of Arka Abhay

Trait	Arka Abhay Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	49.42	51.02	47.00	54.00	2.87	3.05	88.63	2.85	5.58
PH	47.02	44.62	26.76	78.98	19.50	19.61	57.92	9.86	22.09
NB	3.62	3.84	2.00	7.00	30.57	31.10	92.57	1.20	31.25
NF	7.39	8.33	2.00	10.00	44.97	45.13	96.30	7.44	89.31
FL	15.32	13.98	6.21	21.51	16.00	24.59	42.35	3.00	21.45
FW	17.50	18.20	13.10	25.60	2.85	8.85	31.24	0.80	4.39
INT	8.73	10.31	5.00	21.00	29.26	29.32	88.59	2.03	19.69
SFW	10.00	12.01	3.35	24.60	36.96	37.96	95.62	8.95	74.52
NS	48.23	50.41	34.00	116.00	28.02	28.07	89.62	8.92	17.69
SWT	3.65	4.77	1.61	9.12	40.46	40.75	85.56	2.01	42.13
TWT	7.40	7.48	3.86	12.72	25.92	27.03	91.96	3.84	51.33
YLD	92.23	115.81	7.39	258.29	23.33	29.85	64.36	23.51	20.30

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

4.1.1.3.2 Plant height (cm)

The overall average plant height of the M_1 mutant lines of Arka Anamika was 47.19 cm compared to the parent A. Anamika (50.23 cm). Lowest plant height was recorded by the line AN-80-37 (31.13 cm) and highest by AN-50-8 (78.98 cm). Moderate values of GCV (11.67), PCV (19.85), heritability (58.83 %) and genetic advance (16.38) as per cent of mean were noticed for this trait.

In case of Arka Abhay the mutant population has scored the lowest value of plant height was 26.76 cm (AB- 80- 15) and the highest was 78.98 cm (AB- 50- 30) with an average value of 44.62 cm compared to the parent Arka Abhay (47.02 cm). The genotypic and phenotypic coefficients were found moderate (19.50 and 19.61 respectively) with a moderate heritability (57.92 %) accompanied with a high genetic advance of 22.09 as per cent of mean.

4.1.1.3.3 Number of branches

The variation was recorded for this trait among the mutant lines of Arka Anamika was high with values ranging from 2.00 (AN-30-28) to 10.00 (AN-80-21). The mean value of mutants was 4.58 compared to parent Arka Anamika (4.78). A moderate variation in terms of genetic parameters such as PCV (12.26%) and GCV (11.87 %) along with a high heritability of 94.26 per cent and genetic advance (21.39) as per cent was observed.

With respect to Arka Abhay mutants, number of branches ranged has from 2.00 to 7.00 with a mean value of 3.84, whereas parent Arka Abhay mean was 3.62. The lowest number of branches was recorded in the line, AB-80-28 and maximum was recorded in AB-50-23. High genotypic and phenotypic coefficients of variations recorded were 30.57 and 31.10 per cent respectively. High value of Heritability (92.57 %) with an expected genetic advance of 31.25 per cent was observed for this character among the mutant lines.

4.1.1.3.4 Number of fruits

The average number of fruits per plant for parent Arka Anamika was 8.57, whereas its mutants mean was 9.29. The line AN-30.20 has recorded minimum number of fruits (2.00) and the line AN-50-26 (14.00) had the maximum number of fruits, indicating a range of 2.00 to 14.00 fruits per plant. The Genotypic and phenotypic coefficients of variation recorded were high (40.64 and 40.73 %, respectively) and the trait exhibited high heritability (91.59 %) associated with high per cent mean of genetic advance (83.63).

The Arka Abhay mutants population had an average number of fruits of 8.33per plant with a range of 2.00- 10.00 compared to the parent Arka Abhay (7.39). Among the mutant lines, AB- 80- 28 and AB- 50- 11has recorded minimum and

maximum number of fruits per plant. High estimates of GCV (44.97 %) and high PCV (45.13 %) with high heritability (96.30 %) and per cent mean genetic advance (89.31) were observed among the mutants for this trait.

4.1.1.3.5 Fruit length (cm)

The fruit length of Arka Anamika mutants varied from 6.94 cm to 23.74 cm with an average value of 14.22 cm compared to parent Arka Anamika 15.43 cm. The mutant line AN-80-29 has recorded the least fruit length (6.94 cm), while the maximum length of fruit was recorded in AN- 50-2 (23.74 cm). Moderate GCV (15.19) and high PCV (23.83) accompanied with moderate estimates of heritability (40.66 %) and per cent mean genetic advance (19.97) was recorded for this trait.

The overall mean of fruit length in Arka Abhay mutants was 13.98 cm with a wide range of 6.21 cm to 21.51 cm, whereas the parent mean was 15.32 cm. The shortest fruit length was produced in AB-80-2 line and longest was in AB-50-26. A moderate record of GCV (16.00 %) and high estimate of PCV (24.59 %) together with moderate heritability (42.35 %) and high per cent mean genetic advance (21.45) were noticed.

4.1.1.3.6 Fruit width (mm)

The width or the diameter of the fruits had a range from 14.10 mm to 25.60 mm with a mean value of 17.30 mm for Arka Anamika mutants and the parent has scored a mean of 17.20 mm. The mutant lines, AN-80-14 and AN-50-36 had the minimum and maximum width of the fruits, respectively. The Genotypic and phenotypic coefficients of variation were recorded as very low (2.82 and 8.86, respectively) with moderate heritability (32.15 %) and very low genetic advance as per cent of mean (4.33).

In case of mutants of Arka Abhay, the line AB-50-12 (13.10 mm) and AB-50-3 (25.60 mm) had scored minimum and maximum width of the fruits, respectively. The average estimate of this trait in the mutant population was 18.20 mm with that of the parent Arka Abhay (17.50 mm). The genotypic (2.85 %), phenotypic (8.85 %) coefficients of variation were observed as very low, with moderate heritability (31.24 %) and very low value of per cent mean genetic advance (4.39).

4.1.1.3.7 Number of internodes on the main stem

The number of internodes on the main stem of the mutant lines of Arka Anamika has ranged from 3.00 to 20.00 (AN-30-10 and AN-50-26, respectively) with an average number of 8.82. The parent Arka Anamika had an average value of 8.87 for this trait. Low GCV (7.92 %) and PCV (8.14 %) with 93.27 (high) per cent

heritability and 17.91 (moderate) per cent genetic advance as per cent of mean were recorded among the population.

The Arka Abhay mutants exhibited a mean number of 10.31, whereas its parent showed an average number of 8.73 internodes. Among the mutants, the linesAB-30-9and AB-50-28 has recorded minimum and maximum (5.00 and 21.00) number of internodes indicating a wide range of variations. High estimates of GCV and PCV (29.26 and 29.32%), high heritability of 88.59 per cent with moderate (19.69) per cent mean genetic advance were also exhibited by this trait.

4.1.1.3.8 Single fruit weight (g)

Significant variation among the mutant lines of Arka Anamika for the weight of single fruit was noticed. The weight of single okra fruits has ranged from 3.35 g in the mutant line AN-80-6 to 31.31 g in AN-50-23.The overall mean of 12.56 g was scored among the population compared to parent Arka Anamika (11.00g). The estimates of genetic parameters such as phenotypic and genotypic coefficients of variability (41.59 and 40.90, respectively), heritability (96.69 %) and per cent mean genetic advance (82.96) were very high for this trait.

Similarly, Arka Abhay mutants also had a larger variation for the character with a range of 3.35 g to 24.60g. The Parent Arka Abhay has scored an overall mean value of 10.00 compared to the mutant mean of 12.01 g. The line AB-80-25 had maximum weight of single fruit (24.60 g) whereas the line AB-30-40 recorded minimum weight (3.35 g). High GCV (36.96 %), PCV (37.79 %), heritability (95.62 %) and genetic advance of as per cent of mean (74.52) was exhibited by the character among the population.

4.1.1.3.9 Number of seeds per fruit

The overall mean obtained for total number of seeds per fruit in case of Arka Anamika mutants was 51.31 ranging from 21.00 (AN-80-32) to 105.00 (AN-30-37), whereas the parent had an average of 49.62 seeds per fruit. High estimates of genotypic (30.34 %), phenotypic (30.39 %) coefficients of variability with moderate heritability (59.68 %) and relatively high genetic advance as per cent of mean (27.42) were noticed for this character.

Alternatively, in Arka Abhay mutant lines, the line AB-30-5 (34.00) and AB-50-8 (116.00) has recorded the minimum and maximum number of seeds per fruit, respectively. The mean value for the trait among the mutant population was 50.41 compared to the parent Arka Abhay (48.23). The GCV (28.02 %) and PCV (28.07 %) values obtained were high coupled with high heritability of 89.62 per cent and a moderate per cent mean of genetic advance (17.69).

4.1.1.3.10 Weight of seeds per fruit (g)

The average weight of seeds per fruit in the parent Arka Anamika was 3.42 g, whereas its mutant population had an average of 3.65 g seed weight. The minimum (1.63 g) and maximum (9.85 g) weight of seeds per fruit was recorded in AN-30-11 and AN-50-11 lines respectively, indicating range of 1.63 to 9.85 g. The coefficient of variations at phenotypic and genotypic levels were high (41.21 and 41.51 per cent respectively). The trait scored high heritability of 98.52 per cent coupled with high genetic advance (29.58) as per cent of mean.

In case of Arka Abhay mutant population, the mean performance for weight of seeds per fruit was 4.77g and its parent had 3.65 g per fruit. The mutant line AB-30-5has recorded the lowest seed weight per fruit (1.61 g) and highest was in line AB-50-8 (9.12 g). High GCV (40.46) and PCV (40.75) combined with high estimates of heritability (85.56 %) and genetic advance as per cent of mean (42.13) were also observed for this trait.

4.1.1.3.11 Test weight (g)

The range of test weight in mutants of Arka Anamika was 2.40 to 12.14 with an overall mean of 7.24, compared to its parent Arka Anamika (7.13). Maximum test weight of seeds was observed in the line, AN-50-12 (2.40 g) and minimum was in AN-80-37 (12.14 g). The genotypic and phenotypic coefficients of variations noticed were comparatively high (21.00 and 22.48, respectively). The trait also recorded high heritability (87.23 %) associated with high per cent of mean genetic advance (40.47%).

The average weight of hundred seeds in Arka Anamika mutants was 7.48 g, ranging from 3.86 g in AB-80-22 to 12.72 g in the line AB-50-21. The parent Arka Abhay scored a mean value of 7.40 g for the trait. The genotypic and phenotypic coefficients of variation observed were high and values were 25.92 and 27.03 per cent respectively. High heritability (91.96 %) coupled with the high genetic advance as per cent mean (51.33) were also exhibited by the trait in the mutant population.

4.1.1.3.12 Total fruit yield per plant (g)

In the mutants of Arka Anamika, total fruit yield per plant was in a range of 9.04 to 229.30 g with an overall mean of 145.94 g compared to its parent (102.92 g). The mutant line AN-80.2 had minimum fruit yield per plant (9.04 g), contrary to this the line AN-50-24 (229.30 g) scored maximum for this trait. High GCV (30.21 %), PCV (38.27 %) and heritability (79.67 %) with moderate genetic advance as per cent of mean (19.41) were noticed for this character. Similarly, in case of Arka Abhay mutants, the overall mean for the total yield of fruits per plant was 115.81 g with a range of 7.39 g to 258.90 g, while its parental mean was 92.23 g. The maximum and minimum fruit yield was recorded in lines AB-80-5 and AB-50-31, respectively.

The phenotypic (29.85 %) and genotypic (23.33 %) coefficient of variations were found high accompanied with high heritability of 64.36 per cent and moderate genetic advance of 20.30 as per cent of mean.

High GCV and PCV coupled with high heritability and GAM were observed for traits such as number of fruits per plant, single fruit weight, seed weight and test weight in case of Arka Anamika mutants and number of branches per plant, number of fruits per plant, single fruit weight, seed weight and test weight for mutants of Arka Abhay. Similar observations were also furnished by Reddy and Dhaduk (2014) for number of branches per plant, test weight and Ashadevi *et al.* (2017) number of fruits per plant and fruit weight.

4.1.2 Observations in M_2 generation

4.1.2.1 Analysis of variance (ANOVA) for characters in M_2 generation.

The analysis of variance among 300 mutant lines of both Arka Anamika and Arka Abhay was performed for 13 quantitative traits and was presented in Tables 10 and 11, respectively. The results revealed that values of mean sum of squares within the blocks (eliminating treatments), within the treatments (eliminating blocks) and checks vs mutants were significant for yield and its twelve contributing traits, suggesting significant differences among 300 M_2 mutant lines of the both the varieties. Similar results were also reported by Maryam (2017), Amir *et al.* (2018) and Mohite and Gurav (2019) for different traits in gamma radiation induced mutants in okra.

4.1.2.2 Genetic parameters of variability

The parameters of genetic variability such as mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance as per cent of mean of yield and its 12 attributing traits among the M_2 mutant populations of Arka Anamika and Arka Abhay are furnished in the Tables 12 and 13, respectively.

4.1.2.2.1 Days to first flowering

The number of days to first flowering of the mutant lines of Arka Anamika has ranged from 44.00 days to 52.00 days with general mean value of 48.45 days. The GCV and PCV values were low (2.71 and 4.26, respectively) whereas the heritability in broad sense was moderate (49.23 %) coupled with low genetic advance as per cent of mean (4.66). In case of Arka Abhay mutants the values ranged between 45.00 and 54.00 with an average value of 49.70 days. The GCV (2.19) and PCV (2.81) were found low, heritability estimate was moderate (60.71%) associated with low genetic advance as per cent of mean (3.52).

Table 10: Analysis of variance for growth and yield parameters in M_2 mutant families of Arka Anamika variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	NR	SFW	NS	SWT	TWT	YLD
Block	11	17.06 **	445.48 **	8.37 **	73.71 **	68.55 **	0.3 **	62.48 **	0.38 **	391.38 **	3854.35 **	21.05 **	0.94 *	90201.33 **
Treatment	303	2.15 **	31.05 **	2.37 **	5.97 **	9.90 **	0.06 **	8.15 **	0.53 **	73.49 **	526.77 **	4.46 **	2.07 **	3190.57 **
Check	3	27.41 **	34.84 **	7.34 **	21.58 **	19.3 **	0.25 **	0.49	0.001	2.95 **	6.93 *	1.79 **	11.73 **	1602.01 **
Mutants	299	2.5 **	46.55 **	2.46 **	6.93 **	11.92 **	0.07 **	10.3 **	0.53 **	87.18 **	666.21 **	5.22 **	1.95 **	6164.01 **
Mutants vs Check	1	51.11**	270.82 **	49.13 **	480.87 **	118.63 **	1.01 **	72.44 **	4.78 **	490.82 **	2763.71 **	15.05 **	17.44 **	103155.48 **
Error	33	0.77	1.57	0.05	0.17	0.89	0.02	0.43	0.001	0.33	1.82	0.08	0.34	236.08
CV		1.81	2.42	4.68	5.85	5.92	8.58	6.68	0.001	3.87	2.41	6.40	7.92	14.46
CD(5%)(Mutant v/s Control)		2.07	2.97	0.53	0.99	2.24	0.37	1.55	0.001	1.36	3.2	0.67	1.39	36.38
CD (5%)Two Mutants Different Blocks)		2.82	4.03	0.72	1.34	3.04	0.5	2.1	0.001	1.85	4.34	0.91	1.89	49.43

** at 1% level of significance, * at 5 % level of significance

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 11: Analysis of variance for growth and yield parameters in M_2 mutant families of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	NR	SFW	NS	SWT	TWT	YLD
Block	11	23.39 **	387.16 **	7.03 **	70.89 **	84.17 **	0.14 **	35.79 **	0.94 **	260.39 **	1873.73 **	17.65 **	8.83 **	14798.22 **
Treatment	303	1.62 **	124.87 **	3.68 **	4.57 **	7.28 **	0.05 **	13.26 **	0.36 **	19.4 **	491.69 **	3.29 **	5.65 **	1063.40 **
Check	3	27.41 **	34.84 **	7.34 **	21.58 **	19.30 **	0.25 **	0.49	0.001	2.95 **	6.93 *	1.79 **	11.73 **	2866.59 **
Mutants	299	1.95 **	140.35 **	3.91 **	6.30 **	9.88 **	0.05 **	13.94 **	0.39 **	28.58 **	562.9 **	3.93 **	5.9 **	1587.66 **
Mutants vs Check	1	71.94 **	8.98 *	1.76 **	213.03 **	109.51 **	0.92 **	238.3 **	2.00 **	183.24 **	1234.71 **	8.96 **	8.34 **	872.88 **
Error	33	0.77	1.57	0.05	0.17	0.89	0.02	0.43	0.001	0.33	1.82	0.08	0.34	59.72
CV		1.77	2.55	5.56	6.78	5.94	8.61	6.10	0.001	4.20	2.52	6.58	7.74	11.70
CD(5%)(Mutant v/s Control)		2.08	3.00	0.53	1.01	2.31	0.39	1.54	0.001	1.35	3.22	0.69	1.40	18.30
CD (5%) Two Mutants (Different Blocks)		2.79	4.03	0.72	1.37	3.04	0.5	2.11	0.001	1.85	4.37	1.01	1.91	24.24

**** at 1% level of significance, * at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

4.1.2.2.2 Plant height

The range of plant height varied from 38.65 cm to 77.90 cm with an average value of 52.19 cm in case of Arka Anamika mutants. The genotypic (12.85) and phenotypic (13.07) coefficient of variation was found moderate together with high heritability (96.62 %) and moderate per cent genetic advance (20.11). However, the range was 23.76 cm to 98.83 cm with an average of 49.21 cm in case of Arka Abhay mutants. High estimates of GCV (23.94), PCV (24.07), heritability (98.88 %) and genetic advance as per cent of mean (49.11) were observed for this trait.

4.1.2.2.3 Number of branches per plant

The values with regard to number of branches per plant ranged between 2.00 to 11.00 and the average value was 4.93. High GCV (31.55), PCV (31.87), heritability (97.96 %) and GAM (64.50) were noticed among mutants of Arka Anamika. Similarly, the number ranged from 1.00 to 10.00 with an average of 5.45 in Arka Abhay mutants. High estimates of GCV (48.44), PCV (48.75) and heritability
(98.72 %) coupled with moderate genetic advance as per cent of mean (20.73) were calculated for this trait.

4.1.2.2.4 Number of fruits per plant

The trait number of fruits per plant has an overall mean of 13.57 ranging from 2.00 to 21.00 in Arka Anamika mutants. The genotypic (34.33) and phenotypic (34.77) coefficients of variation, heritability (97.48 %) and genetic advance as per cent mean (69.93) were recorded high among the population. Similarly, in case of mutants of Arka Abhay, the trait scored a mean value of 11.45 with a range of 1.00 to 17.00. The GCV (32.40), PCV (38.95), heritability (83.11 %) and GAM (78.07) estimate were high for this character.

4.1.2.2.5 Fruit length

The mutants of Arka Anamika recorded an average value of 16.18 cm with a range of 7.02 to 26.01 cm. High estimates of GCV (20.53) and PCV (27.66) coupled with high heritability (74.22 %) and genetic advance as per cent mean (40.72) were scored. The fruit length varied between 5.89 cm and 24.31 cm with an average of 16.11 cm in case of Arka Abhay mutants. The variability parameters such as GCV (18.60) and PCV (19.50) were moderate whereas heritability (90.96%) and genetic advance as per cent of mean (29.60) were high.

4.1.2.2.6 Fruit width

The overall mean of Arka Anamika mutants for the fruit width was 18.30 mm with a range of 12.50 to 26.40 mm. The genotypic (9.96) and phenotypic (16.99) coefficients of variation has low and moderate estimates respectively. The heritability

(58.62 %) and GAM (19.23) was moderate for this trait. Likewise, the value of fruit width ranged from 10.30 to 25.50 mm with an average of 18.20 mm in case of mutants of Arka Abhay. The GCV (8.73) was low, whereas other variability parameters such as phenotypic coefficient of variation (12.20), heritability (51.24 %) and genetic advance as per cent of mean (12.91) were observed as moderate.

4.1.2.2.7 Number of internodes on the main stem

Number of internodes on the main stem ranged from 3.00 to 19.00 with a mean value of 9.95 in Arka Anamika mutants. The variability parameters such as GCV (31.58), PCV (32.26), heritability (95.85 %) and GAM (45.72) were recorded as high. Similarly, the number of internodes had an average value of 11.01 with a range of 3.00 to 21.00 in mutants of Arka Abhay. High estimate of genotypic (30.38) and phenotypic (39.91) coefficients of variation, heritability (76.94 %) and genetic advance (67.84) as per cent of mean were noticed.

4.1.2.2.8 Number of ridges per fruit

The overall mean of number of ridges per fruit in mutants of Arka Anamika was 5.34 with a range of 5.00 to 9.00. High record of PCV (24.31), moderate GCV (13.68) and heritability (56.21 %) coupled with high range of GAM (28.27) were observed for this trait. In case of Arka Abhay mutants, the mean was 5.22 with a range of 5.00 to 9.00. Moderate values of GCV (12.01) and PCV (13.01), high heritability (98.20 %) together with high genetic advance as per cent of mean (24.71) were recorded for the trait.

4.1.2.2.9 Single fruit weight

Average weight of single fruits in the mutants of Arka Anamika was 17.29 g, ranging between 3.08 g and 25.88 g. The values of GCV (14.48) and PCV (28.02) were moderate and high respectively associated with moderate heritability (50.73 %) and high value of GAM (81.08). Similarly, the trait ranged from 1.79 g to 28.89 g with a mean of 13.97 g among the mutants of Arka Abhay. The parameters such as genotypic (38.06), phenotypic (38.28) coefficients of variation, heritability (98.84 %) and genetic advance as per cent of mean (78.02) were noticed as high.

4.1.2.2.10 Number of seeds per fruit

The Arka Anamika mutants had an average number of 57.00 seeds per fruit with a range of 15.00 to 146.00 seeds. High genotypic and phenotypic coefficients of variations were 42.22 and 45.28 per cent, respectively. Heritability of 92.73 per cent with an expected genetic advance of 58.07 per cent was observed for the trait. In respect to Arka Abhay mutants, the trait ranged from 17.00 to 154.00 with a mean value of 54.33. The GCV (43.60), PCV (43.67), heritability (99.68 %) and genetic advance as per cent of mean (51.59) observed were high.

Table 12: Mean, range and genetic variability parameters for growth and yield traits in M_2 mutant families of Arka Anamika

Trait	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean (GAM)
		Min	Max	GCV	PCV			
DFF	48.45	44.00	52.00	2.71	4.26	49.23	2.26	4.66
PH	52.19	38.65	77.90	12.85	13.07	96.62	10.50	20.11
NB	4.93	2.00	11.00	31.55	31.87	97.96	3.18	64.50
NF	13.57	2.00	21.00	34.33	34.77	97.48	9.49	69.93
FL	16.18	7.02	26.01	20.53	27.66	74.22	6.59	40.72
FW	18.30	12.50	26.40	9.96	16.99	58.62	3.52	19.23
INT	9.95	3.00	19.00	31.58	32.26	95.85	4.55	45.72
NR	5.34	5.00	9.00	13.68	24.31	56.21	1.51	28.27
SFW	17.29	3.08	25.88	14.48	28.02	50.73	14.02	81.08
NS	57.00	15.00	146.00	42.22	45.28	92.73	33.10	58.07
SWT	4.51	1.31	10.26	50.31	59.70	84.27	1.64	36.36
TWT	7.33	4.21	12.22	17.28	19.04	82.30	2.37	32.33
YLD	165.50	9.82	339.73	17.54	34.81	42.25	68.77	41.55

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 13: Mean, range and genetic variability parameters for growth and yield traits in M_2 mutant families of Arka Abhay

Trait	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean (GAM)
		Min	Max	GCV	PCV			
DFF	49.70	45.00	54.00	2.19	2.81	60.71	1.75	3.52
PH	49.21	23.76	98.83	23.94	24.07	98.88	24.17	49.11
NB	5.45	1.00	10.00	48.44	48.75	98.72	1.13	20.73
NF	11.45	1.00	17.00	32.40	38.95	83.11	8.94	78.07
FL	16.11	5.89	24.31	18.60	19.50	90.96	4.77	29.60
FW	18.20	10.30	25.50	8.73	12.20	51.24	2.35	12.91
INT	11.01	3.00	21.00	30.38	39.91	76.94	7.47	67.84
NR	5.22	5.00	9.00	12.01	13.01	98.20	1.29	24.71
SFW	13.97	1.79	28.89	38.06	38.28	98.84	10.90	78.02
NS	54.33	17.00	154.00	43.60	43.67	99.68	28.03	51.59
SWT	4.37	0.77	12.34	44.88	45.35	97.95	2.44	55.83
TWT	7.53	1.69	12.83	31.31	32.27	94.16	4.72	62.68
YLD	130.54	6.46	305.18	34.02	50.24	51.44	71.81	55.01

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

4.1.2.2.11 Weight of seeds per fruit

Weight of seeds per individual fruits among Arka Anamika ranged from 1.31 g to 10.26 g with an overall mean of 4.51 g. The high ranges of genotypic and phenotypic coefficients of variation were 50.31 and 59.70 per cent, respectively. This trait exhibited high heritability (84.27 %) with high per cent mean genetic advance (36.36).With respect to mutants of Arka Abhay, the trait had an average of 4.37 g with a range of 0.77 to 12.34 g. all the parameters such as GCV (44.88), PCV (45.35), heritability (97.95 %) and GAM (55.83) were scored as high.

4.1.2.2.12 Test weight

The overall mean of the trait was 7.33 g, ranging from 4.21 to 12.22 g among the mutants of Arka Anamika. Although the GCV (17.28) and PCV (19.04) were recorded as moderate, heritability (82.30 %) and genetic advance as per cent of mean (32.33) were high for the trait. Similarly, the range of this trait was 1.69 g to 12.83 g with a mean of 7.53 g among the mutants of Arka Abhay. Four of the genetic parameters computed such as GCV (31.31), PCV (32.27), heritability (94.16 %) and genetic advance as per cent of mean (62.68) were noticed as high.

4.1.2.2.13 Fruit yield per plant

Significant variation among the mutants of Arka Anamika for the total fruit yield per plant was observed. The total yield ranged between 9.82 g to 339.73 g with a mean value of 165.50 g. Moderate estimate of GCV (17.54) and high estimate of PCV (34.81) coupled with moderate heritability (42.25 %) and high genetic advance as per cent of mean (41.55) were observed for this trait. Among the mutants of Arka Abhay the trait ranged from 6.46 g to 305.18 g with an overall mean of 130.54 g. The GCV and PCV estimate were high (34.02 and 50.24, respectively), whereas the heritability (51.44 %) was moderate combined with high GAM (55.01).

From the results it was clear that the mean values of major yield contributing traits such as number of branches per plant, number of fruits per plant, fruit length, single fruit weight, number of seeds per fruit, seed weight per fruit and test weight has increased in the M_2 generation compared to the M_1 generation for both the varieties. These results were further confirmed with that of Hegazi and Hamideldin (2010) and Elangovan and Pavadai (2015) in okra.

In present investigation, the M_2 population has exhibited increased population variance and range of characters over the M_1 generation and untreated control for all the traits under consideration. However, the range of characters has varied with respect to the generation, variety and dose of the gamma radiation. These findings were also supported by Jadhav *et al.* (2012) in okra mutant lines induced by gamma radiation. Singh *et al.* (1998) suggested that the occurrence of polygenic mutations with equal or unequal frequencies towards positive and negative directions can be the

reason for altered range of characters. The highest range observed for plant height, total fruit yield, length of the fruits, days to first flowering, fruit weight, number of seeds per fruit and number of internodes on the main stem in the M_1 and M_2 generations, suggesting that these traits can be improved by simple selection. These results were confirmed with the findings of Guddadamath *et al.* (2011) in okra for plant height, length and weight of fruits and total fruit yield per plant, Jadhav *et al.* (2012) for days to first flowering and Syfullah *et al.* (2018) for number of seeds per fruit. It was observed that the range of most of the traits has increased in the M_2 generation compared to the M_1 generation. These result was in agreement with that of Warghat *et al.* (2011) and Elangovan and Pavadai (2015) in okra. Taking in to consideration of the results, Jadhav *et al.* (2012) suggested that selection for economically important traits could be made in M_2 generation as wide variability is available which decreases when the population gets advanced to $M_3$and next segregating generations.

High GCV and PCV estimates were observed for traits such as number of branches per plant, number of fruits per plant, fruit length, number of internodes on the main stem and number of seeds in mutants of Arka Anamika whereas, in case of Arka Abhay, other traits such as plant height, single fruit weight and total yield also exhibited high GCV and PCV in the M_2 generation of gamma induced mutants. Similar observations were also furnished by Reddy and Dhaduk (2014) for number of branches per plant, number of internodes on main stem, fruit length and fruit yield per plant, Ashadevi *et al.* (2017) for plant height, number of fruits per plant, fruit weight and number of seeds per fruit. Days to first flowering in the mutants of both the varieties exhibited lower values of GCV and PCV whereas, plant height, fruit width, number of ridges per fruit, single fruit weight, and test weight recorded moderate estimates of coefficients of variability in mutants of Arka Anamika. Likewise, fruit width and number of ridges per fruit showed moderate values of variability parameters in Arka Abhay mutants. Sravanthi (2016) also found moderate estimates of GCV and PCV for plant height, fruit width and number of ridges per fruit. The total fruit yield per plant has recorded highest difference between the values of GCV and PCV indicating the predominance of environment in determining the trait in both the varieties. Das *et al.* (2012) and Archana *et al.* (2015) also mentioned similar results.

High heritability coupled with high GAM was observed for the traits *viz.*, number of branches per plant, number of fruits per plant, fruit length, number of seeds per fruit, weight of seeds per fruit and test weight in case of M_2 mutant population of Arka Anamika and Arka Abhay. Nwangburuka *et al.* (2012) noticed similar results in okra for fruit length, number of branches per plant and days to first flowering, Khajuria *et al.* (2015) for weight of seeds per fruit and number of fruits per plant, Rathod *et al.* (2019) for fruit length and number of fruits. The lowest genetic advance

combined with moderate heritability was observed for days to first flowering followed by fruit width. The influence of non- additive gene action and considerable contribution of environment towards the expression of these characters are reasoned for this observation. Works on okra by Jindal *et al.,* (2010) and Das *et al.,* (2012) also showed parallel observations for fruit diameter.

4.1.2.3 Character association studies for yield and yield contributing characters in the M_2 mutant population

The phenotypic correlations between total fruit yield and eleven yield governing traits among the M_2 mutant lines of Arka Anamika and Arka Abhay were calculated to understand the nature and degree of association existing among them. The results are presented in Tables 14 and 15 respectively. Yield is a complex and multigenic trait and most crucial target in any crop breeding. Knowledge of correlation effect of different yield contributing traits with yield and their association among themselves is considered to be of paramount importance for the direct selection of easily observable traits in any crop.

4.1.2.3.1Fruit yield

Fruit yield per plant in the M_2 mutant populations of both Arka Anamika and Arka Abhay showed significant positive association with almost all the traits except for days to first flowering and test weight. Similar observations of significant positive correlation for number of fruits per plant and single fruit weight with the total yield were also observed by Yadav *et al.* (2010), Adiger *et al.* (2011), Kumar *et al.* (2012), Jagan *et al.* (2013), Archana *et al.* (2015), Deepanshu and Shamad (2017), Raval *et al*. (2018), Dixit *et al*. (2019) and Ashraf *et al.* (2020). The days to first flowering exhibited a non- significant negative correlation with the yield whereas the trait test weight recorded a positive but non- significant correlation with yield in the mutant populations of both the varieties. Singh *et al.,* (2006) and Das *et al.* (2012) also reported negative correlation of days to first flowering with fruit yield.

4.1.2.3.2 Days to first flowering

Days to first flowering showed positive significant correlation with number of branches per plant (0.2044),number of fruits per plant (0.2719), fruit width (0.3236) and number of internodes on the main stem (0.2930) whereas a significant negative correlation was observed for fruit length (-0.2315) and single fruit weight (-0.2813) among the M_2 population of Arka Anamika. Similarly, in case of mutants of Arka Abhay, a positive significant correlation was observed for number of fruits (0.2703) and number of internodes on the main stem (0.3659) and a significant negative correlation was exhibited by plant height (-0.2904) and single fruit weight (-0.2418). The mutant population of Arka Anamika and Arka Abhay had a negative but a non-significant association with the total fruit yield (-0.1442 and -0.1403, respectively).

Table 14: Phenotypic correlation for yield and yield attributing characters in M_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
DFF	1	-0.1403	0.2044*	0.2719**	-0.2315**	0.3236**	0.2930**	-0.2813**	-0.1430	-0.0924	0.0147	-0.1442
PH		1	0.2116*	0.0074	0.2395**	-0.0190	0.0133	0.3367**	0.0682	0.0320	-0.0638	0.3165**
NB			1	0.4549**	-0.0450	0.1767*	0.3312**	-0.1053	0.0260	-0.0667	-0.1781*	0.1884*
NF				1	-0.1370	0.3113**	0.8120**	-0.0788	-0.0012	-0.2494**	-0.1373	0.6277**
FL					1	0.0365	-0.2416**	0.3729**	0.2594**	0.1764*	-0.0154	0.2462**
FW						1	-0.0270	0.1321	0.1917*	0.1037	-0.1461	0.1538*
INT							1	-0.1263	-0.1018	-0.0803	-0.0140	0.5130**
SFW								1	0.1932*	0.1953*	0.2628**	0.5240**
NS									1	0.8056**	-0.0197	0.1860**
SWT										1	0.5305**	0.2353**
TWT											1	0.0183
YLD												1

**** = Highly significant at 1 %** *** = Significant at 5 %**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 15: Phenotypic correlation for yield and yield attributing characters in M_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
DFF	1	-0.2904**	0.1097	0.2703**	-0.0914	-0.0031	0.3659**	-0.2418**	-0.1470	-0.1425	-0.0699	-0.1403
PH		1	0.3710**	0.0552	0.3285**	-0.0847	0.0370	0.2299**	0.2678**	0.2323**	0.0781	0.1764*
NB			1	0.3265**	0.1915*	0.0808	0.2759**	-0.1972*	0.1403	0.1253	0.0231	0.1964*
NF				1	0.0483	0.2059*	0.6771**	-0.2399**	-0.0552	-0.0537	0.0157	0.5351**
FL					1	-0.0228	0.0173	0.2462**	0.3003**	0.2771**	0.2843**	0.2626**
FW						1	0.1074	-0.0195	0.1830*	0.2281**	0.1183	0.1634*
INT							1	-0.1687*	-0.0219	-0.0544	-0.0221	0.4662**
SFW								1	0.2497**	0.2549**	0.3102**	0.3983**
NS									1	0.7162**	0.1819*	0.1959*
SWT										1	0.6746**	0.1911*
TWT											1	0.0832
YLD												1

**** = Highly significant at 1 %** *** = Significant at 5 %**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

4.1.2.3.3 Plant height

The trait had a significant positive correlation with various traits like fruit yield (0.3165), number branches per plant (0.2116), fruit length (0.2395) and single fruit weight (0.3367) in case of Arka Anamika mutants. Similarly, the mutants of Arka Abhay also recorded a positive significant correlation with fruit yield (0.1764), number of branches per plant (0.3710), fruit length (0.3285), single fruit weight (0.2299), number of seeds per fruit (0.2678) and weight of seeds per fruit (0.2323). Both the mutant population had a negative but non-significant correlation of plant height with the fruit width.

4.1.2.3.4 Number of branches per plant

Significant positive correlation was observed in number of branches per plant with yield (0.1184), days to first flowering (0.2044), plant height (0.2116), number of fruits (0.4549), fruit width (0.1767) and number of internodes on the main stem (0.3312) in case of Arka Anamika mutant lines. The trait test weight (-0.1781) has exhibited negative and significant correlation with the trait. In case of Arka Abhay mutants, fruit yield (0.1964), plant height (0.3710), number fruits per plant (0.3265), fruit length (0.1915) and number of internodes on the main stem (0.2759) had showed significant and positive correlation. Single fruit weight was the trait which exhibited significant negative correlation (-0.1972) with number of branches per plant.

4.1.2.3.5 Number of fruits per plant

The number of fruits per plant scored significant positive correlation in Arka Anamika mutants with fruit yield (0.6277), days to first flowering (0.2719), number of branches per plant (0.4549),fruit width (0.3113) and number of internodes on the main stem (0.8120) whereas weight of seeds per plant (-0.2494) had a negative and significant correlation with the trait. Similarly, in case of Arka Abhay mutants, the trait exhibited positive and significant association with fruit yield (0.5351), days to first flowering (0.2703), number of branches per plant (0.3265), fruit width (0.2059) and number of internodes on the main stem (0.6771). Single fruit weight negatively and significantly was correlated (-0.2399) with the number of fruits per plant.

4.1.2.3.6 Fruit length

In Arka Anamika mutants fruit length showed significant positive correlation with fruit yield (0.2462), plant height (0.2395), single fruit weight (0.3729), number of seeds per fruit (0.2594) and weight of seeds per fruit (0.1764) although a negative significant correlation was observed for days to first flowering (-0.2315) and number of internodes on the main stem (-0.2416). Fruit yield (0.2626), plant height (0.3285), number of branches per plant (0.1915), single fruit weight (0.2462), number of seeds per fruit (0.3003), weight of seeds per fruit (0.2771) and test weight (0.2843) were the

characters which showed significant positive correlation with fruit length in case of Arka Abhay mutants.

4.1.2.3.7 Fruit width

Phenotypic correlation of Arka Anamika mutants for this trait was positively significant with fruit yield (0.1538), days to first flowering (0.3236), number of branches per plant (0.1767), number of fruits per plant (0.3113) and number of seeds per fruit (0.1917). Likewise, in Arka Abhay mutants, the traits fruit yield (0.1634), number of fruit per plant (0.2059), number of seeds per fruit (0.1830) and weight of seeds per fruit (0.2281) recorded significant and positive correlation with fruit width.

4.1.2.3.8 Number of internodes on the main stem

The number of internodes on the main stem recorded significant positive correlation in Arka Anamika mutants with fruit yield (0.5130), days to first flowering (0.2930), number of branches per plant (0.3312) and number of fruits per plant (0.8120) while a significant negative correlation was observed for fruit length (-0.2416). In case of Arka Abhay mutant population, a positive and significant association was observed with fruit yield (0.4662), days to first flowering (0.3659), number of branches per plant (0.2759) and number of fruit per plant (0.6771). Weight of single fruit (-0.1687) recorded a negative but significant correlation with the trait.

4.1.2.3.9 Single fruit weight

Positive and significant phenotypic correlation of this trait among the mutants of Arka Anamika was noticed for fruit yield (0.5240), plant height (0.3367), fruit length (0.3729), number of seeds per fruit (0.1932), weight of seeds per fruit (0.1953) and test weight (0.2628). Significant but a negative correlation was observed for days to first flowering (-0.2813) among the population. Correspondingly in the mutant population of Arka Abhay positive and significant correlation was observed for fruit yield (0.3983), plant height (0.2299), fruit length (0.2462), number of seeds per fruit (0.2497), weight of seeds per fruit (0.2549) and test weight (0.3102). Negative significant correlation was observed for days to first flowering (-0.2418), number of branches per plant (-0.1972), number of fruits per plant (-0.2399) and number of internodes on the main stem (-0.1687).

4.1.2.3.10 Number of seeds per fruit

Number of seeds per fruit expressed significant and positive association with fruit yield (0.1860), fruit length (0.2594), fruit width (0.1917) and weight of seeds per fruit (0.8056) in case of mutants of Arka Anamika. Likewise, mutants of Arka Abhay has exhibited positive significant correlation with fruit yield (0.1959), plant height (0.2678), fruit length (0.3003), fruit width (0.1830), single fruit weight (0.2497) seed weight (0.7162) and test weight (0.1819).

4.1.2.3.11 Weight of seeds per fruit

A positive and significant correlation among the mutant population of Arka Anamika was recorded for fruit yield (0.2353), length of the fruit (0.1764), single fruit weight (0.1953), number of seeds per fruit (0.8056) and test weight (0.5305) while number of fruits per plant (-0.2494) has shown a significant negative correlation with the trait. Characters such as fruit yield (0.1911), plant height (0.2323), fruit length (0.2771), fruit width (0.2281), single fruit weight (0.2549), number of seeds per fruit (0.7162) and test weight (0.6746) recorded significant positive correlation among mutants of Arka Abhay.

4.1.2.3.12 Test weight

In Arka Anamika mutant population, weight of hundred seeds was found to have significant positive correlation with single fruit weight (0.2628) and weight of seeds per fruit (0.5305) and the negative significant correlation was observed for number of branches per plant (-0.1781). Positive but non- significant association of test weight with yield (0.0183) was observed. Identically mutants of Arka Abhay also showed a positive but non- significant correlation (0.0832) with the yield. Fruit length (0.2843), single fruit length (0.3102), number of seeds per fruit (0.1819) and weight of seeds per fruit (0.6746) were the traits exhibited positive association with the test weight.

4.1.2.4 Path coefficient analysis

The association of various component characters among themselves and with yield is very crucial for formulating an efficient basis of selection for fruit yield. Correlation studies together with path analysis provide a better insight in to the relationship of different traits with the yield. The observed correlation coefficients are partitioned into direct and indirect effects using path coefficient analysis. The results of path coefficient analysis for 11independent characters with fruit yield are presented in Tables 16 and 17 for Arka Anamika and Arka Abhay mutant populations, respectively.

4.1.2.4.1 Direct effect of yield attributing traits on the fruit yield

Path coefficient analysis among M_2 mutant population of Arka Anamika revealed that the trait number of fruits per plant recorded the highest positive direct effect (0.5161) on yield followed by single fruit weight (0.4935) and seed weight per plant (0.2250). Plant height (0.1378), fruit length (0.0032), number of internodes on the main stem (0.0615) and number of seeds per fruit (0.2063) were the traits which showed direct positive effect on yield. Alternatively, a negative direct effect was exhibited by days to first flowering (-0.1660), number of branches per plant (-0.0763), fruit width (-0.0608) and test weight (-0.0850).

Table 16: Phenotypic path of different yield components on fruit yield in M_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT
DFF	**-0.1660**	-0.0193	-0.0153	-0.1373	-0.0007	-0.0195	0.0178	-0.1382	0.0289	-0.0702	-0.0008
PH	0.0352	**0.1378**	0.0116	0.0072	0.0008	0.0012	0.1406	0.1018	-0.0144	0.0067	0.0051
NB	-0.0332	0.0289	**-0.0763**	0.2522	-0.0001	-0.0109	0.0203	-0.0543	-0.0062	-0.0557	0.0153
NF	-0.0448	0.0014	0.0683	**0.5161**	-0.0005	-0.0189	0.1499	-0.0795	0.000	-0.0812	0.0119
FL	0.0382	0.0331	0.0031	-0.1272	**0.0032**	-0.0024	-0.0148	0.1826	-0.0124	0.018	0.0017
FW	-0.0331	-0.0028	-0.0137	0.2020	0.0001	**-0.0608**	-0.0018	0.0342	-0.0392	0.0225	0.0127
INT	-0.0242	0.0114	0.1252	0.4100	-0.0008	0.0018	**0.0615**	-0.0642	0.0206	-0.0918	0.0008
SFW	0.0465	0.0469	0.0684	-0.0973	0.1712	0.1079	0.0908	**0.4935**	-0.0206	0.0225	-0.0051
NS	0.0232	0.0096	-0.0023	0.0000	0.0002	0.0656	-0.0062	0.0494	**0.2063**	0.1422	0.0017
SWT	0.0149	0.0741	0.0053	-0.0358	0.0003	0.0791	0.0549	0.0494	-0.1671	**0.2250**	-0.0450
TWT	-0.0014	-0.0083	0.0137	-0.1192	0.0601	0.0091	-0.0006	0.0296	0.0041	0.1192	**-0.0850**
r value	-0.1441	0.3165**	0.1884**	0.6277**	0.2462**	0.1538**	0.5130**	0.5240**	0.1860**	0.2353**	0.0183

Residual value: 0.2142

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Table 17: Phenotypic path of different yield components on fruit yield in M_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT
DFF	**-0.2991**	0.0369	0.0068	-0.3459	-0.0001	0.0000	0.1064	-0.1617	-0.1460	0.0622	-0.1212
PH	0.0867	**-0.1272**	0.0228	0.0324	0.0003	0.1023	0.0115	0.0262	0.0127	0.1021	-0.0743
NB	-0.0329	-0.0471	**0.0618**	0.2083	0.0002	-0.0023	0.0805	-0.1297	0.0429	-0.0577	0.0061
NF	-0.0808	-0.0076	0.0204	**0.5503**	0.0122	-0.0060	0.1955	-0.1307	-0.1184	0.0222	0.0061
FL	0.0269	-0.0420	0.0517	0.0270	**0.0010**	0.0006	0.0057	0.1371	0.0219	0.1243	-0.1443
FW	0.0000	0.0102	0.0049	0.1135	0.0140	**-0.0286**	0.0316	-0.0811	0.0052	0.0021	0.0364
INT	-0.0107	-0.0051	0.0173	0.3674	0.1510	-0.0032	**0.2875**	-0.0933	-0.2261	0.0222	-0.0761
SFW	0.0718	-0.0292	-0.0124	-0.1297	0.0732	0.0006	-0.0489	**0.5486**	0.0766	-0.1110	0.0334
NS	0.0449	-0.0343	0.0086	-0.0324	0.0103	0.0852	-0.0057	0.0971	**0.3064**	-0.1197	0.0000
SWT	0.0419	-0.0292	0.0080	-0.1577	0.0003	0.0066	-0.1844	0.1371	0.2206	**0.4440**	0.2033
TWT	0.0209	-0.0102	0.0012	-0.0908	0.0001	-0.0034	-0.0057	0.0603	0.0000	-0.2975	**0.2135**
r value	-0.1403	0.1764**	0.1964**	0.5351**	0.2626**	0.1634**	0.4663**	0.3980**	0.1958**	0.1911**	0.0830

Residual value: 0.3121

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield

Similarly, in case of Arka Abhay mutant lines, number of fruits per plant had the highest positive effect on total fruit yield (0.5503) preceded by single fruit weight (0.5486) and weight of seeds per fruit (0.4440). Number of branches per plant (0.0618), fruit length (0.0010), number of internodes on the main stem (0.2875), number of seeds per fruit (0.3064) and test weight (0.2135) were the other traits recorded for positive direct effect. On the other hand, characters such as days to first flowering (-0.2991), plant height (-0.1272) and fruit width (-0.0286) had displayed direct but negative effect on total yield of fruit.

The results indicated that the trait number of fruits per plant recorded the highest positive direct effect on yield followed by single fruit weight and seed weight per plant. Thus it can be concluded that these characters should be relied upon and given prime importance for the selection of genotypes for better yield. Chaukhande *et al.* (2011) and Das *et al.,* (2012) also noticed similar findings of direct effects of number of fruits per plant and fruit weight on fruit yield per plant, Mohammed *et al.* (2020) for seed yield per fruit and number of fruits per plant and Sujata *et al.* (2019) for average fruit weight. On the other hand, negative direct effect on fruit yield by days to 50 per cent flowering and fruit diameter was reported by Ramya and Kumar (2009) and Chaukhande *et al.* (2011) and Rana *et al.* (2020) for number of branches per plant.

4.1.2.4.2 Indirect effect of yield attributing traits on the fruit yield

The highest indirect and positive effect on fruit yield per plant among the mutants of Arka Anamika was scored by number of internodes on the main stem (0.4100) and number of branches per plant (0.2522) *via* number of fruits per plant. However, the highest negative indirect effect on fruit yield was exhibited by weight of seeds per fruit via number of seeds per fruit (-0.1671) followed by single fruit weight *via* days to first flowering (-0.1382).

Likewise, among the mutants of Arka Abhay, the positive indirect effects were indicated by number of internodes on the main stem *via* number of fruits (0.3674), weight of seeds per fruits *via* number of seeds per fruit (0.2206) and number of branches per plant *via* number of fruits (0.2083). Nevertheless, high but negative indirect effect of days to first flowering *via* number of fruits per plant (-0.3459) was also observed among the population. Similar observations were also noticed by Jagan *et al.* (2013) for number of branches per plant and Pithiya *et al.* (2017) for number of fruits per plant and number of branches per plant.

4.1.2.5 Identification of desirable mutants

Large scale variation could be observed among the M_2 mutant population of Arka Anamika and Arka Abhay induced by gamma radiation of different doses. Major polygenic traits such as days to first flowering, plant height, number of branches per plant and number of internodes on the main stem, number of fruits per

plant, fruit length, single fruit weight and the total fruit weight per plant varied significantly among the treatments compared to their parent variety. Based on the mean performance of the lines for these traits, superior ones were selected and forwarded to the third generation (M_3).

Among the 300 M_2 lines of Arka Anamika, 55.34 per cent of them showed higher performance compared to the average performance of parent (91.29 g) for the total fruit yield per plant. Fifty three lines among 300 mutant lines (17.67 %) were early flowering mutants in comparison to the check (48 days). Out of which ten lines were reasonably higher yielding compared to the Arka Anamika composing 3.33 per cent of the total population (Figure 1). In case of number of fruits per plant, 64.67 per cent of the total lines exhibited superior potential whereas, 59.34 per cent were superior for fruit length and 50.66 % for single fruit weight.

On the other hand, 60.33 per cent of the total 300 lines of Arka Abhay displayed better yielding ability compared to their parent. 23.33 per cent of the population (70 lines) were early flowering out of which twelve lines (4.00 %) were yielding remarkably (Figure 1). In the mutant population, 65.66 per cent of them were better performing in terms of number of fruits per plants, 51.33 per cent of them were satisfactory for the fruit length and 50.33 per cent of them were good in terms of weight of single fruits. From both the populations, accounting other important traits as well, top fifteen superior mutant lines (5 % of the total population) each were selected and listed in Tables 18 and 19.

From the mutant lines of Arka Anamika, the line, AN-50-10 was early flowering mutant with highest yield performance (375.50 g) and also found superior for other traits like number of fruits (21.00), fruit length (19.00 cm), single fruit weight (22.50 g), number of branches (6.00) and internodes (10.00). Two other lines, AN-30-21, and AN-50-13 were also early flowering types (45 days each) with remarkably significant fruit yield (218.00 g and 166.25 g) compared to the parent (91.29 g). The line AN-50-47 also exhibited higher fruit yield (323.20 g) and other yield determining characters suggesting to be other superior line among the population.

In case of Arka Abhay mutant population, the line AB-50-95 was the highest fruit yielder (327.10 g) which is also identified to flower earlier (47.00 days) than the control (49.00 days). The number of fruits (17.00), fruit length (20.00 cm), single fruit weight (19.30 g), number of branches (4.00) and internodes (14.00) were also recorded to be high in the line. Other lines *viz*., AB-50-21 and AB-50-82 were also early flowering mutants (48 and 47 days, respectively) with higher fruit yield (190.00 g and 145.40 g) and other yield parameters. Line, AB-30-35 recoded 270.00 g of total fruit weight per plant among the population, confirming the potential of the line.

Table18: Top fifteen lines identified in M_2 population of Arka Anamika variety

Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TWT	YLD
1	Control	48.00	52.19	4.93	8.57	15.18	8.50	17.20	50.00	3.51	7.13	91.29
2	AN-30-21	45.00	51.50	5.00	10.00	20.00	8.00	30.00	82.00	8.71	10.37	218.00
3	AN-30-74	46.00	57.00	7.00	12.00	17.50	4.00	17.00	65.00	5.79	7.89	192.00
4	AN-50-10	46.00	52.00	6.00	21.00	19.00	10.00	22.50	56.00	3.68	6.57	375.50
5	AN-50-13	45.00	70.50	7.00	11.00	20.50	11.00	25.90	82.00	8.00	9.76	166.25
6	AN-50-14	46.00	69.00	7.00	11.00	21.00	10.00	26.20	80.00	8.51	10.11	171.00
7	AN-50-23	50.00	68.00	7.00	15.00	21.50	7.00	22.00	95.00	8.46	8.91	307.30
8	AN-50-41	50.00	59.00	6.00	12.00	24.50	15.00	35.20	146.00	10.27	7.67	283.60
9	AN-50-43	50.00	62.00	7.00	14.00	18.50	8.00	19.00	82.00	6.58	8.02	294.00
10	AN-50-47	50.00	70.00	7.00	14.00	21.00	8.00	27.00	79.00	8.39	12.62	323.20
11	AN-50-79	50.00	51.50	5.00	12.00	19.00	9.00	26.50	87.00	7.35	8.45	307.00
12	AN-50-81	46.00	52.00	6.00	12.00	20.00	10.00	27.00	98.00	8.58	8.76	276.00
13	AN-50-82	46.00	48.50	6.00	13.00	19.50	11.00	23.50	76.00	7.68	10.11	297.20
14	AN-50-87	46.00	60.50	7.00	11.00	22.50	10.00	30.00	104.00	9.00	8.65	156.35
15	AN-50-88	46.00	59.00	5.00	11.00	24.00	9.00	34.00	125.00	9.21	7.37	251.50
16	AN-50-96	46.00	49.00	7.00	10.00	20.50	16.00	29.80	85.00	8.11	9.54	146.25
CD		2.07	2.97	0.53	0.99	2.24	1.55	1.36	3.20	0.67	1.39	36.38

DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit length (cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g), YLD=Yield *per* plant

Table 19: Top fifteen lines identified in M_2 population of Arka Abhay variety

Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TWT	YLD
1	Control	49.00	48.12	3.50	7.40	15.55	8.52	11.59	48.00	3.72	7.50	87.54
2	AB-30-6	50.00	65.50	6.00	10.00	17.30	12.00	17.10	54.00	4.32	7.80	158.80
3	AB-30-30	48.00	70.25	7.00	10.00	18.00	9.00	18.40	62.00	4.96	8.20	139.20
4	AB-30-35	49.00	57.00	5.00	15.00	17.50	14.00	16.80	54.00	4.32	7.98	270.00
5	AB-50-9	49.00	52.00	5.00	11.00	17.40	15.00	14.00	52.00	4.37	6.33	131.60
6	AB-50-21	48.00	70.50	7.00	14.00	21.00	15.00	18.00	52.00	2.69	4.88	190.00
7	AB-50-22	49.00	55.60	6.00	12.00	15.60	17.00	13.90	40.00	3.36	4.59	141.00
8	AB-50-50	49.00	44.60	4.00	9.00	19.00	11.00	19.00	70.00	5.88	9.33	135.50
9	AB50-55	50.00	68.90	6.00	11.00	13.00	9.00	19.50	32.00	2.69	6.46	152.50
10	AB50-57	49.00	49.80	5.00	10.00	18.00	12.00	16.00	62.00	5.21	9.97	150.00
11	AB-50-61	50.00	79.80	7.00	12.00	18.20	17.00	20.50	35.00	2.92	7.70	132.60
12	AB-50-82	47.00	40.50	3.00	11.00	17.50	16.00	18.50	51.00	4.28	8.54	145.40
13	AB-50-86	49.00	45.20	4.00	10.00	18.00	14.00	16.60	58.00	4.87	8.89	138.20
14	AB-50-87	50.00	44.50	5.00	11.00	19.50	8.00	19.20	74.00	6.22	9.57	160.50
15	AB-50-95	47.00	67.50	4.00	17.00	20.00	14.00	19.30	52.00	5.53	9.96	327.10
16	AB-80-30	51.00	65.00	8.00	13.00	13.50	18.00	16.80	47.00	3.57	6.02	154.50
CD		2.08	3.00	0.53	1.01	2.31	1.54	1.35	3.22	0.69	1.40	24.24

DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit lengt
(cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g)
YLD=Yield *per* plant

Mutation breeding has been widely practiced to enhance the crop yield, quality traits, biotic and abiotic stress resistance and produced germplasm with novel, desired traits (Maluszynski *et al.,* 1995). Reports of many productive mutants were developed and released globally in many crop plants (Ahloowalia *et al.* 2004).Induced mutation is highly effective in enhancing natural genetic resources and has been used in developing improved cultivars of vegetables, cereals, fruits and other crops (Lee *et al.,* 2002). There are reports in okra where mutants have been isolated through mutation breeding. The examples of such mutant varieties are Punjab-8, Pusa Swani, and Parbhani Tillu (Dhankhar *et al.,* 2009). Gamma rays are used to improve characters and productivity of many crops like potato, cowpea, maize and rice (Singh and Datta, 2010).

4.2 Experimental Studies in okra using epigenetic mutagens

4.2.1 Observation in S_1 generation using Sodium butyrate (SB)

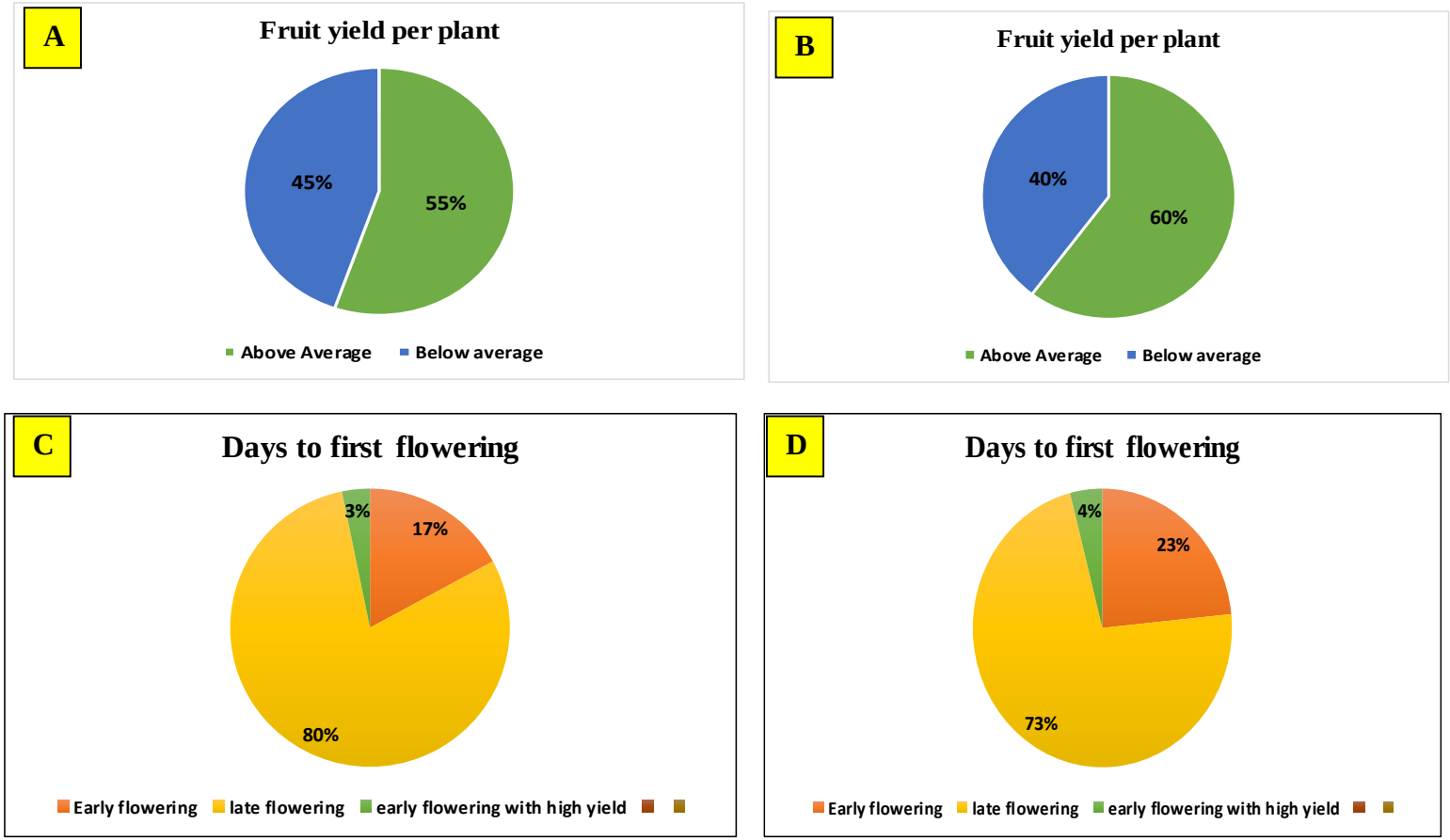
Epigenetic mode of gene regulation by acetylation or deacetylation of DNA histone proteins had shown to play an important role in developing phenotypical variations in crop plants. There are number of epigens which can induce epi-mutations in the plants. Sodium butyrate is one of such histone deacetylating agent, producing such non- genetic mutations in plants on treatment. The visible morphological mutations and micro- mutations on various traits induced by sodium butyrate on two okra varieties, namely Arka Anamika and Arka Abhay are scored and discussed below.

4.2.1.1 Morphological mutations

Spectrum of different morphological variants was evident, following the sodium butyrate treatment among both the varieties. The total field emergence and survival of the treated seedlings was observed to be less compared to the control even though the germination was higher in the petri dishes (Table 20).The maximum number of survived plants in both the varieties were observed in control treatment followed by treatment with 150 µM sodium butyrate incubated for three days. Similar observation was also quoted by Pagano *et al.* (2017) from the study on *Medicago truncatula* using sodium butyrate where the number of germinated seeds was more in sodium butyrate treated plate compared to the control plates. In a study using *Arabidopsis thaliana,* which focused on plants overexpressing HDACs has revealed that the treated seeds outcompeted their corresponding wild-type regarding the seed germination (Perrella *et al.* 2013). The chromatin is densely packed in dry seeds, but it is proposed that during the seed germination, chromatin is subjected to reversible condensation/ de-condensation, mostly enhanced by desiccation–imbibition cycles (Leprince *et al.* 2017). Sodium butyrate is an HDAC inhibitor that can cause a

Table 20: Effect of sodium butyrate treatments on germination parameters seeds of Arka Anamika and Arka Abhay

Variety	Treatment	Total number of seeds incubated	No. of germinated seeds in petridish	Field germination (%)	Survival percentage (%)
ARKA ANAMIKA	Control (T_1)	100	60	73	71
	T_2	100	59	40	36
	T_3	100	49	31	20
	T_4	100	61	54	50
	T_5	100	47	37	33
ARKA ABHAY	Control (T_6)	100	62	74	73
	T_7	100	55	40	37
	T_8	100	44	39	32
	T_9	100	65	55	51
	T_{10}	100	49	34	32



A and B: Percentage of superior mutant lines for fruit yield in Arka Anamika and Arka Abhay respectively,
C and D: Percentage of early flowering mutant lines in Arka Anamika and Arka Abhay respectively

Figure 1: Percentage of superior lines in the mutant population of Arka Anamika and Arka Abhay induced by gamma radiation

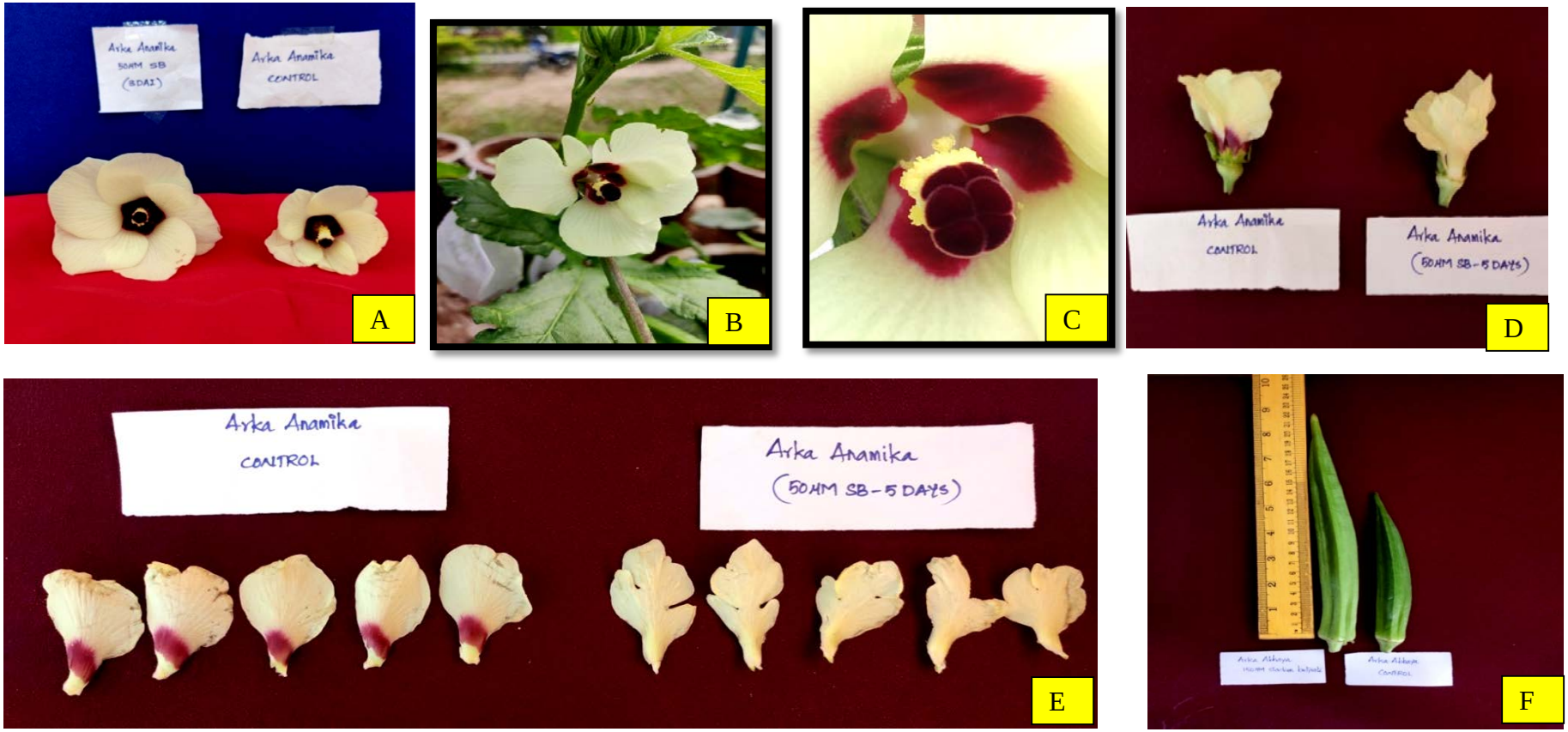
significant increase in genomic histone acetylation (Chua *et al.*, 2003; Bandyopadhyay *et al.,* 2004) and the increased histone acetylation may affect chromatin condensation and folding (Zhang *et al.,* 2016). These statements substantiate the increased seed germination of okra seeds treated with HDAC inhibitors in petri dishes under controlled (dark) conditions.

Most of the seedlings of all the treatments were dwarf and they exhibited chlorosis in their cotyledon leaves. Leaves were crinkled and puckered in most of the treatments.

Studies of Zhang *et al.* (2016) in maize treated with sodium butyrate showed that the treatment has significantly inhibited root growth and that the root length decreased about 40 per cent compared with the control group after four days of treatment with the chemical. Simultaneously, the shoot growth was also noticed to be retarded (approximately 50 % that of the control group) after the treatment with HDAC inhibitors.

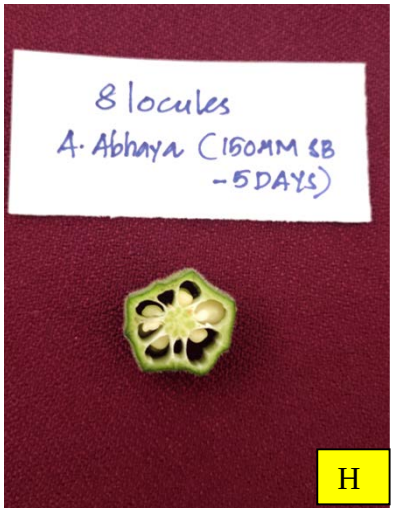
Noticeable variations in flowers such as bigger petal size and style size, petals with unusual shapes and sizes, flowers with less than five petals, flowers with more than five petals and increased number of stigmata (Plate 4) were also recorded. Studies with maize hda108/hda108 mutant by Forestan, (2018) found that, reduced deacetylation has altered both male and female inflorescence patterning, female and male fertility, length of the tassel and its ramifications number, anther maturation, and ear development. HDAC treated okra plants exhibited an unusual delay in first flowering compared to their checks. In Arabidopsis, the hda6/rts1 mutants displayed a very mild phenotype (Aufsatz *et al.*, 2002) and a delay in flowering (Probst *et al.*, 2004).

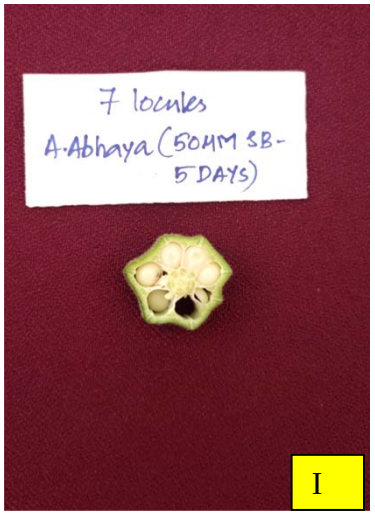
A peculiar mutant with flowers lacking purple pigmentation on the backside of the petals (Plate 4; Picture: E) identified in the S_1 generation treated with 50 µM SB was interestingly found inherited and presented itself in the S_2 generation as well. This result indicate that at least some of the epigenetic mutations are trans-generational, which can inherit in to the progenies. Jones (2012) has opined that epigenetically acquired traits can be inherited across generations without any change in the DNA sequences. Eichte *et al.* (2014) and Schmitz *et al*. (2013) had identified methylation as a major epigenetic mark that can be inherited stably through mitosis and meiosis for multiple generations, whereas modified histones and small RNA induced epigenetic changes may also contribute to the trans-generational inheritance of epigenetic memory. Interestingly, all the selfed progenies of this particular mutant had the same flower peculiarity, and there was no segregation observed for this trait it in the S_2 generation. This suggests that the character has inherited in a non-Mendelian fashion. Rassoulzadegan *et al.* (2006) has reported an RNA-mediated non-Mendelian inheritance of an epigenetic change in the mouse. Zebularine (DNA methylation agent) induced epigenetic variations for spikelet



A: Flower size, B: Flower with four petals, C: flower with more than five stigamta, D and E: Flower without outer petal pigmentation, F: Size difference of fruit,

Plate 7: Spectrum of visible mutations induced by sodium butyrate in the S_1 generation contd…





G: difference in ridge type, H and I: Increse in number of locules, J: Color difference of fruits, K: Color and size difference of seeds

Plate 7: (Contd…..) Spectrum of visible mutations induced by sodium butyrate in the S_1 generation

number in semi- spring wheat was reported to be inherited as non-Mendelian fashion by Finnegan *et al*. (2019), also authenticate this research outcome.

Unusual plants with increased height, broader leaves and larger intermodal length or increased number of axillary branches bearing fruits were noticed. Some of the plants bear fruits which were longer in size, increased number of ridges and locules and differences in the ridge shapes such as concave and convex were also observed in various treatments. The colour of the fruits were also varied from light green to dark green (Plate 4). The seeds varied for sizes and shapes and they also exhibited differences in colours such as grey, dark grey, brown and black. Eliminating the non- significant response of the two varieties for the treatment of sodium butyrate, a general trend of increase in morphological variations as increase in the number of incubation days as well as the dose of the chemical was noticed. Tian and Chen (2000) opined that inhibiting histone deacetylation might reactivate some factors, such as transposable elements, causing unstable mutations that might produce aberrant phenotypes that may inherit on selfing.

Histones are proteins which are subjected to various post-translational modifications such as acetylation, methylation, phosphorylation and ubiquitination (Strahl and Allis 2000). These histone modifications play an important role in many biological processes (Fischle *et al.,* 2003). Sodium butyrate is a powerful histone deacetylase (HDAC) inhibitor that can induce a significant elevation in histone acetylation (Chua *et al.,* 2003; Bandyopadhyay *et al.,* 2004) and has been extensively used to study the biological functions of HDAC (Clayton *et al.,* 2006; Marks *et al.,* 2000).

4.2.1.2 Analysis of variance (ANOVA) for characters in S_1 generation.

Analysis of variance among the sodium butyrate treated S_1 population (First mutant population of Sodium butyrate) of Arka Anamika and Arka Abhay were critically analysed for remarkable differences in the total fruit yield and its thirteen contributing parameters and are presented in Table 21 and Table 22, respectively. The ANOVA for both the varieties showed that the mean sum of squares within blocks (eliminating treatments), within treatments (eliminating blocks)and checks vs mutants were significant for all the 14 traits such as days to first flowering, plant height (cm), number of branches, number of internodes, number of fruits per plant, fruit length (cm), fruit width (mm), number of ridges per fruit, number of locules in a fruit, single fruit weight (g), number of seeds per fruit, weight of seeds per fruit (g), test weight (g) and fruit yield (g) showing significant differences among the mutant lines. This has indicated the existence of high significant differences for all the major yield governing characters in the mutant lines of two okra varieties, Arka Anamika and Arka Abhay.

Table 21: Analysis of variance for growth and yield parameters in mutant families (S_1) of Arka Anamika variety

Source	Df	DFF	PH	NB	NF	FL	FW	NR	NL	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	7	19.77 *	707.7 **	5.74 **	10.34 **	5.7 **	0.1 **	0.18 **	0.1 **	54.1 **	13.91 **	103.93 **	7.24 **	18.62 **	6542.29 **
Treatment (eliminating Blocks)	83	20.19 **	683.74 **	3.11 **	10.67 **	4.03 **	0.09 **	0.36 **	0.22 **	24.71 **	35.28 **	142.5 **	5.41 **	18.53 **	4905.21 **
Checks	3	123.39 **	135.47 **	4.98 **	25.28 **	14.56 **	0.17 **	0.001	0.001	6.58	14.08 **	194.2 **	12.11 **	12.25 **	1438.92 **
Mutants	79	111.94 **	693.31 **	2.44 **	9.94 **	3.89 **	0.07 **	0.37 **	0.23 **	28.91 **	27.87 **	110.77 **	5.45 **	19.62 **	5661.88 **
Mutants vs Check	1	468.53 **	6471.14 **	90.57 **	94.02 **	13.04 **	2.01 **	1.57 **	1.16 **	75.36 **	794.22 **	3176.73 **	22.08 **	74.96 **	728.34 **
Residuals	21	7.56	6.96	0.04	0.68	1.22	0.01	0.001	0.001	5.43	3.14	22.63	1.87	1.40	81.67
CV		5.90	4.25	7.72	17.55	7.34	6.48	0.001	0.001	14.00	10.38	11.71	13.59	12.62	13.60
CD (5%) (Mutant v/s Control)		6.78	6.51	0.48	2.04	2.73	0.30	0.001	0.001	5.74	4.37	4.73	3.37	2.91	12.29
CD (5%) Two Mutants (Different Blocks)		9.04	8.67	0.64	2.71	3.63	0.39	0.001	0.001	7.66	5.83	5.64	4.49	3.89	19.72

DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit length (cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g), YLD=Yield *per* plant

Table 22: Analysis of variance for growth and yield parameters in mutant families (S_1) of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	NR	NL	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	5	14.03 **	3492.31 **	0.95 **	22.53 **	18.66 **	0.2 **	0.09 **	0.04 **	106.3 **	18.12 **	1303.35 **	2852.18 **	14.05 **	5928.82 **
Treatment (eliminating Blocks)	69	8.89 **	591.79 **	2.25 **	4.67 **	12.35 **	0.09 **	0.41 **	0.37 **	21.16 **	40.93 **	193.01 **	323.15 **	9.28 **	1821.54 **
Checks	3	13.96 **	167.91 **	4.32**	12.35 **	16.14 **	0.16 **	0.001	0.001	1.12	1.49 *	4.98	0.63 **	3.44 **	905.83 **
Mutants	65	8.99 **	849.94 **	1.17 **	2.25 **	13.66 **	0.08 **	0.42 **	0.38 **	29.49 **	30.74 **	274.72 **	540.34 **	10.61 **	2241.03 **
Mutants vs Check	1	53.28 **	2522.99 **	70.86 **	10.76 **	0.81	1.83 **	1.46 **	1.17 **	70.49 **	906.81 **	1941.74 **	1434.25 **	10.26 **	271.60 **
Residuals	15	0.68	10.91	0.07	10.18**	1.18	0.01	0.001	0.001	0.66	0.44	2.13	0.06	0.26	42.92
CV		1.74	5.66	10.29	11.2	7.28	5.28	0.001	0.001	7.96	3.90	3.52	2.35	6.84	10.85
CD (5%) (Mutant v/s Control)		2.11	8.50	0.69	1.08	2.80	0.26	0.001	0.001	2.09	1.70	3.76	0.64	1.31	16.86
CD (5%) Two Mutants (Different Blocks)		2.77	11.13	0.90	1.42	3.66	0.34	0.001	0.001	2.74	2.23	4.92	0.83	1.71	22.08

DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit length (cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g), YLD=Yield *per* plant

Bossdorf *et al.* (2010) treated a set of natural *Arabidopsis* genotypes with 5-azacytidine (demethylating agent) and noticed considerable effect on plant's phenotypic plasticity, in which an organism changes its phenotype in response to environmental changes. Similarly, an idea of soft inheritance in which the phenotypes of organisms can be modified by their environment which can be inherited to the next generation (trans-generational epigenetics) was put forth by Mayr and Province (1980).

For further validation, DMRT (Duncan Multiple Range Test) significant test at P = 0.05, was conducted for major traits governing the yield (Table 23). Significant differences among the S_1 population of Arka Anamika and Arka Abhay were observed from the test.

4.2.1.2.1 Effect of sodium butyrate treatment on different characters

From the DMRT analysis (Table 23), it is clear that, treatment means of important yield governing traits varied significantly from each other. Traits such as total yield, plant height, number of fruits, fruit length, single fruit weight, number of seeds, seed weight per fruit and test weight of the seeds were remarkably higher in the control, followed by treatment 4 of Arka Anamika (150 µM SB) and treatment 9 of Arka Abhay (150 µM SB) compared to other treatments. The DMRT test indicated the significant advantage of the 150 µM of sodium butyrate treatment incubated for three days among both the varieties. Likewise, the below par performance of 150 µM SB incubated for five days in Arka Anamika (treatment 5) and Arka Abhay (treatment 10) seeds was also identified by the test. Traits such as days to first flowering and plant height in treatments T_5 and T_{10} were significantly superior compared to the other treatments, whereas, major yield contributing traits and the total yield of fruits in the treatments T_5 and T_{10} performed comparably poor similar to other treatments.

Significant differences for the fourteen traits were observed for varied doses and different incubation time. Selective advantage of 150 µM of sodium butyrate treatment was observed for majority of the economic traits of okra as compared to the 50 µM dose. On the other hand, deleterious effects were found to be increased as the incubation period extended. Number of germinated seeds, field emergence percentage and the survival percentage of the seedlings was reduced as the incubation period of seeds increased (Table 20).

Table 23: DMRT results for different treatments and characters among S_1 population of Arka Anamika and Arka Abhay varieties

Variety	Treatment	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
ARKA ANAMIKA	Control (T_1)	48.44^{B}	51.20^{A}	4.95^{A}	6.61^{A}	16.15^{AB}	15.30^{C}	10.20^{B}	20.45^{AB}	49.39^{AB}	3.78^{BC}	11.35^{B}	111.35^{AB}
	T_2	53.60^{AB}	41.63^{B}	3.60^{B}	3.70^{B}	16.30^{AB}	19.40^{B}	9.50^{B}	17.04^{B}	$38.36B^{C}$	5.99^{AB}	7.90^{BC}	53.96^{B}
	T_3	54.60^{A}	40.05^{B}	2.55^{BC}	3.75^{B}	14.86^{B}	18.00^{BC}	10.05^{B}	16.88^{BC}	34.01^{C}	3.72^{BC}	6.56^{C}	48.40^{BC}
	T_4	49.56^{B}	50.80^{AB}	3.26^{B}	8.80^{AB}	17.63^{A}	19.80^{B}	12.80^{A}	22.45^{A}	58.71^{A}	7.62^{A}	15.00^{A}	136.70^{A}
	T_5	54.40^{A}	39.05^{B}	1.30^{C}	2.50^{B}	11.74^{C}	24.50^{A}	7.72^{BC}	13.04^{CD}	28.40^{C}	2.62^{C}	6.22^{C}	40.96^{B}
	Mean	51.92	45.77	2.76	3.53	15.36	20.10	10.12	18.03	42.90	5.09	10.07	58.45
	CD (5%)	1.78	6.51	0.48	2.04	1.73	1.30	2.74	3.37	7.73	3.37	2.91	12.29
ARKA ABHAY	Control (T_6)	49.22^{b}	47.92^{ab}	3.74^{a}	4.27^{a}	17.49^{a}	18.00^{b}	8.67^{b}	17.95^{ab}	50.0^{a}	3.85^{b}	7.65^{ab}	98.95^{ab}
	T_7	56.38^{a}	42.50^{b}	2.00^{b}	2.33^{b}	17.04^{bc}	19.00^{ab}	7.38^{b}	18.14^{ab}	31.55^{c}	3.48^{b}	6.74^{b}	50.27^{bc}
	T_8	55.77^{a}	40.38^{b}	1.77^{bc}	2.27^{b}	15.23^{b}	19.90^{ab}	9.44^{b}	18.60^{ab}	45.77^{ab}	2.39^{b}	7.31^{ab}	58.38^{b}
	T_9	52.83^{b}	52.91^{a}	2.83^{b}	4.50^{a}	18.83^{a}	18.70^{ab}	19.16^{a}	21.88^{a}	50.87^{a}	7.00^{a}	9.84^{a}	104.33^{a}
	T_{10}	56.27^{a}	41.33^{b}	2.05^{b}	2.33^{b}	10.14^{c}	21.10^{a}	9.77^{b}	14.25^{b}	$37.86b^{c}$	3.47^{b}	3.91^{c}	38.16^{c}
	Mean	51.93	42.36	2.24	3.09	14.10	19.60	10.57	18.26	41.46	12.16	7.26	59.84
	CD (5%)	2.11	8.50	0.90	1.08	1.80	2.26	2.49	3.70	3.76	0.64	1.31	16.86

Mean with same superscript within a column do not differ at 5 % level of significance

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total yield
NL: No. of Locules

4.2.1.3 Genetic parameters of variability

Genetic enhancement of any population by selection of elite breeding lines from a base population primarily depends upon the amount of genetic variability exists among them. The quality of the selection is mainly dependent upon the existence of genetic variability present within or among the mutant population under the selection. High heritability coupled with high magnitude of genetic advance of a trait indicates the presence of additive gene action. Such traits are readily available and responsive for the visual selection and thus the improvement of those traits are possible. The details of various genetic parameters assessed among the S_1 mutant population of Arka Anamika and Arka Abhay are tabulated in Tables 24 and 25 respectively.

4.2.1.3.1 Days to first flowering (DFF)

The trait, number of days to first flowering has ranged from 39 days to 62 days in Arka Anamika mutant population with an average days of 51.53, indicating a significant variation for the trait. Among the 80 selected mutant lines, the line AN-50-5-2 exhibited the early flowering (39 days) and the line AN-50-5-14 recorded the late flowering (62 days) compared to the parent, Arka Anamika (46.80 days). Low phenotypic (7.59) and genotypic (4.60) coefficient of variation combined with moderate heritability of 36.70 per cent and low genetic advance as per cent of mean (5.74) were observed.

Similarly, the trait had a mean value of 52.86 days of first flowering with a range of 40 and 58 days among the Arka Abhay mutants. The parent Arka Abhay has scored an average days of flowering of 49.90 days which is significantly high compared to the mean value of 80 mutant lines. The lines AB-150-3-12 and AB-150-5-8 has recorded the lowest and the highest number of days to first flowering which is 40 days and 58 days respectively. The amount of GCV (4.15) and PCV (9.52) were very low, which is associated with a moderate heritability (43.59 %) and a low genetic advance as per cent of mean (5.25).

4.2.1.3.2 Plant height (cm)

The average plant height of the S_1 mutant lines of Arka Anamika was 56.06 cm as compared to parent A. Anamika (61.23 cm) ranging from 22.30 cm to 120.34 cm. Lowest plant height was recorded by the line AN-50-3-17 and highest by AN-50-3-8. High values of GCV (29.66), PCV (38.86) and heritability (76.32 %) coupled with high genetic advance of 20.85 as per cent of mean were noticed for this trait.

In case of Arka Abhay the trait has scored a lowest value of 20.66 cm (AB-50-3-14) and the highest was 176.71 cm (AB- 150-3-8) with a mean height of

Table 24: Mean, range and genetic variability parameters for growth and yield traits in mutant families (S_1) of Arka Anamika

Trait	Arka Anamika Mean	Mean	Range		Coefficients of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	46.80	51.53	39.00	62.00	4.60	7.59	36.70	2.96	5.74
PH	61.23	56.06	22.30	120.34	29.66	38.86	76.32	11.69	20.85
NB	4.98	2.03	0.00	9.00	11.26	12.87	98.47	1.17	57.63
NF	10.61	4.35	1.00	13.00	10.91	14.19	76.88	2.67	61.37
FL	16.43	15.24	7.36	19.73	10.71	12.94	68.57	2.79	18.30
FW	15.33	19.22	11.90	27.18	12.23	13.73	79.33	4.32	22.47
INT	8.27	10.14	3.00	26.00	47.80	53.03	81.23	5.37	52.95
NR	5.00	5.25	5.00	9.00	11.64	11.65	99.99	1.26	24.00
NL	5.00	5.21	5.00	9.00	9.14	9.15	99.99	0.98	18.81
SFW	17.04	18.48	9.29	39.19	26.92	28.57	88.73	9.67	52.32
NS	49.39	37.83	15.00	70.00	24.81	27.82	79.57	17.28	45.67
SWT	3.72	4.24	1.15	10.17	11.65	19.08	61.03	0.96	22.64
TWT	11.33	9.80	2.00	14.15	28.56	48.20	59.25	2.59	26.42
YLD	112.92	66.71	3.12	453.12	10.98	32.80	33.47	15.98	23.95

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 25: Mean, range and genetic variability parameters for growth and yield traits in mutant families (S_1) of Arka Abhay

Trait	Arka Abhay Mean	Mean	Range		Coefficients of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	49.90	52.86	40.00	58.00	4.15	9.52	43.59	2.78	5.25
PH	58.85	50.86	20.66	176.71	13.76	17.95	78.72	14.01	27.54
NB	3.74	3.34	1.00	16.00	14.45	15.69	90.15	1.20	35.92
NF	8.27	4.29	1.00	12.00	20.89	27.91	74.84	2.34	54.54
FL	15.19	14.96	4.97	25.03	23.62	24.71	91.37	3.97	26.53
FW	18.00	19.60	13.80	25.50	13.17	14.12	86.95	4.97	25.35
INT	8.67	10.63	2.00	25.00	15.90	18.60	85.48	6.14	57.76
NR	5.00	5.27	5.00	8.00	12.35	12.36	99.90	1.34	25.42
NL	5.00	5.24	5.00	8.00	11.74	11.75	99.90	1.27	24.23
SFW	17.95	18.45	6.87	33.88	24.83	36.05	68.87	4.28	23.19
NS	50.00	39.32	16.00	84.00	11.99	16.15	74.24	13.93	35.42
SWT	3.85	6.41	1.39	10.89	5.16	10.66	48.40	1.01	15.75
TWT	7.65	7.28	1.37	16.72	24.22	44.77	54.09	1.26	17.30
YLD	98.95	66.06	10.49	227.64	11.59	25.84	44.84	12.09	18.30

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

50.86 compared to the parent Arka Abhay (58.85 cm). The genotypic and phenotypic coefficients were found moderate (13.76 and 17.95, respectively) with high heritability (78.72 %) and high genetic advance as per cent of mean (27.54).

4.2.1.3.3 Number of branches

The average number of branches among the mutant lines of Arka Anamika ranged from 0.00 (AN-150-5-20) to 9.00 (AN-50-5-20). The mean value of mutants was 2.03 compared to parent Arka Anamika (4.98). Moderate variation in terms of genetic parameters such as the GCV (11.26%) and PCV (12.87 %) along with a high heritability of 98.47 per cent and genetic advance (57.63) as per cent was observed.

In case of Arka Abhay mutants, the number of branches ranged from 1.00 to 16.00 with a mean value of 3.34, whereas parent Arka Abhay mean was 3.74. The lowest number of branches was recorded in the line, AB-50-5-19 and maximum was recorded in AB-150-5-3. Moderate phenotypic and genotypic coefficients of variations recorded were 14.45 and 15.69 per cent respectively. High value of heritability (90.15 %) with an expected genetic advance of 35.92 per cent was observed for this character among the mutant lines.

4.2.1.3.4 Number of fruits

The average number of fruits per plant for parent Arka Anamika was 10.61, whereas its mutants mean was 4.35. The line AN-150-5.20 has recorded minimum number of fruits (1.00) and the line AN-150-3-18 (13.00) had maximum number of fruits indicating a range of 1.00 to 13.00 fruits per plant. The GCV and PCV recorded were moderate (10.91 and 14.19 per cent respectively) and the trait exhibited high heritability (76.88 %) associated with high with per cent mean of genetic advance (61.37).

The Arka Abhay mutants population had an average number of 4.29 fruits per plant with a range of 1.00- 12.00 compared to the parent Arka Abhay (8.27). Among the mutant lines, AB-50-5-19 and AB-150-3-10 has recorded minimum and maximum number of fruits per plant. High estimates of GCV (20.89 %) and high PCV (27.91 %) with high heritability (74.84 %) and per cent mean genetic advance (54.54) were observed among the mutants for this trait.

4.2.1.3.5 Fruit length (cm)

The fruit length of Arka Anamika mutants varied from 7.36 cm to 19.73 cm with an average value 15.24 cm compared to parent Arka Anamika 16.43 cm. The mutant line AN-50-3-9 has recorded least fruit length (7.36 cm), while maximum length of fruit was recorded in AN- 150-3-24 (19.73 cm). Moderate GCV (10.71) and PCV (12.94) accompanied with high estimates of heritability (68.57 %) and moderate per cent mean genetic advance (18.30) was recorded for this trait.

The overall mean of fruit length in Arka Abhay mutants was 14.96 cm with a wide range of 4.97 cm to 25.03 cm, whereas the parent mean was 15.19 cm. A shortest fruit length was produced in AB-50-3-10 line and longest was in AB-150-3-10. High record of genotypic (23.62 %) and phenotypic (24.71 %) coefficient of variation together with high heritability (91.37 %) and high per cent mean genetic advance (26.53) were noticed.

4.2.1.3.6 Fruit width (mm)

The width of the fruits ranged from 11.90 mm to 27.18 mm with a mean value of 19.22 mm for Arka Anamika mutants and the parent has scored a mean of 15.33 mm. The mutant lines, AN-150-3-6 and AN-50-5-6 had the minimum and maximum width of the fruits respectively. The genotypic and phenotypic coefficients of variation were recorded as moderate (12.23 and 13.73, respectively) with high heritability (79.33 %) and a high genetic advance as per cent of mean (22.47).

In case of mutants of Arka Abhay, the line AB-150-3-6 (13.80 mm) and AB-150-5-10 (25.50 mm) had scored minimum and maximum width of the fruits respectively. The average estimate of this trait in the mutant population was 19.60 mm with that of the parent Arka Abhay (18.00 mm). The genotypic (13.17 %), phenotypic (14.12 %) coefficients of variation were observed as moderate, with high heritability (86.95 %) and high estimate of per cent mean genetic advance (25.35).

4.2.1.3.7 Number of internodes on the main stem

The number of internodes on the main stem of the mutant lines of Arka Anamika has ranged from 3.00 to 26.00 (AN-150-5-19 and AN-150-3-24) with an average number of 10.14 internodes. The parent Arka Anamika had an average value of 8.27 for this trait. High GCV (47.80 %) and PCV (53.05 %) with high estimates of heritability (81.23 %) and genetic advance as per cent of mean (52.95) was recorded among the population.

The Arka Abhay mutants exhibited a mean number of 10.63, whereas its parent showed average number of 8.67 internodes. Among the mutants, the lines AB-50-3-12 and AB-150-3-13 has recorded minimum and maximum (2.00 and 25.00) number of internodes indicating a wide range of variations. Moderate estimates of GCV and PCV (15.90 and 18.60 %), high heritability of 85.48 per cent with high (57.76) per cent mean genetic advance were also exhibited by this trait.

4.2.1.3.8 Number of ridges per fruit

The trait has ranged from 5.00 to 9.00 among Arka Anamika mutants and 5.00 to 8.00 among Arka Abhay mutants. The parents scored a mean value of 5.00 against Arka Anamika mutants (5.25) and Arka Abhay mutants (5.27). Maximum number of ridges was scored by AN-50-3-13 (9.00) and AB-150-3-9 (8.00)

in the respective population. Moderate estimates of GCV (11.64) and PCV (11.65) with high heritability (99.99) coupled with high GAM (24.00) was observed for S_1 mutants of Arka Anamika. Similarly, Arka Abhay mutants also exhibited moderate estimates of GCV (12.35), PCV (12.36) with high GAM (25.42) and heritability (99.90 %).

4.2.1.3.9 Number of locules per fruit

Both the check varieties had a mean value of 5.00 compared to mutants of Arka Anamika (5.21) and Arka Abhay (5.24). The trait had range of 5.00 to 9.00 (AN-50-3-13) in Arka Anamika mutants and 5.00 to 8.00 (AB-150-3-9) in Arka Abhay mutants. Low estimates of GCV (9.14) and PCV (9.15), high heritability (99.99 %) coupled with moderate GAM (18.81) were noticed for the mutants of Arka Anamika. Moderate estimates of GCV (11.74) and PCV (11.75) coupled with high estimates of heritability (99.90 %) and genetic advance as per cent of mean (24.23) were observed among Arka Abhay mutants.

4.2.1.3.10 Single Fruit Weight (g)

Significant variation among the mutant lines of Arka Anamika for the weight of single fruit was noticed. The average weight of single fruit has ranged from 9.29 g in the mutant line AN-150-5-19 to 39.19 g in AN-150-3-1. The overall mean of 18.48 g was scored among the population compared to parent Arka Anamika (17.04 g). The estimates of genetic parameters such as GCV and PCV (26.92 and 28.57, respectively), heritability (88.73 %) and per cent mean genetic advance (52.32) were very high for this trait.

Similarly, Arka Abhay mutants also had a larger variation for the character with a range of 6.87 g to 33.88 g. The Parent Arka Abhay has scored an overall mean value of 17.95 g compared to the mutant mean of 18.45 g. The line AB-150-3-6 had maximum weight of single fruit (33.88 g) whereas the line AB-150-5-2 recorded minimum weight (6.87 g). High GCV (24.83), PCV (36.05), heritability (68.87 %) and genetic advance of as per cent of mean (23.19) were exhibited by the character among the population.

4.2.1.3.11 Number of seeds per fruit

The overall mean obtained for total number of seeds per fruit in case of Arka Anamika mutants was 37.83 ranging from 15.00 (AN-150-5-20) to 70.00 (AN-150-3-18), whereas the parent had an average of 49.39 seeds per fruit. High estimates of genotypic (24.81), phenotypic (27.82) coefficients of variability, heritability (79.57 %) and genetic advance as per cent of mean (45.67) were noticed for this character.

Alternatively in Arka Abhay mutant lines, the line AB-150-3-13 (16.00) and AB-150-3-1 (84.00) has recorded the minimum and maximum number of seeds per fruit respectively. The mean value for the trait among the mutant population was 39.32 compared to the parent Arka Abhay (50.00). The GCV (11.99) and PCV (16.15) values obtained were moderate coupled with high heritability of 74.24 per cent and GAM (35.42).

4.2.1.3.12Weight of seeds per fruit (g)

The average weight of seeds per fruit in the parent Arka Anamika was 3.72 g, whereas its mutant population had an average of 4.24 g seed weight. The minimum (1.15 g) and maximum (10.17 g) weight of seeds per fruit was recorded in the lines AN-150-3-8 and AN-50-5-10 respectively, indicating range of 1.15 to 10.17 g. The moderate coefficient of variations at phenotypic and genotypic level was 11.65 and 19.08 per cent respectively. The trait scored high heritability of 61.03 per cent coupled with high genetic advance (22.64) as per cent of mean.

In case of Arka Abhay mutant population, the mean performance for weight of seeds per fruit was 6.41 g and its parent had 3.85 g per fruit. The mutant line AB-50-3-10 has recorded lowest seed weight per fruit (1.39 g) and highest was in line AB-150-3-7 (10.89 g). Low GCV (5.16) and PCV (10.66) combined with moderate estimates of heritability (48.40 %) and genetic advance as per cent of mean (15.75) were also observed for this trait.

4.2.1.3.13 Test weight (g)

The range of test weight in mutants of Arka Anamika was 2.00 g to 14.15 g with an overall mean of 9.80 g, compared to its parent Arka Anamika (11.33 g). Maximum test weight of seeds was observed in the line, AN-150-3-8 (2.00 g) and minimum was in AN-50-5-10 (14.15 g). The genotypic and phenotypic coefficients of variations noticed were comparatively high (28.56 and 48.20 respectively). The trait recorded moderate heritability (59.25 %) associated with high per cent of mean genetic advance (26.42 %).

The average weight of hundred seeds in Arka Abhay mutants was 7.28 g, ranging from 1.37 g in AB-150-3-13 to 16.72 g in the line AB-150-3-7. The parent Arka Abhay scored a mean value of 7.65 g for the trait. The genotypic and phenotypic coefficients of variation observed were high and values were 24.22 and 44.77 per cent, respectively. Moderate heritability (54.09 %) coupled with moderate genetic advance as per cent mean (17.30) were also exhibited by the trait in the mutant population.

4.2.1.3.14 Total fruit yield per plant (g)

In the mutants of Arka Anamika, total fruit yield per plant was in a range of 3.12 g to 453.12 g with an overall mean of 66.71 g compared to its parent (112.92 g). The mutant line AN-50-5-16 had minimum fruit yield per plant (3.12 g), contrary to this the line AN-150-3-20 (453.12 g) scored maximum for this trait. Moderate GCV (10.98 %), high PCV (32.80%) and moderate estimate of heritability (33.47 %) coupled with high genetic advance as per cent of mean (23.95) were noticed for this character.

Similarly, in case of Arka Abhay mutants, the overall mean for the total yield of fruits per plant was 66.06 g with a range of 10.47 g to 227.64 g, whereas its parental mean was 98.95 g. The maximum and minimum fruit yield was recorded in lines, AB-150-5-6 and AB-150-3-10, respectively. The phenotypic (25.84 %) and genotypic (11.59 %) coefficient of variations were found high and moderate respectively for the trait, accompanied with moderate heritability of 44.48 per cent and moderate genetic advance of 18.30 as per cent of mean.

4.2.2 Observations in S_2 generation

4.2.2.1 Analysis of variance (ANOVA) for characters in S_2 generation.

The analysis of variance among 120sodium butyrate treated mutant lines of both Arka Anamika and Arka Abhay was performed for 14 quantitative traits and presented in Tables 26 and 27, respectively. The results revealed that values of mean sum of squares within the blocks (eliminating treatments), within the treatments (eliminating blocks) and checks vs mutants were significant for yield and its thirteen contributing traits suggesting significant differences among 120 S_2 mutant lines of the both the varieties.

4.2.2.2 Genetic parameters of variability

The parameters of genetic variability such as, mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance as per cent of mean (GAM) of yield and its 13 attributing traits among the S_2 mutant populations of Arka Anamika and Arka Abhay are furnished in the Tables 28 and 29, respectively.

4.2.2.2.1 Days to first flowering

The number of days to first flowering of the mutant lines of Arka Anamika has ranged from 40.00 to 62.00 days with general mean value of 50.75 days and its control flowered in a mean days of 47.25. The GCV and PCV values were low (3.58 and 7.22, respectively) and the heritability in broad sense were also low (24.54 %) coupled with a low genetic advance as per cent of mean (3.29). In case of

Table 26: Analysis of variance for growth and yield parameters in mutant families (S_2) of Arka Anamika variety

Source	df	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	7	49.86 **	1486.93 **	11.74 **	17.86 **	11.71 **	17.44 **	78.84 **	0.50 **	0.44 **	24.35 **	392.35 **	20.70 **	36.43 **	6769.21 **
Treatment (eliminating Blocks)	123	47.49 **	517.72 **	2.66 **	7.73 **	3.70 **	5.93 **	18.87 **	0.36 **	0.38 **	26.26 **	124.14 **	4.67 **	14.4 **	3483.75 **
Checks	3	142.89 **	124.58 **	4.77 **	26.91 **	13.54 **	0.13 **	4.74	0.001	0.001	5.24	194.21 **	12.11 **	12.25 **	1502.48 **
Mutants	119	44.92 **	575.89 **	2.46 **	7.35 **	3.96 **	7.05 **	23.06 **	0.38 **	0.39 **	22.29 **	108.24 **	5.46 **	16.38 **	3939.76 **
Mutants vs Check	1	333.25 **	5068.46 **	97.33 **	112.39 **	17.09 **	11.86 **	67.83 **	2.40 **	2.95 **	724.92 **	4462.78 **	22.87 **	33.92 **	1159.63 **
Residuals	21	8.24	12.44	0.06	0.80	1.48	0.02	5.35	0.001	0.001	3.09	22.59	1.87	1.40	85.14
CV		6.19	5.71	10.02	13.33	8.00	6.88	10.68	0.001	0.001	10.21	12.18	7.93	13.15	15.11
CD (5%) (Mutant v/s Control)		1.08	4.70	0.63	2.20	3.00	0.37	5.71	0.001	0.001	4.34	4.72	3.37	2.91	12.75
CD (5%) Two Mutants (Different Blocks)		2.44	6.60	0.84	2.94	4.01	0.49	7.61	0.001	0.001	5.78	5.63	4.49	3.89	16.34

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 27: Analysis of variance for growth and yield parameters in mutant families (S_2) of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	NR	NL	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	5	14.05 **	1585.39 **	4.85 **	11.22 **	43.8 **	0.21 **	0.11 **	0.18 **	103.31 **	85.96 **	236.97 **	225.93 **	15.46 **	2246.43 **
Treatment (eliminating Blocks)	123	8.87 *	443.79 **	2.58 **	4.49 **	18.13 **	0.12 **	0.43 **	0.47 **	23.09 **	35.54 **	123.32 **	34.62 **	38.73 **	1560.31 **
Checks	3	24.46 **	770.4 **	7.35 **	11.52 **	10.17 *	0.16 **	0.001	0.001	1.53	23.83**	5.61	0.64 **	3.74 *	1305.57 **
Mutants	119	9.11 *	495.65 **	2.74 **	4.93 **	19.83 **	0.13 **	0.44 **	0.48 **	27.27 **	38.89 **	132.74 **	43.8 **	39.31 **	1648.28 **
Mutants vs Check	1	10.38**	477.25**	121.24 **	27.95 **	14.42 **	1.46 **	2.01 **	2.11 **	43.74 **	742.61 **	733.26 **	13.89 **	8.14 **	6966.65 **
Residuals	15	3.08	110.58	0.59	0.24	2.64	0.01	0.001	0.001	1.02	1.51	2.60	0.06	0.74	38.88
CV		3.77	12.70	3.40	9.24	11.35	5.32	0.001	0.001	10.07	7.12	3.64	5.45	11.47	10.89
CD (5%) (Mutant v/s Control)		1.52	7.07	1.98	1.26	3.19	0.26	0.001	0.001	2.60	3.16	4.15	0.64	2.21	9.05
CD (5%) Two Mutants (Different Blocks)		2.92	8.44	2.59	1.65	5.48	0.34	0.001	0.001	3.41	4.14	5.43	0.84	2.89	11.01

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total Yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

Arka Abhay mutants the values ranged between 42.00 and 64.00 with an average value of 51.01 days, whereas the parent had a mean value of 49.27 days. The GCV (5.19) and PCV (6.45) were found low, heritability estimate was moderate (60.19 %) associated with low genetic advance as per cent of mean (7.78).

4.2.2.2.2 Plant height (cm)

The range of plant height varied from 22.88 to 109.05 cm with an average value of 64.33 cm in case of Arka Anamika mutants compared to their parent (71.40 cm). The genotypic (12.90) and phenotypic (17.31) coefficient of variation was found moderate together with high heritability (71.52 %) and moderate per cent genetic advance (18.57). However the range was 20.01 to 111.08 cm with an average of 63.47 cm in case of Arka Abhay mutants and 80.55 cm in the parent. Moderate estimates of GCV (11.79), high PCV (24.96), moderate estimate of heritability (47.34 %) coupled with high genetic advance as per cent of mean (24.42) were observed for this trait.

4.2.2.2.3 Number of branches per plant

The values with regard to number of branches per plant ranged from 1.00 to 9.00 and the average value was 3.19. The parent has a mean value of 4.15 for this trait. High GCV (22.77), PCV (28.65), heritability (81.46 %) and GAM (36.05) were noticed among mutants of Arka Anamika. Similarly, the number ranged from 1.00 to 7.00 with an average of 3.23 in Arka Abhay mutants and 3.77 in Arka Abhay parent. High estimates of GCV (25.75), PCV (37.25) and heritability (68.22 %) coupled with high genetic advance as per cent of mean (35.29) were calculated for this trait.

4.2.2.2.4 Number of fruits per plant

The trait number of fruits per plant has an overall mean of 13.02in parent and 7.45 in the mutants, ranging from 1.00 to 24.00 in Arka Anamika mutants. The genotypic (24.15) and phenotypic (30.54) coefficients of variation, heritability (79.01 %) and genetic advance as per cent mean (28.72) were recorded high among the population. Similarly, in case of mutants of Arka Abhay, the trait scored a mean value of 9.34 in comparison to Arka Abhay parent (8.12). The trait had ranged from 1.00 to 15.00 among the mutants. The GCV (13.69) and PCV (19.55) were moderate with high heritability (71.54 %) together with high GAM (45.61) were observed among the mutants for this character.

4.2.2.2.5 Fruit length

The mutants of Arka Anamika recorded an average value of 15.38 cm with a range of 10.77 cm to 20.29 cm whereas, the parent had 15.11 cm of fruit length. Moderate estimates of GCV (10.23) and PCV (12.94) coupled with high heritability (62.53 %) and moderate genetic advance as per cent mean (16.71) were scored. The

Table 28: Mean, range and genetic variability parameters for growth and yield traits in mutant families (S_2) of Arka Anamika

Trait	Arka Anamika Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	47.25	50.75	40.00	62.00	3.58	7.22	24.54	1.67	3.29
PH	71.40	64.33	22.88	109.05	12.90	17.31	71.52	11.95	18.57
NB	4.15	3.19	1.00	9.00	22.77	28.65	81.46	1.15	36.05
NF	13.02	7.45	1.00	24.00	24.15	30.54	79.01	2.14	28.72
FL	15.11	15.38	10.77	20.29	10.23	12.94	62.53	2.57	16.71
FW	15.41	17.10	11.81	19.18	14.05	19.80	69.54	5.46	31.93
INT	9.52	10.06	2.00	16.00	20.19	27.72	70.33	1.16	11.53
NR	5.00	5.30	5.00	9.00	11.68	11.69	99.94	1.28	24.15
NL	5.00	5.33	5.00	8.00	11.79	11.82	99.90	1.30	24.39
SFW	18.55	20.05	9.42	39.32	24.10	25.97	86.12	3.74	18.65
NS	45.60	36.67	15.00	70.00	25.24	28.37	79.13	16.98	46.30
SWT	4.75	4.25	1.21	10.43	9.57	15.25	59.74	0.59	13.88
TWT	10.20	9.20	2.05	21.15	22.09	29.10	74.61	1.58	17.17
YLD	126.35	101.85	3.88	453.88	10.03	21.87	45.56	11.31	11.10

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 29: Mean, range and genetic variability parameters for growth and yield traits in mutant families (S_2) of Arka Abhay

Trait	Arka Abhay Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	49.27	51.01	42.00	64.00	5.19	6.45	60.19	3.97	7.78
PH	80.55	63.47	20.01	111.08	11.79	24.96	47.34	15.50	24.42
NB	3.77	3.23	1.00	7.00	25.75	37.25	68.22	1.14	35.29
NF	8.12	9.34	1.00	15.00	13.69	19.55	71.54	4.26	45.61
FL	16.05	14.24	4.94	23.00	29.44	31.57	86.92	7.06	49.57
FW	15.12	19.30	11.40	26.20	17.18	17.95	91.62	6.55	33.93
INT	8.77	10.18	1.00	25.00	19.80	27.76	71.25	4.47	43.91
NR	5.00	5.31	5.00	8.00	12.45	12.45	99.99	1.36	25.61
NL	5.00	5.31	5.00	8.00	12.95	12.95	99.99	1.42	26.74
SFW	17.59	19.19	5.06	31.92	24.27	31.99	62.95	7.88	41.06
NS	50.25	43.51	14.00	77.00	26.03	26.29	98.02	13.13	30.17
SWT	5.62	8.73	0.41	12.06	12.09	14.19	58.77	1.85	21.19
TWT	10.20	8.30	1.38	11.29	26.38	37.18	70.95	1.38	16.62
YLD	86.20	116.88	3.24	231.69	9.74	20.06	47.52	22.27	19.05

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

fruit length has varied between 4.94 and 23.00 cm with an average of 14.24 cm in case of Arka Abhay mutants and 16.05 cm in the parent. The variability parameters such as GCV (29.44) and PCV (31.57), heritability (86.92 %) and genetic advance as per cent of mean (49.57) were high for the trait.

4.2.2.2.6 Fruit width

The overall mean of Arka Anamika for the fruit width was 15.41 mm and that of the mutants was 17.10 mm with a range of 11.81 to 19.18 mm. The genotypic (14.05) and phenotypic (19.80) coefficients of variation were moderate. The heritability (69.54 %) and GAM (31.93) were high for this trait. Likewise, the value of fruit width ranged from 11.40 to 26.20 mm with an average of 19.30 mm in case of mutants and 15.12 mm in the parent, Arka Abhay. The phenotypic coefficient of variation (17.95), GCV (17.18) was moderate, whereas, the heritability (91.62 %) and genetic advance as per cent of mean (33.93) were observed as high.

4.2.2.2.7 Number of internodes on the main stem

Number of internodes on the main stem ranged from 2.00 to 16.00 with a mean value of 10.06 in Arka Anamika mutants and 9.52 in the parent. The variability parameters such as GCV (20.19), PCV (27.72), and heritability (70.33 %) were high and a moderate GAM (11.53) were recorded for the trait. Similarly, the number of internodes had an average value of 10.18 with a range of 1.00 to 25.00 in mutants of Arka Abhay. The trait had an average value of 8.77 in the parent, Arka Abhay. Moderate estimate of genotypic (19.80) and high phenotypic (27.76) coefficients of variation, high heritability (71.25 %) coupled with high genetic advance (43.91) as per cent of mean were noticed.

4.2.2.2.8 Number of ridges per fruit

The overall mean number of ridges per fruit in Arka Anamika was 5.00 and in the mutant was 5.30 with a range of 5.00 to 9.00. Moderate range of GCV (11.68), PCV (11.69) with high heritability (99.94 %) coupled with high range of GAM (24.15) were observed for this trait. In case of Arka Abhay mutants, the mean was 5.31 and 5.00 in case of the parent. The trait ranged from 5.00 to 8.00 in the mutants. Moderate values of GCV (12.45) and PCV (12.45), high heritability (99.99 %) together with high genetic advance as per cent of mean (25.61) were recorded for the trait.

4.2.2.2.9 Number of locules per fruit

Both the check varieties had a mean value of 5.00 compared to mutants of Arka Anamika (5.33) and Arka Abhay (5.31). The trait had range of 5.00 to 8.00 in Arka Anamika mutants and Arka Abhay mutants. Moderate estimates of GCV (11.79) and PCV (11.82), high heritability (99.90 %) coupled with high GAM (24.39) were

noticed for the mutants of Arka Anamika. Moderate estimates of GCV (12.95) and PCV (12.95) associated with high estimates of heritability (99.99 %) and genetic advance as per cent of mean (26.74) were observed among Arka Abhay mutants.

4.2.2.2.10 Single fruit weight (g)

Average weight of single fruits in the mutants of Arka Anamika was 20.05 g that of parent (18.55), which ranged from 9.42 and 39.32 g. The values of GCV (24.10) and PCV (25.97) were high associated with high heritability (86.12 %) and moderate value of GAM (18.65). Similarly, the trait ranged from 5.06 to 31.92 g with a mean of 19.19 g among the mutants and 17.59 in the parent Arka Abhay. The parameters such as genotypic (24.27), phenotypic (31.99) coefficients of variation, heritability (62.95 %) and genetic advance as per cent of mean (41.06) were noticed as high.

4.2.2.2.11 Number of seeds per fruit

The Arka Anamika mutants had an average number of 36.67 seeds per fruit with a range of 15.00 to 70.00 seeds. The average number of seeds in the Arka Anamika control plants was 45.60. High phenotypic and genotypic coefficients of variations were 25.24 and 28.37 per cent, respectively. Heritability of 79.13 per cent with an expected genetic advance of 46.30 per cent was observed for the trait. In respect to Arka Abhay mutants, the trait ranged from 14.00 to 77.00 with a mean value of 43.51 whereas, the parent scored a mean value of 50.25. The GCV (26.03), PCV (26.29), heritability (98.02 %) and genetic advance as per cent of mean (30.17) observed were high.

4.1.2.2.11 Weight of seeds per fruit (g)

Weight of seeds per individual fruits among Arka Anamika ranged from 1.21 to 10.43 g with an overall mean of 4.25 g as compared to the control (4.75 g). Low value of GCV (9.57) and moderate estimate of PCV (15.25) were recorded. This trait exhibited moderate heritability (59.74%) with moderate per cent mean genetic advance (13.88).With respect to mutants of Arka Abhay, the trait had an average of 8.73 g with a range of 0.41 to 12.06 g. All the parameters such as GCV (12.09), PCV (14.19) and heritability (58.77 %) were moderate and GAM (21.19) was scored high.

4.1.2.2.12 Test weight (g)

The overall mean of the trait was 10.20 g in the control and the mutants had an average value of 9.20 g, ranging from 2.05 to 21.15 g. Although the GCV (22.09) and PCV (29.10) and heritability (74.61 %) were recorded as high, the genetic advance as per cent of mean (17.17) was moderate for the trait. Similarly, the range of this trait was 1.38 to 11.29 g with a mean of 8.30 g among the mutants and 10.20 g among the

control, Arka Abhay. The genetic parameters computed such as GCV (26.38), PCV (37.18) and heritability (70.95 %) were high and the genetic advance as per cent of mean (16.62) noticed was moderate.

4.1.2.2.13 Fruit yield per plant

Significant variation among the mutants of Arka Anamika for the total fruit yield per plant was observed. The total yield ranged between 3.88 to 453.88 g with a mean value of 101.85 g among the mutants and 126.35 g for the control. Low estimate of GCV (10.03) and high estimate of PCV (21.87) coupled with moderate heritability (45.56 %) and moderate genetic advance as per cent of mean (11.10) were observed for this trait. Among the mutants of Arka Abhay the trait ranged from 3.24 to 231.69 g with an overall mean of 116.88 g and the control had an average yield of 86.20 g. The GCV value was low and PCV estimate was high (9.74 and 20.06 respectively), whereas the heritability (47.52 %) was moderate combined with moderate GAM (19.05).

Significant differences for the fourteen traits were observed for varied doses and different incubation time in the present study. Mean performance of the major economic traits such as total fruit yield per plant, plant height, number of fruits, fruit length, single fruit weight, number of seeds, seed weight per fruit and test weight of the seeds were remarkably higher in the control set, on the other hand all the treatments of sodium butyrate exhibited comparatively below average performance in comparison to their parents. Alternatively, all the treatments has exhibited delay in flowering by recording higher mean number of days to first flowering compared to the parent varieties. Deleterious effects were found to be increased as the concentration of chemical and incubation period increased. The range of characters were higher, more importantly in case of fruit yield, plant height and days to first flowering.

In the treatments of sodium butyrate, traits such as number of branches per plant, number of fruits per plant, number of internodes on the main stem, single fruit weight, number of seeds per fruit and test weight exhibited higher values of GCV and PCV in the S_2 mutant of Arka Anamika. Days to first flowering exhibited lower values on the other hand, plant height, fruit length, fruit width, number of ridges and locules per fruit, seed weight and total fruit yield recorded moderate estimates of variability parameters. Similarly, in the S_2 mutants of Arka Abhay, days to first flowering showed low values of genotypic and phenotypic coefficients of variation. Moderate estimates were recorded by number of fruits per plant, fruit width, number of ridges and locules per fruit and seed weight. Total yield per plant has exhibited a low GCV combined with high PCV indicating that the trait could be more influenced by the environment. A similar observation was also made by Nwangburuka *et al.* (2012) for the fruit yield in cultivated okra.

Traits such as number of branches per plant, number of fruits per plant, fruit width, number of ridges and locules per fruit and number of seeds per fruit among the S_2 population of Arka Anamika showed high heritability coupled with high genetic advance as per cent of mean. Similarly, number of branches per plant, number of fruits per plant, fruit length, fruit width, number of internodes on the main stem, number of ridges and locules per fruit and number of seeds per fruit were the traits exhibited high heritability combined with high GAM. Selection of these characters with high heritability associated with high GAM would help in achieving high fruit yield (Das *et al.* 2012). High heritability coupled with high genetic advance showed a greater proportion of additive genetic variance and consequence a high genetic gain expected from selection (Devi and Mariappan, 2013). Fruit yield per plant recorded moderate estimates of heritability and genetic advance as per cent of mean indicating that the traits are governed by non-additive gene action and selection for such characters may not be effective (Singh and Singh, 2006).

4.2.2.3 Character association studies for yield and yield contributing characters in the S_2 mutant population

Yield is a complex trait governed by many genes and is the most crucial target in any crop improvement programme. Knowledge on trait associations among themselves and with the yield is considered to be very important for the direct selection of easily observable traits in any crop. The phenotypic correlations between total fruit yield and its thirteen contributing characters among the S_2 mutant lines of Arka Anamika and Arka Abhay were worked out to understand the degree and direction of association existing among them. The results are presented in Tables 30 and 31 respectively.

4.2.2.3.1 Fruit yield

Fruit yield per plant in the S_2 mutant populations of both Arka Anamika and Arka Abhay showed a significant positive association with almost all the traits except for days to first flowering, number of ridges per fruit, number of locules per fruit and test weight in both the mutant populations. Similar observations of significant positive correlation of the total yield with number of fruits, fruit length and single fruit weight were also observed by Raval *et al*. (2018), Dixit *et al*. (2019) and Ashraf *et al.* (2020) in mutant population of okra. The days to first flowering exhibited a non- significant negative correlation with the yield in Arka Anamika (-0.0101), whereas a non- significant positive correlation was noticed in Arka Abhay mutants (0.0882). The other trait such as number of ridges per fruit, number of locules per fruit and test weight recorded a positive but a non- significant correlation in the mutant populations of both the varieties.

Table 30: Phenotypic correlation for yield and yield attributing characters in S_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
DFF	1	-0.2216*	0.2852*	0.1014	-0.1855**	-0.3381*	-0.0649	0.0173	-0.0613	-0.2980*	0.3046*	0.0446	-0.2413*	-0.0101
PH		1	-0.0056	0.3310*	0.4187*	0.5303*	0.6070*	0.0048	0.1089	0.5718*	0.0004	0.2421*	0.3560*	0.5453*
NB			1.0000	0.6521*	0.1026	-0.2374*	0.4259*	-0.0791	-0.0940	-0.1818**	0.3287*	0.2568*	-0.0794	0.4391*
NF				1	0.3982*	-0.0520	0.6863*	-0.0484	-0.0729	0.0925	0.2403*	0.2327*	-0.0121	0.8542*
FL					1	0.0317	0.3407*	0.1998**	0.2683*	0.5181*	0.0599	0.2539*	0.2376*	0.4704*
FW						1	0.1722**	0.3039*	0.3264*	0.6688*	-0.0978	0.0859	0.2494*	0.2268*
INT							1	0.0682	0.0013	0.3453*	-0.0357	0.0859	0.0350	0.7993*
NR								1	0.9287*	0.1899**	0.0225	0.0577	0.0985	0.0497
NL									1	0.1813**	0.0616	0.1051	0.1687**	0.0054
SFW										1	0.1498**	0.1460**	0.1898**	0.3986*
NS											1	0.5808*	0.1139	0.1798**
SWT												1	0.6217*	0.1308**
TWT													1	0.0070
YLD														1

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 31: Phenotypic correlation for yield and yield attributing characters in S_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
DFF	1	-0.2742*	0.3277*	0.2392*	-0.0890	-0.1907**	0.2172**	-0.1073	-0.1328**	-0.1943**	0.3570*	0.1118	-0.0731	0.0882
PH		1	0.5827*	0.6398*	0.3933*	0.2228*	0.7785*	0.0479	0.0065	0.3345*	0.2918*	0.5501*	-0.0357	0.5210*
NB			1	0.6329*	0.2713*	-0.2171**	0.5560*	-0.1217	-0.0766	-0.0844	0.5813*	0.6640*	-0.0358	0.1995**
NF				1	0.5474*	0.1479**	0.6657*	-0.0739	-0.0548	-0.1301**	0.3771*	0.5505*	-0.0266	0.7328*
FL					1	0.0804	0.4369*	0.0306	-0.0067	0.4737*	0.1637**	0.2752*	-0.0151	0.6006*
FW						1	0.3060*	0.2680*	0.2004**	0.6351*	0.1149	-0.0899	0.0311	0.4600*
INT							1	0.0417	-0.0376	0.3022*	0.2117**	0.6191*	-0.0313	0.5347*
NR								1	0.8928*	0.2162**	0.0232	0.0318	-0.0509	0.0569
NL									1	0.1692*	0.0247	-0.0125	0.0849	0.0168
SFW										1	0.1765**	0.1432**	0.1554**	0.5486*
NS											1	0.4264*	0.1632**	0.1827**
SWT												1	0.3220*	0.2374*
TWT													1	0.0618
YLD														1

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

4.2.2.3.2 Days to first flowering

Days to first flowering showed a positive significant correlation with number of branches per plant (0.2852) and number of seeds per fruit (0.3046) whereas a significant negative correlation was observed for plant height (-0.2216), fruit length (-0.1855), fruit width (-0.3381), single fruit weight (-0.2980) and test weight (-0.2413) among the S_2 population of Arka Anamika. Similarly, in case of mutants of Arka Abhay, a positive significant correlation was observed for number of branches per plant (0.3277), number of fruits (0.2392), number of internodes on the main stem (0.2172) and number of seeds per fruit (0.3570), and a significant negative correlation was exhibited by plant height (-0.2742), fruit width (-0.1907), number of locules per plant (-0.1328) and single fruit weight (-0.1943). The mutant population of Arka Anamika had negative but non- significant association with the fruit yield (-0.0101) whereas and Arka Abhay had positive but non- significant correlation (0.0882) with the fruit yield.

4.2.2.3.3 Plant height

The trait had a significant positive correlation with various traits like fruit yield (0.5433), number of fruits per plant (0.3310), fruit length (0.4187) fruit width (0.5303), number of internodes on the main stem (0.6070), single fruit weight (0.5718), seed weight per fruit (0.2421) and test weight (0.3560) in case of Arka Anamika mutants. Similarly, the mutants of Arka Abhay also recorded a positive significant correlation with fruit yield (0.5210), number of branches per plant (0.5827), number of fruits per plant (0.6398), fruit length (0.3933), fruit width (0.2228), number of internodes on the main stem (0.7785), single fruit weight (0.3345), number of seeds per fruit (0.2918) and weight of seeds per fruit (0.5501). Both the mutant population had a positive but non-significant correlation of plant height with number of ridges per fruit and number of locules per fruit.

4.2.2.3.4 Number of branches per plant

Significant positive correlation was observed in number of branches per plant with yield (0.4391), days to first flowering (0.2852), number of fruits (0.6521), number of internodes on the main stem (0.4259), number of seeds per fruit (0.3287) and weight of seeds per fruit (0.2568) in case of Arka Anamika mutant lines. The trait, fruit width (-0.2374) and single fruit weight (-0.1818), had negative and significant correlation with the trait. In case of Arka Abhay mutants, fruit yield (0.1995), days to first flowering (0.3277), plant height (0.5827), number of fruits per plant (0.6329), fruit length (0.2713), number of internodes on the main stem (0.5560), number of seeds per fruit (0.5813) and weight of seeds per fruit (0.6640) had showed significant and positive correlation. Fruit width (-0.2171) was the trait which exhibited significant negative correlation with number of branches per plant.

4.2.2.3.5 Number of fruits per plant

The number of fruits per plant scored significant positive correlation in Arka Anamika mutants with fruit yield (0.8542), plant height (0.3310), number of branches per plant (0.6521), fruit length (0.3982), number of internodes on the main stem (0.6883), number of seeds per fruit (0.2403) and weight of seeds per fruit (0.2327). Similarly, in case of Arka Abhay mutants, the trait exhibited positive and significant association with fruit yield (0.7328), days to first flowering (0.2392), plant height (0.6398), number of branches per plant (0.6329), fruit length (0.5474), fruit width (0.1479), number of internodes on the main stem (0.6657), number of seeds per fruit (0.3771) and weight of seeds per fruit (0.5505). Single fruit weight was negatively and significantly correlated (-0.1301) with the number of fruits per plant.

4.2.2.3.6 Fruit length

In Arka Anamika mutants, fruit length showed significant positive correlation with fruit yield (0.4704), plant height (0.4187), number of fruits (0.3982),number of internodes on the main stem (0.3407), number of ridges (0.1998) and locules (0.2683) per fruit, single fruit weight (0.5181), weight of seeds per fruit (0.2539) and test weight (0.2376). Fruit yield (0.6006), plant height (0.3933), number of branches per plant (0.2713),number of fruits per plant (0.5474) number of internodes on the main stem (0.4369), single fruit weight (0.4737), number of seeds per fruit (0.1637) and weight of seeds per fruit (0.2752) were the characters which showed significant positive correlation with fruit length in case of Arka Abhay mutants.

4.2.2.3.7 Fruit width

Phenotypic correlation of Arka Anamika mutants for this trait was positively significant with fruit yield (0.2268), plant height (0.5303), number of internodes on the main stem (0.1722), number of ridges (0.3039) and locules (0.3264) per fruit, single fruit weight (0.6688) and test weight (0.2494), on the other hand, days to first flowering (-0.3381) and number of branches per plant (-0.2374) were significantly and negatively associated. Likewise, in Arka Abhay mutants, the traits, fruit yield (0.4600), plant height (0.2228), number of fruit per plant (0.1479), number of internodes on the main stem (0.3060), number of ridges (0.2680) and locules (0.2004) per fruit and single fruit weight (0.6351) recorded significant and positive correlation with fruit width. Days to first flowering (-0.1907) and number of branches per plants (-0.2171) were significantly and negatively correlated to fruit width.

4.2.2.3.8 Number of internodes on the main stem

The number of internodes on the main stem recorded significant positive correlation in Arka Anamika mutants with fruit yield (0.7993), plant height (0.6070), number of branches per plant (0.4259), number of fruits per plant (0.6863), fruit length (0.3407), fruit width (0.1722) and single fruit weight (0.3453). In case of

Arka Abhay mutant population, a positive and significant association was observed with fruit yield (0.5347), days to first flowering (0.2172), plant height (0.7785), number of branches per plant (0.5560), number of fruits per plant (0.6657), fruit length (0.4369), fruit width (0.3060), weight of single fruit (0.3022), number of seeds per fruit (0.2117) and weight of seeds per fruit (0.6191).

4.2.2.3.9 Number of ridges per fruit

The trait had significant positive association with number of locules per fruit (0.9287), fruit length (0.1998), fruit width (0.3039) and single fruit weight (0.1899) in Arka Anamika mutant population. Similarly, in case of Arka Abhay mutants, the trait had positive significant correlation with fruit width (0.2680), number of locules per fruit (0.8928) and single fruit weight (0.2162). The trait recorded positive non- significant correlation with the yield in mutants of Arka Anamika (0.0497) and Arka Abhay.

4.2.2.3.10 Number of locules per fruit

Number of locules per fruit positively and significantly associated with fruit length (0.2683), fruit width (0.3264), number of ridges per fruit (0.9287), single fruit weight (0.1813) and test weight (0.1687) in mutants of Arka Anamika. On the other hand, number of ridges per fruit (0.8928), fruit width (0.2004) and single fruit width (0.1692) showed positive and significant association with the trait in Arka Abhay mutant population. Days to first flowering (-0.1328) had a negative significant correlation. A positive non-significant association was observed for fruit yield in Arka Anamika and Arka Abhay mutants (0.0054 and 0.0168, respectively).

4.2.2.3.11 Single fruit weight

Positive and significant phenotypic correlation among the mutants of Arka Anamika was noticed for fruit yield (0.3986), plant height (0.5718), fruit length (0.5181), fruit width (0.6688), number of internodes on the main stem (0.3453), number of ridges per plant (0.1899), number of locules per plant (0.1813), number of seeds per fruit (0.1498), weight of seeds per fruit (0.1460) and test weight (0.1898). Significant but a negative correlation was observed for days to first flowering (-0.2980) and number of branches per plant (-0.1818) among the population. Correspondingly in the mutant population of Arka Abhay positive and significant correlation was observed for fruit yield (0.5486), plant height (0.3345),fruit length (0.4737), fruit width (0.6351), number of internodes on the main stem (0.3022), number of ridges per plant (0.2162), number of locules per plant (0.1692), number of seeds per fruit (0.1765), weight of seeds per fruit (0.1432) and test weight (0.1554) whereas, negative significant correlation was observed for days to first flowering (-0.1943) and number of fruits per plant (-0.1301).

4.2.2.3.12 Number of seeds per fruit

Number of seeds per fruit expressed significant and positive association with total yield (0.1798), days to first flowering (0.3046), number of branches per plant (0.3287), number of fruits per plant (0.2403), weight of single fruits (0.1498) and weight of seeds per fruit (0.5808) in case of mutants of Arka Anamika. Likewise, mutants of Arka Abhay has exhibited positive significant correlation with fruit yield (0.1827), days to first flowering (0.3570), plant height (0.2918), number of branches per plant (0.5813), number of fruits per plant (0.3771), fruit length (0.1637), number of internodes on the main stem (0.2117), single fruit weight (0.1765), weight of seeds per fruit (0.4264) and test weight (0.1632).

4.2.2.3.13 Weight of seeds per fruit

A positive and significant correlation among the mutant population of Arka Anamika was recorded for fruit yield (0.1308), plant height (0.2421), number of branches per plant (0.2568), number of fruits per plant (0.2327), length of the fruit (0.2539), single fruit weight (0.1460) and number of seeds per fruit (0.5808). Characters such as fruit yield (0.2374), plant height (0.5501), number of branches per plant (0.6640), number of fruits per plant (0.5505), fruit length (0.2752), number of internodes on the main stem (0.6191), single fruit weight (0.1432), number of seeds per fruit (0.4264) and test weight (0.3220) recorded significant positive correlation among mutants of Arka Abhay.

4.2.2.3.14 Test weight

In Arka Anamika mutant population, weight of hundred seeds was found to have significant positive correlation with plant height (0.3560), fruit length (0.2376), fruit width (0.2494), number of locules per fruit (0.1687), single fruit weight (0.1898) and weight of seeds (0.6217). Positive but non- significant association of test weight with yield (0.0070) was observed. Identically mutants of Arka Abhay also showed a positive but non- significant correlation (0.0618) with the yield. Single fruit weight (0.1554), number of seeds per fruit (0.1632) and weight of seeds per fruit (0.3220) were the traits exhibited positive association with the test weight.

4.2.2.4 Path coefficient analysis

Path coefficient is standardized partial regression coefficient which partitions the correlation coefficients into the direct and indirect effects of a group of independent variables on the dependent variable. It is also known as cause and effect relationship of different variables. Correlation studies together with path analysis provide a better insight in to the relationship of different traits with the yield and helps in the improvement of dependent variable through the selection of independent variables. The results of path coefficient analysis for 13 independent characters with

fruit yield are presented in Tables 32 and 33 for Arka Anamika and Arka Abhay mutant populations respectively.

4.2.2.4.1 Direct effect of yield attributing traits on the fruit yield

Path coefficient analysis of the S_2 mutant population of Arka Anamika revealed that the trait number of fruits per plant recorded the highest positive direct effect (0.4020) on fruit yield followed by single fruit weight (0.2593) and number of internodes on the main stem (0.1710). Plant height (0.0759), number of branches per plant (0.1058), fruit length (0.0469), fruit width (0.0642), number of ridges per fruit (0.0893), number of seeds per fruit (0.0745), seed weight per fruit (0.0106) and test weight (0.0902) were the traits which showed direct positive effect on yield. Alternatively, a negative direct effect was exhibited by days to first flowering (-0.1708) and number of locules per fruit (-0.0605).

Similarly, in case of Arka Abhay mutant lines, number of fruits per plant had the highest positive effect on total fruit yield (0.5030) preceded by single fruit weight (0.3635) and fruit length (0.3066). Plant height (0.0066), number of branches per plant (0.2929), number of internodes on the main stem (0.0909), number of ridges per fruit (0.1549), number of seeds per fruit (0.1056), weight of seeds per fruit (0.2333) and test weight (0.0380) were the other traits recorded for positive direct effect. On the other hand, characters such as days to first flowering (-0.0079), fruit width (-0.0729) and number of locules per fruit (-0.1632) had displayed direct but negative effect on total yield of fruit. The results highlights traits which are primary determinant of yield and suggests that the selection of these characters would be beneficial for improvement in okra. Rynjah *et al.* (2020) noticed positive direct effects of fruit length and fruit weight and Rana *et al.* (2020) noticed for number of fruits per plant. Negative direct effects of days to first flowering on yield was also noticed by Rynjah *et al.* (2020) while working with okra.

4.2.2.4.2 Indirect effect of yield attributing traits on the fruit yield

The highest indirect and positive effect on fruit yield per plant among the mutants of Arka Anamika was scored by number of internodes on the main stem (0.4576), number of branches per plant (0.3176) and fruit length (0.2401) *via* number of fruits per plant. However, the highest negative indirect effect on fruit yield was exhibited by days to first flowering *via* single fruit weight (-0.2708).

Likewise, among the mutants of Arka Abhay, the positive indirect effects were indicated by number of internodes on the main stem (0.4050), plant height (0.2779), number of branches per plant (0.2689) *via* number of fruits and also by fruit width (0.2966) *via* single fruit weight. Nevertheless, high but negative indirect effect of days to first flowering *via* number of fruits per plant (-0.2438) was also observed among the population.

Table 32: Phenotypic path of different yield components on fruit yield in S_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT
DFF	**-0.1708**	-0.0167	-0.0017	0.0750	0.0089	-0.0218	-0.0103	0.0018	0.0036	-0.2708	-0.0223	0.0004	0.0216
PH	0.0876	**0.0759**	0.0001	0.1076	-0.0197	0.0340	0.1043	-0.0179	-0.0085	0.0908	0.0032	0.0025	-0.0325
NB	-0.0495	-0.1108	**0.1058**	0.3176	0.1047	-0.0154	0.0735	-0.0471	0.0054	-0.0287	-0.0246	0.0028	0.0072
NF	-0.0171	0.0250	0.1538	**0.4020**	-0.0688	-0.0032	0.1780	-0.0745	0.0042	0.0143	-0.0179	0.0024	0.0009
FL	0.0325	0.0319	-0.0006	0.2401	**0.0469**	0.0340	0.0881	0.0179	-0.0163	0.0828	-0.0045	0.0026	-0.0216
FW	0.0581	0.0402	0.0014	-0.0375	-0.0249	**0.0642**	0.0791	-0.0268	-0.0210	0.1067	0.0074	0.0010	-0.0225
INT	0.0102	0.1063	-0.0025	0.4576	-0.0159	0.0109	**0.1710**	0.0062	0.0000	0.0558	0.0630	0.0010	-0.0036
NR	-0.0014	0.0152	0.0005	-0.2175	-0.0094	0.0193	0.0120	**0.0893**	0.0564	0.0423	-0.0015	0.0006	-0.0090
NL	-0.0002	0.0106	0.0005	-0.1995	-0.0127	0.0212	0.0191	0.0630	**-0.0605**	0.0287	-0.0045	0.0112	-0.0153
SFW	0.0512	0.0433	0.0010	0.0675	0.1779	0.0430	0.0598	0.0170	-0.0109	**0.2593**	0.0097	0.0005	-0.0171
NS	-0.0512	0.0057	0.0710	-0.2301	0.1258	-0.0064	-0.0068	0.0018	0.0700	-0.0207	**0.0745**	0.0887	-0.0099
SWT	-0.0068	0.0182	0.0805	0.0725	0.0767	0.0058	0.0154	0.0054	-0.0067	0.0080	0.0532	**0.0106**	0.0189
TWT	0.0410	0.0273	0.0305	-0.1975	0.0813	0.0041	0.0068	0.0089	-0.0103	0.0303	0.0382	0.0066	**0.0902**
r value	-0.0101	0.5453**	0.4390**	0.8543**	0.4704**	0.2268**	0.7995**	0.0497	0.0055	0.3986**	0.1798**	0.1309**	0.0071

RESIDUAL: 0.0950

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 33: Phenotypic path of different yield components on fruit yield in S_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT
DFF	**-0.0079**	0.0018	-0.0966	-0.2438	0.0006	0.0139	0.0200	-0.0870	0.0212	-0.0881	0.0380	-0.0257	-0.0027
PH	0.0021	**0.0066**	0.1699	0.2779	-0.0026	-0.0160	0.0709	0.0077	0.0016	-0.1853	0.0306	-0.1283	-0.0137
NB	0.0026	0.1938	**0.2929**	0.2689	-0.0018	0.0175	0.0509	-0.0796	0.0131	-0.0371	0.0612	0.0184	-0.0137
NF	0.0019	0.1442	0.1815	**0.5030**	-0.0037	-0.0109	0.0609	-0.0108	0.0082	-0.1793	0.0001	-0.1283	-0.0103
FL	-0.0007	0.0026	-0.0791	0.2466	**0.3066**	-0.0277	0.0400	0.0001	0.0016	0.2179	0.0169	0.0653	-0.0008
FW	-0.0015	0.0015	0.0703	-0.1354	-0.0025	**-0.0729**	0.0282	0.0108	-0.0326	0.2966	-0.0264	0.0210	0.0011
INT	0.0017	0.1652	-0.1640	0.4050	-0.0029	-0.0226	**0.0909**	0.0062	0.0065	0.0891	-0.0782	0.1446	-0.0125
NR	-0.0009	0.0003	0.0351	-0.1632	-0.0002	-0.0197	0.0036	**0.1549**	0.1452	0.0069	0.0021	-0.0070	-0.0019
NL	-0.0010	-0.0001	0.0234	-0.0851	0.0001	-0.0146	-0.0036	0.0508	**-0.1632**	0.0088	0.0021	0.0023	0.0030
SFW	-0.0015	0.0022	0.0234	0.0554	0.1341	0.0767	0.0273	0.0031	0.0297	**0.3635**	-0.0084	-0.0327	0.0023
NS	0.0929	0.0019	-0.1699	-0.1991	0.0711	0.0182	0.0191	0.0031	-0.0033	-0.0371	**0.1056**	-0.1003	-0.0023
SWT	0.0009	0.0036	-0.1933	0.0266	0.1019	0.0066	0.0564	0.0046	0.0016	0.0649	0.0454	**0.2333**	0.0752
TWT	-0.0006	-0.0024	0.1054	-0.2167	0.0001	-0.0022	0.0730	-0.0077	-0.0131	0.0278	-0.0063	0.1747	**0.0380**
r value	0.0882	0.5212**	0.1995**	0.7401**	0.6006**	0.4600**	0.5347**	0.0562	0.0165	0.5486**	0.1827**	0.2373**	0.0617

RESIDUAL: 0.1629

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Residual effect value of path analysis were 0.0950 and 0.1629 (Arka Anamika and Arka Abhay respectively) which is low in value and indicated that most of the important characters contributing towards fruit yield had been included in the study.

4.2.2.5 Identification of desirable mutants

Majority of the traits considered under the study had varied significantly observed among the S_2 mutant population of Arka Anamika and Arka Abhay induced by sodium butyrate of various concentrations and different incubation periods. Characters such as days to first flowering, plant height, number of branches and internodes per plant, number of fruits per plant, fruit length, single fruit weight, the total fruit weight per plant and other traits were remarkably inferior in the treatments compared to their control. From among the 120 mutant lines of each variety, superior ones were selected and forwarded to the third generation (S_3) based on the average performance of the lines for these traits.

Among the 120 mutant lines of Arka Anamika, 19.17 per cent of them showed higher performance compared to the average performance of parent (125.00 g) for the total fruit yield per plant. Twenty three lines among 120 mutant lines (19.16 per cent) were early flowering mutants in comparison to the check (47 days). Out of which four lines (AN-50-3-1, AN-150-3-2, AN-150-3-18 and AN-150-3-29) were reasonably higher yielding compared to the Arka Anamika composing 3.33 per cent of the total population (Figure 2). In case of number of fruits per plant, 33.34 per cent of the total lines exhibited superior performance whereas, 28.34 per cent for fruit length and 20.84 per cent for single fruit weight.

On the other hand, 24.17 per cent of the total 120 lines of Arka Abhay displayed better yielding ability compared to their parent. 16.67 per cent of the population (20 lines) were early flowering, out of which five lines (AB-50-3-8, AB-50-3-12, AB-150-3-12, AB-150-3-17 and AB-150-3-20) were yielding remarkably (Figure 2), composing 4.16 per cent of the total population. In the mutant population, 39.17 per cent of them were better performing in terms of number of fruits per plant, 32.50 per cent of them were satisfactory for the fruit length and 28.34 per cent of them were good in terms of weight of single fruits. From both the populations, accounting for other important traits as well, the top fifteen superior mutant lines (12.50 per cent of the total population) each were selected and listed in Tables 34 and 35.

Among the mutant lines of Arka Anamika, the line AN-50-3-1 was the early flowering mutant (46 days), with the highest yield performance (450.00 g) and was also found superior for other traits like number of fruits (24.00), fruit length (17.45 cm), single fruit weight (19.50 g), number of branches (7.00) and internodes

Table 34: Top fifteen lines identified in S_2 population of Arka Anamika variety

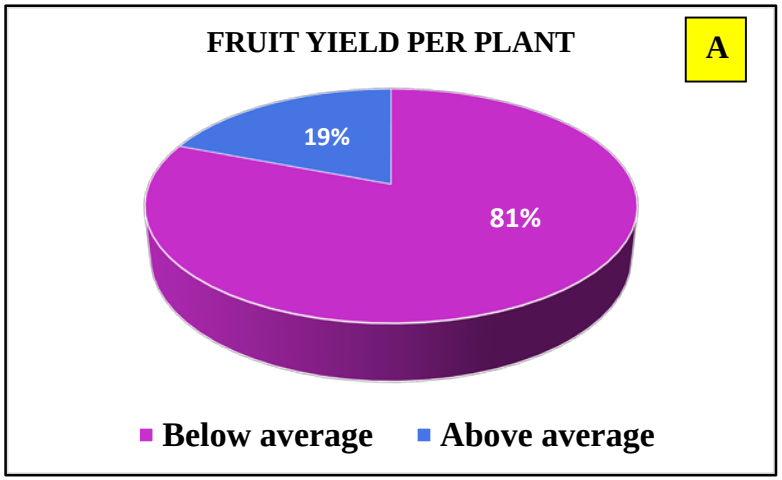
Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TSW	YLD
1	Control	47.00	70.25	3.55	12.20	14.25	9.50	16.00	47.00	4.75	10.20	125.00
2	AN-50-3-1	46.00	110.00	7.00	24.00	17.45	15.00	19.50	40.00	5.95	16.50	450.00
3	AN-50-3-2	48.00	75.00	4.00	15.00	14.20	17.00	18.00	54.00	5.42	9.64	214.52
4	AN-50-3-5	50.00	69.50	5.00	14.00	13.80	14.00	16.50	47.00	4.12	8.91	201.20
5	AN-50-3-9	51.00	77.50	5.00	13.00	15.15	16.00	17.45	55.00	5.56	10.25	199.05
6	AN-50-5-5	51.00	88.00	4.00	11.00	14.25	9.00	19.50	49.00	4.88	10.25	191.20
7	AN-50-5-20	52.00	69.50	5.00	13.00	13.75	6.00	17.60	46.00	4.65	9.64	198.75
8	AN-150-3-2	45.00	72.00	4.00	12.00	15.00	10.00	14.00	45.00	5.19	11.23	208.00
9	AN-150-3-18	44.00	52.00	2.00	15.00	18.00	8.00	18.50	52.00	6.05	10.65	212.65
10	AN-150-3-19	50.00	108.00	4.00	16.00	17.50	16.00	12.55	42.00	4.45	10.02	207.22
11	AN-150-3-21	50.00	73.00	4.00	14.00	17.00	12.00	14.40	44.00	4.82	11.54	200.50
12	AN-150-3-22	49.00	75.00.	3.00	12.00	17.50	12.00	22.45	54.00	6.81	15.64	193.00
13	AN-150-3-29	46.00	90.00	4.00	13.00	16.50	14.00	21.50	52.00	6.26	14.93	207.00
14	AN-150-3-34	54.00	102.00	9.00	14.00	20.00	16.00	20.50	52.00	4.56	9.51	225.00
15	AN-150-5-9	53.00	96.00	4.00	14.00	18.00	12.00	27.30	51.00	4.02	12.98	192.00
16	AN-150-5-10	54.00	91.00	5.00	16.00	17.50	11.00	31.00	45.00	3.72	11.69	331.00
CD		1.08	4.70	0.63	2.20	3.00	5.71	4.34	4.72	3.37	2.91	12.75

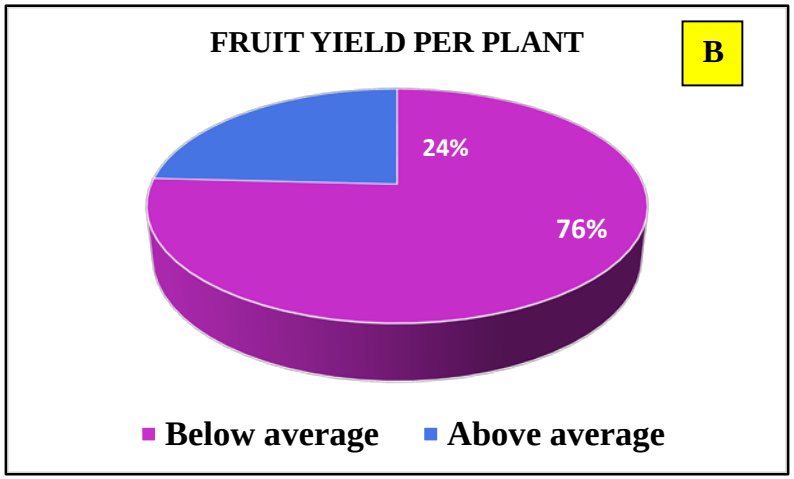
DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit length (cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g), YLD=Yield *per* plant

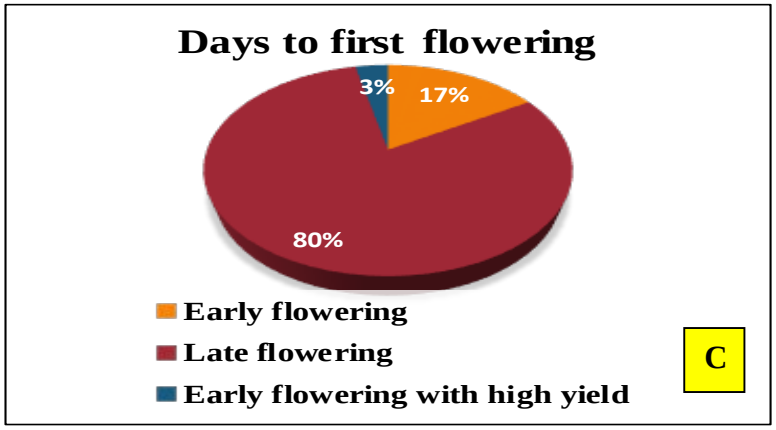
Table 35: Top fifteen lines identified in S_2 population of Arka Abhay variety

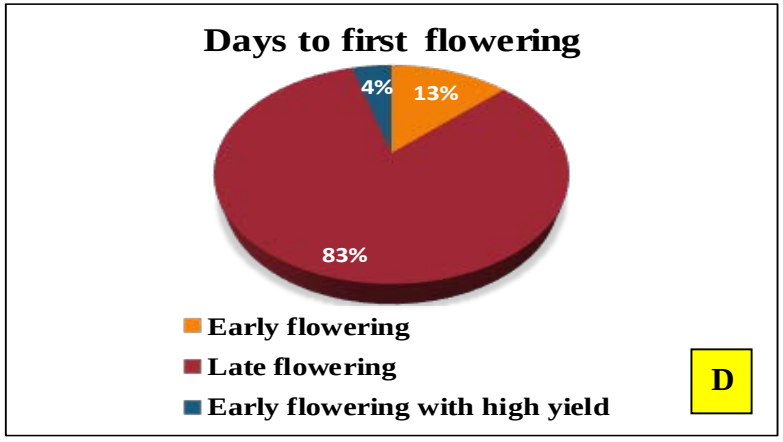
Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TSW	YLD
1	Control	49.20	81.25	3.70	8.05	15.22	8.50	17.15	50.00	5.60	10.00	86.20
2	AB-50-3-5	53.00	90.00	5.00	10.00	18.50	13.00	30.40	51.00	5.00	10.25	111.00
3	AB-50-3-8	46.00	66.00	4.00	12.00	17.55	10.00	24.00	37.00	3.65	8.62	114.00
4	AB-50-3-12	44.00	102.00	6.00	13.00	18.20	14.00	31.50	42.00	4.02	9.97	121.00
5	AB-50-5-5	55.00	90.00	2.00	10.00	19.50	12.00	27.20	58.00	4.55	11.65	122.60
6	AB-50-5-8	54.00	61.00	3.00	12.00	17.00	13.00	18.50	52.00	3.56	6.86	124.70
7	AB-50-5-15	57.00	65.20	4.00	10.00	19.00	12.00	31.00	55.00	3.26	7.58	145.00
8	AB-50-5-17	55.00	64.35	4.00	15.00	18.50	12.00	25.00	55.00	5.25	11.22	231.50
9	AB-150-3-10	58.00	118.00	7.00	11.00	21.00	25.00	13.43	41.00	4.11	8.17	145.30
10	AB-150-3-11	50.00	66.00	4.00	11.00	21.00	19.00	14.00	50.00	5.50	10.20	135.00
11	AB-150-3-12	45.00	55.00	3.00	13.00	21.30	20.00	16.50	52.00	6.10	11.23	128.10
12	AB-150-3-13	54.00	57.00	4.00	12.00	20.50	20.00	16.20	55.00	5.50	9.88	130.26
13	AB-150-3-14	55.00	58.00	4.00	14.00	19.60	19.00	17.00	54.00	5.20	11.40	121.20
14	AB-150-3-16	55.00	63.54	4.00	14.00	22.00	15.00	20.00	60.00	5.40	8.24	122.36
15	AB-150-3-17	45.00	71.50	5.00	10.00	21.55	22.00	18.75	62.00	6.10	7.35	140.00
16	AB-150-3-20	45.00	31.00	3.00	10.00	18.00	11.00	18.33	43.00	4.35	9.12	124.00
CD		1.52	7.07	1.98	1.26	3.19	2.60	3.16	4.15	0.64	2.21	9.05

DFF =Days to first flowering, PH =Plant height at maturity, NB=Number of branches *per* plant, NF=Number of fruits per plant, FL=Fruit length (cm), INT=Number of Internodes, SFW= Single Fruit weight, NS=Number of seeds *per* fruit, SWT = Seed weight per fruit, TWT= Test weight (g), YLD=Yield *per* plant









A and B: Percentage of superior mutant lines for fruit yield in Arka Anamika and Arka Abhay respectively,
C and D: Percentage of early flowering mutant lines in Arka Anamika and Arka Abhay respectively

Figure 2: Percentage of superior lines in the mutant population of Arka Anamika and Arka Abhay induced by sodium butyrate

(15.00). Three other lines, AN- 150-3-2 (45 days), AN-150-3-18 (44 days) and AN-150-3-29 (46 days) were also early flowering types with remarkably significant fruit yield (208.00 g, 212.65 g and 207.00 g, respectively) compared to the parent (125.00 g). The lines AN-150-5-10 and AN-150-3-34 also exhibited higher fruit yield (331.00 g and 225.00 g, respectively) and other yield determining characters suggesting to be other superior lines among the population.

In case of Arka Abhay mutant population, the line AB-150-3-17(45.00 days) was the highest fruit yielder (140.00 g) in the early flowering types compared to the control (49.20 days). The number of fruits (10.00), fruit length (21.25 cm), single fruit weight (18.75 g), number of branches (5.00) and internodes (22.00) were also recorded to be high in the line. The line AB-50-5-17 was the highest yielder (231.50 g) in the total population, which first blossomed on the 55^{th} day. The number of branches per plant (4.00), number of fruits per plant (15.00), fruit length (18.50), number of internodes on the main stem (12.00), single fruit weight (25.00) and other yield contributing traits were also higher in this line. Other lines *viz*., AB-50-3-8, AB-50-3-12, AB-150-3-12 and AB-150-3-20 were also early flowering mutants with higher fruit yield and other yield parameters.

Recent studies have provided ample evidences to support that many plant species possess natural variations in epigenetic modifications, comparable and in conjunction with changes in DNA sequence (Cervera *et al.* 2002, Riddle and Richards 2002, Keyte *et al.*, 2006, Vaughn *et al.* 2007 and Zhang *et al.* 2008). It is postulated that at least some of these variations are heritable to subsequent generations and are independent of genetic variation, and have the potential to respond to evolution by natural selection (Kalisz and Purugganan 2004, Jablonka and Lamb 2005, Rapp and Wendel 2005, Richards, 2006 and Johannes *et al*., 2008.

4.3 Experimental Studies in okra using epigenetic mutagen, Trichostatin-A (TSA)

4.3.1 Observation in TS_1 generation using Trichostatin-A (TSA)

Epigenetic changes in the genetic material such as DNA methylation, demethylation and post-translational histone modifications are known to impart visual variations in many organisms. Various enzymes such as histone acetylases and histone deacetylases can add or remove the acetyl group from the amino terminal of the histone proteins. Trichostatin-A is one of such organic compounds which interferes the gene expression by actively hamper the removal of acetyl groups in the histones. In this part of the experiment, various observable mutations and micro- mutations on various traits induced by Trichostatin-A on two okra varieties, namely Arka Anamika and Arka Abhay are investigated and discussed below.

4.3.1.1 Morphological mutations

Visible and noticeable morphological variants were evident, following the Trichostatin-A treatment among both the okra varieties. The total number of seedlings emerged in the field and the percentage of survival of the seedlings were observed to be fewer in Trichostatin-A treated seeds compared to the parental control (Table 36). The maximum number of survived plants in both the varieties were observed in control treatment followed by treatment with 0.4 µM Trichostatin-A incubated for three days. In contrast, the number of seedlings germinated in petri dishes under dark conditions were considerably high for 0.4 µM Trichostatin-A and 1.2 µM Trichostatin-A treatments incubated for three days whereas, the number decreased drastically when seeds were incubated in chemical for five days.

Correlations between DNA repair and chromatin modifications were identified in response to HDAC inhibitors such as TSA and NaB during *Medicago truncatula* seed germination (Pagano *et al.,* 2017, 2019). A dose-dependent impairment of seed germination and seedling growth was associated with enhanced accumulation of DNA damage, upregulation of genes involved in base excision repair (BER), and chromatin assembly factors. In a different study using *Petunia hybrida*, Pagano *et al.* (2020) identified that the seedlings treated with HDAC inhibitors under light conditions had severely affected with seedling developments as reflected by the decreased root and shoot elongation accompanied by increased DNA damage. On the other hand, when seedlings were treated and grown under dark conditions, the damaging effects were reduced.

They also postulated that the treatment with HDAC inhibitors under light conditions had resulted in increased expression of HAT/HDAC (HISTONE ACETYL TRANSFERASES/ HISTONE DEACTEYLASES) genes along with repression of genes involved in DNA repair. Likewise, under dark conditions, the expression of DNA repair genes was enhanced by the HDAC treatment which reduced the levels of total DNA damage in the seedlings. The present study is in accordance with observation, in which the seed germination was higher in petri plates under dark conditions, whereas the substantial reduction was recorded in the number of plants survived in the main field under light conditions.

The seedlings that emerged in the field in all the treatments were dwarf and had shorter internodes. Leaves were crinkled and serrated in most of the treatments. Forestan (2018) reported that the phenotype of maize hda108/hda108 mutant plants developed by HDA108 (maize Rpd3/HDA1 family of histone deacetylases) gene knockout is correlated with many developmental defects, including remarkable reduction in the plant height, alterations of shoot and leaf development combined with internodal shortening. Reduced number of leaves, alterations in leaf morphology, twisting of leaves, leaf knots, leaf blade length reduction and disorganized differentiation of the blade–sheath boundary.

Table 36: Effect of Trichostatin-A treatments on germination parameters seeds of Arka Anamika and Arka Abhay

Variety	Treatment	Total number of seeds incubated	No. of germinated seeds in petri dish	Field germination (%)	Survival percentage (%)
ARKA ANAMIKA	Control (T_{11})	100	42	79	76
	T_{12}	100	52	40	34
	T_{13}	100	36	23	18
	T_{14}	100	41	35	30
	T_{15}	100	33	26	22
ARKA ABHAY	Control (T_{16})	100	51	88	84
	T_{17}	100	67	61	56
	T_{18}	100	47	37	30
	T_{18}	100	63	51	48
	T_{20}	100	48	43	32

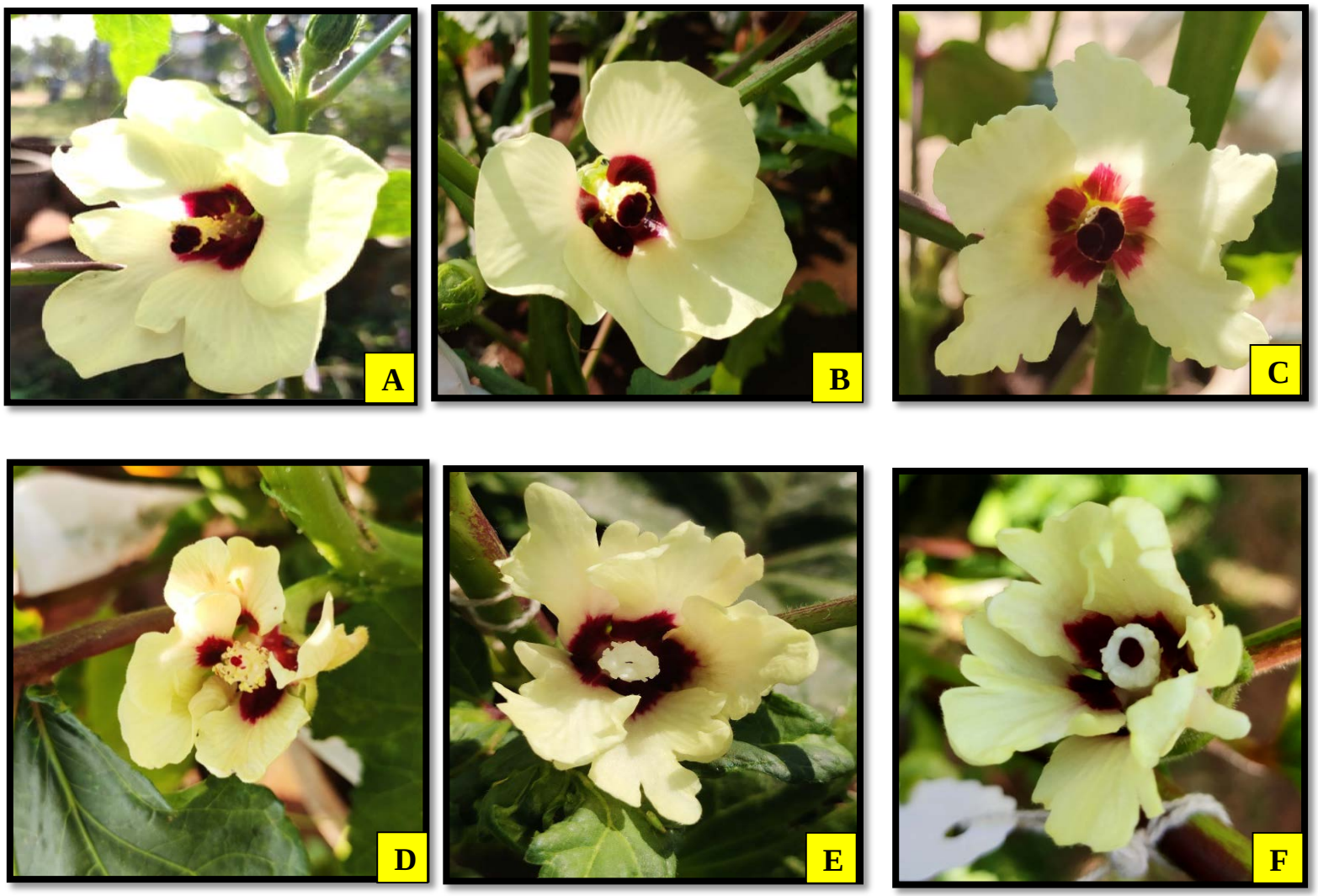
Noticeable variations in flowers such as petals with unusual shape and size, flowers with less than five petals, flowers with more than five petals, increased number of stigmata, decreased number of stigmata, complete absence of male organs, complete absence of female flower part and flowers plants with high percentage of sterility (Plate 8) were also recorded.

Tian and Chen (2000) examined an Arabidopsis mutant plant expressing the antisense AtHD1 which causes a dramatic reduction in endogenous AtHD1 transcription, resulting in the accumulation of acetylated histones. He furnished that the changes in acetylation profiles in the mutant were associated with various developmental abnormalities, early senescence of the plants, homeotic changes, suppression of apical dominance, a heterochronic shift toward juvenility and thereby delay in flowering, various flower defects and male and female sterility. They also postulated that the increased levels of tetra acetylated H4 histone protein resulted in ectopic expression of tissue-specific genes such as SUPERMAN (SUP gene: Controls the boundary between carpel and stamen development in flower) together with the presence of abnormal flowers without sepals and petals but with extra stamens. Inhibiting histone deacetylation affects not only SUP gene expression but also down regulated some additional genes (e.g., B function genes) required for normal flower (sepals and petals) developments on the other hand, induced function of *serrate* alleles (single gene controlling the leaf margin serration) in *Arabidopsis thaliana*.

Some of the plants in TSA treatment were found too bear fruits which were wider, an increased number of ridges and locules and with the difference in the colour of the fruits were also observed. The seeds varied for sizes and shapes and they also exhibited differences in colours such as grey, dark grey, brown and black (Plate 8). Keeping the response of the two varieties for the treatment of Trichostatin-A aside, a general trend of reduced germination, delayed flowering, reduced plant height and other morphological characters were exhibited by the plants of various treatments in contrast to their control.

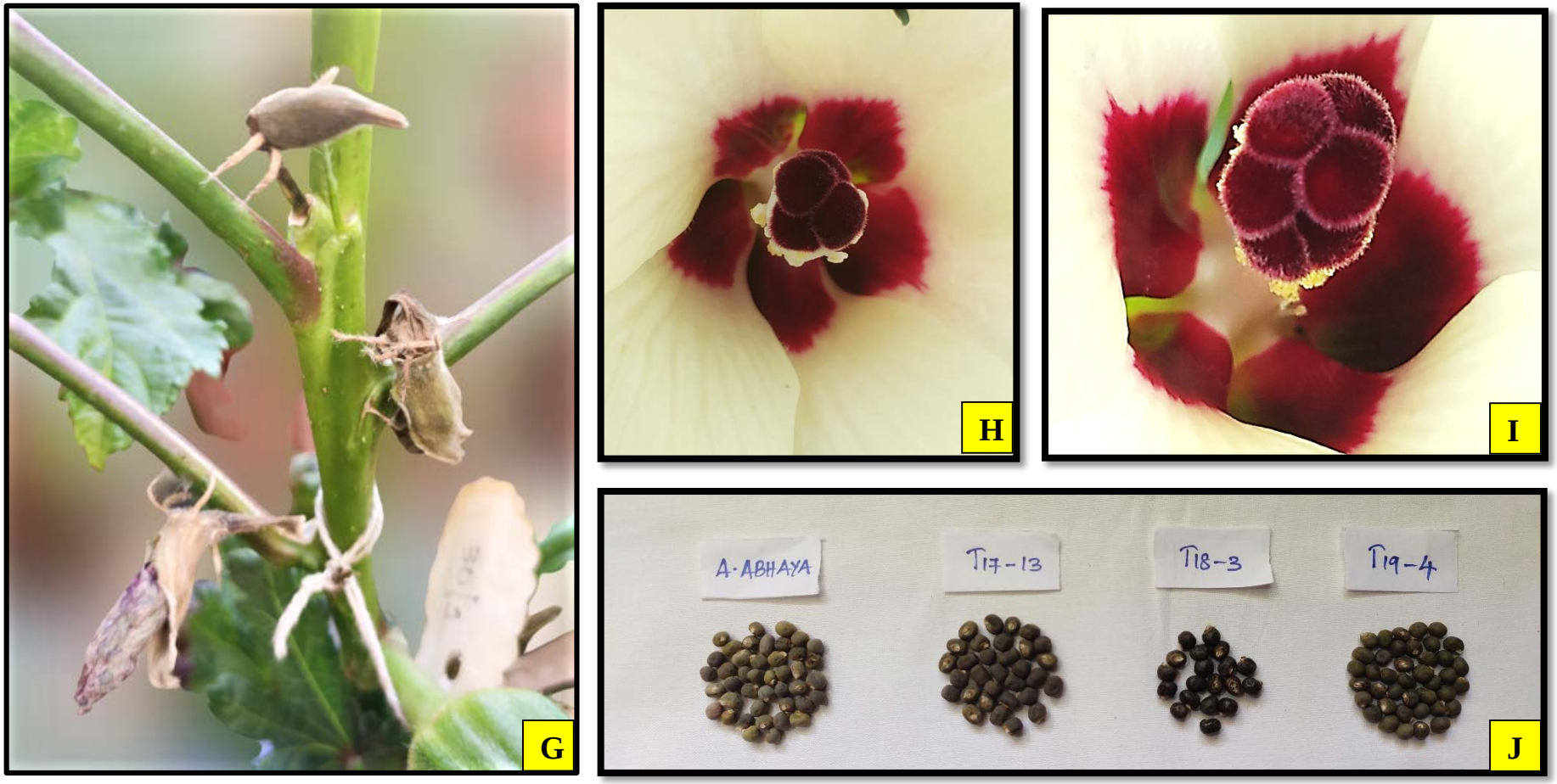
4.3.1.2 Analysis of variance (ANOVA) for characters in TS_1 generation.

Analysis of variance for among the Trichostatin-A treated TS_1 population (First mutant population of Trichostatin-A) of Arka Anamika and Arka Abhay were critically analysed for remarkable differences in total fruit yield and its thirteen contributing parameters and are presented in Table 37 and Table 38 respectively. The analysis of variance for both the varieties showed that the mean sum of squares within blocks (eliminating treatments), within treatments (eliminating blocks) and checks vs mutants were significant for all the 14 traits such as days to first flowering, plant height (cm), number of branches, number of internodes on main stem, number of fruits per plant, fruit length (cm), fruit width (mm), number of ridges on the fruit,



A: Flower with six petals, B: Flower with four petals, C: flower with altered petal shape aestivation, D -F: Partial or complete absence of male and female reproductive parts

Plate 8: Spectrum of visible mutations induced by Trichostatin-A in the TS_1 generation contd…….



G: Plant with more than 50% sterility, H: Flower with four stigmata, I: Flower with six stigmata, J: variations for seed colour and size

Plate 8: (Contd….) Spectrum of visible mutations induced by Trichostatin-A in the TS_1 generation

Table 37: Analysis of variance for growth and yield parameters in mutant families (TS_1) of Arka Anamika variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	5	332.06 **	582.83 **	4.75 **	2.41**	4.43**	0.12 **	39.76 **	0.25 **	0.30 **	7.17 **	133.17 **	0.45 **	1.50**	3828.79 **
Treatment (eliminating blocks)	63	113.6 **	195.61 **	2.56 **	2.82**	4.8 **	0.07 **	31.2 **	0.55 **	0.46 **	14.92 **	158.68 **	1.28 **	2.30 **	3194.69**
Checks	3	13.31 **	18.14 **	3.75 **	11.68 **	11.81 **	0.14 **	0.63	0.001	0.001	6.57 **	14.73**	0.34 *	2.47 **	1387.79**
Mutants	59	129.49 **	251.4 **	2.48 **	4.23**	4.23 **	0.08 **	34.58 **	0.55 **	0.47 **	11.89 **	144.26 **	0.64 **	1.26 **	3531.14**
Mutants vs Check	1	1129.84 **	343.23 **	27.23 **	24.55**	24.55 **	0.07**	121.37 **	3.22 **	2.3 **	264.14 **	2116.4 **	43.83 **	65.29 **	7335.20**
Residuals	15	0.67	1.73	0.04	0.25	1.19	0.02	0.7	0.001	0.001	0.52	2.62	0.08	0.19	31.29
CV		1.51	2.83	6.5	12.69	8.01	7.93	7.97	0.001	0.001	4.97	3.92	9.98	6.65	10.72
CD (5%) (Mutant v/s Control)		2.11	3.38	0.51	1.28	2.81	0.34	2.16	0.001	0.001	1.86	4.16	0.70	1.13	14.40
CD (5%) Two Mutants (Different Blocks)		2.77	4.43	0.67	1.67	3.68	0.45	2.83	0.001	0.001	2.44	5.45	0.92	1.48	18.85

**** at 1% level of significance , *at 5 % level of significance**

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

Table 38: Analysis of variance for growth and yield parameters in mutant families (TS_1) of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TSW	YLD
Block (eliminating Treatment)	6	173.98 **	301.24 **	7.43 **	8.93 **	4.45**	0.05**	78.64 **	0.70 **	0.99 **	65.07 **	457.9 **	0.92 **	1.84 **	1584.4 **
Treatment (eliminating Blocks)	87	118.64 **	279.86 **	3.03 **	6.12 **	4.9 **	0.06 **	36.45 **	0.72 **	0.74 **	36.83 **	302.77 **	1.81 **	3.73 **	1506.01 **
Checks	3	15.13 **	22.55 **	4.15 **	12.77 **	12.01 **	0.14 **	0.61	0.001	0.001	1.34	6.01	0.58 **	3.78 **	2090.29 **
Mutants	83	124.15 **	309.94 **	3.51 **	6.36 **	4.19 **	0.05 **	38.67 **	0.73 **	0.78 **	37.41 **	266.63 **	0.84 **	2.99 **	1528.44 **
Mutants vs Check	1	1008.7 **	354.96 **	4.38 **	18.54 **	41.40 **	0.22 **	430.49 **	5.76 **	5.76 **	479.54 **	6919.32 **	91.97 **	75.65 **	7107.64 **
Residuals	18	0.81	1.51	0.04	0.25	1.18	0.02	0.61	0.001	0.001	0.50	2.37	0.11	0.32	122.37
CV		1.67	2.64	5.55	13.93	8.08	7.37	6.50	0.001	0.001	4.62	4.32	14.24	8.65	12.94
CD (5%) (Mutant v/s Control)		2.26	3.09	0.50	1.26	2.72	0.32	1.97	0.001	0.001	1.78	3.86	0.83	1.42	7.78
CD (5%) Two Mutants (Different Blocks)		2.98	4.08	0.66	1.67	3.60	0.42	2.60	0.001	0.001	2.36	5.11	1.10	1.88	8.75

**** at 1% level of significance , *at 5 % level of significance**

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

number of locules per fruit, single fruit weight (g), number of seeds per fruit, weight of seeds per fruit (g), test weight (g) and fruit yield per plant (g). This has indicated the existence of high significant differences for all the major economic characters in the mutant lines of two okra varieties, Arka Anamika and Arka Abhay.

For further validation, DMRT (Duncan Multiple Range Test) significant test at P = 0.05, was conducted for major traits governing the yield. Significant differences among the treatments of Trichostatin-A for the TS_1 population of Arka Anamika and Arka Abhay was observed from the test.

4.3.1.2.1 Effect of Trichostatin-A (TSA) treatment on different characters

From the DMRT analysis (Table 39), it is clear that, treatment means of important yield governing traits varied significantly from each other. Majority of the traits such as total yield, plant height, number of fruits, number of branches per plant, single fruit weight, number of seeds, seed weight per fruit and test weight were higher in the control, followed by treatment 14 of Arka Anamika (1.2 µM TSA) and treatment 19 of Arka Abhay (1.2 µM TSA) compared to other treatments. The DMRT test indicated the significant advantage of the 1.2 µM of Trichostatin-A treatment incubated for three days in both varieties. Whereas, the below par performance of seeds treated with1.2 µM TSA and incubated for five days in Arka Anamika (treatment 15) and Arka Abhay (treatment 20) were also identified by the test. TSA of dose 0.4 µM incubated for three and five days in both the varieties were also significantly inferior for many economic traits. Major yield contributing traits and the total yield of fruits in the treatments T_{15} and T_{20} performed comparably poor contrary to the other treatments. On the other hand, characters such as days to first flowering and fruit width were higher than the control plants in treatments T_{15} and $T_{20.}$

Significant differences for the fourteen traits were observed for all doses and for different incubation times. The selective advantage of 1.2 µM of Trichostatin-A treatment (incubated for three days) was observed for majority of the economic traits of okra as compared to the 0.4 µM dose incubated for three and five days in the dark. Meticulously, deleterious effects were found to be increased as the incubation period extended. The number of germinated seeds, field emergence percentage and the survival percentage of the seedlings was reduced as the incubation period of seeds increased (Table 36).

4.3.1.3 Genetic parameters of variability

The existence of sufficient level of genetic variability is a prerequisite for any breeding programme that aims at variety development, hence detailed appraisal of the accessions for different morphological, agronomical and quality traits is necessary to identify useful traits either for direct use or to pave the way for hybridization

Table 39: DMRT results for different treatments and characters among TS_1 population of Arka Anamika and Arka Abhay

Variety	Treatment	DFF	PH	NB	NF	FL	FW	INT	SFW	NS	SWT	TWT	YLD
Arka Anamika	Control (T_{11})	47.44^{AB}	61.20^{A}	4.95^{A}	10.61^{A}	16.15^{AB}	15.30^{C}	8.20^{B}	17.04^{B}	51.39^{AB}	3.78^{BC}	13.35^{AB}	105.35^{B}
	T_{12}	52.60^{A}	48.63^{B}	3.60^{B}	5.70^{B}	16.30^{AB}	19.40^{B}	9.50^{B}	20.45^{AB}	38.36^{BC}	5.99^{AB}	7.90^{BC}	53.96^{C}
	T_{13}	53.60^{A}	44.05^{B}	$2.55B^{C}$	4.75^{B}	14.86^{B}	18.00^{BC}	10.55^{B}	16.88^{BC}	34.01^{C}	3.72^{BC}	6.56^{C}	48.40^{C}
	T_{14}	49.56^{AB}	56.80^{AB}	3.16^{B}	9.80^{A}	18.63^{A}	19.80^{B}	15.80^{A}	22.45^{A}	58.71^{A}	7.62^{A}	15.00^{A}	136.70^{A}
	T_{15}	55.40^{A}	40.05^{BC}	1.30^{C}	2.50^{BC}	11.74^{C}	24.50^{A}	7.72^{BC}	13.04^{CD}	28.40^{C}	2.62^{C}	6.22^{C}	40.96^{C}
	Mean	52.79	47.37	2.76	5.68	14.36	20.10	10.12	18.03	42.90	5.09	10.07	68.45
	CD (5%)	3.78	6.51	0.48	2.04	2.73	3.30	5.74	4.37	8.73	3.37	2.91	10.40
Arka Abhay	Control (T_{16})	49.22^{bc}	67.92^{a}	3.74^{a}	9.27^{a}	15.19^{b}	18.00^{b}	8.67^{b}	19.95^{ab}	50.00^{a}	3.85^{b}	7.65^{ab}	98.95^{bc}
	T_{17}	50.38^{b}	50.50^{b}	2.00^{b}	2.33^{b}	15.74^{bc}	19.00^{ab}	7.38^{bc}	16.14^{b}	31.55^{c}	3.48^{b}	6.14^{b}	101.27^{b}
	T_{18}	55.77^{a}	39.38^{c}	1.77^{b}	2.27^{b}	15.23^{b}	19.90^{ab}	9.44^{b}	15.60^{b}	45.77^{ab}	2.39^{bc}	7.31^{ab}	58.38^{c}
	T_{19}	51.83^{b}	55.91^{b}	2.83^{ab}	9.50^{a}	19.83^{a}	18.70^{ab}	19.16^{a}	21.88^{a}	50.87^{a}	7.00^{a}	9.84^{a}	154.33^{a}
	T_{20}	56.27^{a}	49.33^{bc}	2.05^{b}	3.33^{b}	10.14^{c}	21.10^{a}	9.77^{b}	11.25^{c}	37.86^{bc}	3.47^{b}	3.91^{c}	38.16^{d}
	Mean	52.93	50.36	2.24	3.09	14.10	19.60	10.57	18.26	41.46	12.16	7.26	69.84
	CD (5%)	2.11	8.50	1.32	1.08	2.80	2.26	2.09	3.70	7.76	2.64	2.31	9.19

Mean with same superscript within a column do not differ at 5 % level of significance.

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total yield
NL: No. of Locules

programs. The availability of genetic variability, its collection, evaluation, characterization, documentation, maintenance and use for improvement in economic traits are necessary and very useful in crop breeding programmes. The details of various genetic parameters assessed among the TS_1 mutant population of Arka Anamika and Arka Abhay are tabulated in Tables 40 and 41 respectively.

4.3.1.3.1 Days to first flowering (DFF)

The trait number of days to first flowering has ranged from 39 to 83 days in Arka Anamika mutant population with an average day of 56.11, indicating significant variation for the trait. Among the 60 selected mutant lines, the line AN-1.2-3-11 exhibited the early flowering (39 days) and the line AN-1.2-5-4 recorded the late flowering (83 days) compared to the parent, Anamika (46.50 days). High phenotypic (26.28) and moderate genotypic (15.23) coefficient of variation combined with moderate heritability of 56.75 per cent and moderate genetic advance as per cent of mean (20.22) were observed.

Similarly, the trait had a mean value of 55.10 days of first flowering with a range of 39 and 79 days among the eighty Arka Abhay mutants. The parent Abhay has scored an average days of flowering of 49.20 days which is significantly high compared to the mean value of 84 mutant lines. The lines AB-0.4-3-13 and AB-1.2-5-5 has recorded the lowest and the highest number of days to first flowering which is 39 days and 79 days respectively. Moderate amount of GCV (17.16) and high value of PCV (27.92) with a moderate heritability (58.79 %) and a high genetic advance as per cent of mean (23.30) were noticed.

4.3.1.3.2 Plant height (cm)

The average plant height of the TS_1 mutant lines of Arka Anamika was 49.45 cm as compared to parent Arka Anamika (62.54cm) ranging from 13.66 to 86.99 cm. The lowest plant height was recorded by the line AN-0.4-5-5 and highest by AN-1.2-5-9. High values of GCV (30.11), PCV (34.89) and heritability (86.29 %) coupled with high genetic advance of 45.46 as per cent of mean were noticed for this trait.

In case of Arka Abhay the trait has scored the lowest value of 15.32 cm (AB-1.2-5-3) and the highest was 82.66 cm (AB- 1.2-3-28) with a mean height of 45.73 compared to the parent Arka Abhay (65.41cm). The genotypic and phenotypic coefficient were found high (28.40 and 38.49, respectively) with high heritability (73.61 %) and high genetic advance as per cent of mean (35.29).

4.3.1.3.3 Number of branches

The average number of branches among the mutant lines of Arka Anamika ranged from 1.00 (AN-1.2-5-11) to 7.00 (AN-1.2-3-13). The mean value of mutants

was 2.78 compared to parent Arka Anamika (4.88). High variation in terms of genetic parameters such as the GCV (35.27 %) and PCV (46.73 %) along with a high heritability of 75.60 per cent and genetic advance (36.69) as per cent was observed.

In case of Arka Abhay mutants, the number of branches ranged from 0.00 to 8.00 with a mean value of 3.51, whereas parent Arka Abhay mean was 3.74. The lowest number of branches was recorded in the line, AB-0.4-5-1 and maximum was recorded in AB-1.2-3-17. High phenotypic and genotypic coefficients of variations recorded were 33.36 and 27.06 per cent, respectively. High value of Heritability (81.20 %) with an expected genetic advance of 55.27 per cent was observed for this character among the mutant lines.

4.3.1.3.4 Number of fruits

The average number of fruits per plant for parent Arka Anamika was 10.25, whereas its mutants mean was 5.05. The line AN-0.4-5-5 has recorded minimum number of fruits (1.00) and the line AN-1.2-3-13 (15.00) had maximum number of fruits, indicating a range of 1.00 to 15.00 fruits per plant. The GCV and PCV recorded were moderate (16.66 and 17.83 per cent respectively) and the trait exhibited high heritability (93.43 %) associated with high per cent mean of genetic advance (47.12).

The Arka Abhay mutants population had an average number of 3.41 fruits per plant with a range of 1.00- 11.00 compared to the parent Arka Abhay (9.26). Among the mutant lines, AB-0.4-5-1 and AB-1.2-3-26 has recorded minimum and maximum number of fruits per plant. High estimates of GCV (22.41 %) and high PCV (25.90 %) with high heritability (88.60 %) and per cent mean genetic advance (64.22) were observed among the mutants for this trait.

4.3.1.3.5 Fruit length (cm)

The fruit length of Arka Anamika mutants varied from 8.75 to 18.75 cm with an average value of 13.36 cm compared to parent Arka Anamika 16.11 cm. The mutant line AN-1.2-3-11have recorded the least fruit length (8.75 cm), while maximum length of fruit was recorded in AN- 1.2-3-14 (18.75 cm). Moderate GCV (13.05) and PCV (15.40) accompanied with high estimates of heritability (71.85 %) and high per cent mean genetic advance (22.82) was recorded for this trait.

The overall mean of fruit length in Arka Abhay mutants was 13.14 cm with a wide range of 9.04 cm to 17.91 cm, whereas the parent mean was 15.19 cm. A shortest fruit length was produced in AB-0.4-5-4 line and longest was in AB-1.2-3-26. Moderate record of genotypic (13.21 %) and phenotypic (15.58 %) coefficient of variation together with high heritability (71.93 %) and high per cent mean genetic advance (23.13) were noticed.

4.3.1.3.6 Fruit width (mm)

The width of the fruits ranged from 10.50 mm to 24.40 mm with a mean value of 16.90mm for Arka Anamika mutants and the parent has scored a mean of 15.10 mm. The mutant lines, AN-1.2-3-5 and AN-0.4-5-6had the minimum and maximum width of the fruits respectively. The Genotypic and phenotypic coefficients of variation were recorded as moderate (12.60 and 16.61, respectively) with moderate heritability (57.32 %) and very low genetic advance as per cent of mean (2.66).

In case of mutants of Arka Abhay, the line AB-1.2-5-1 (10.80 mm) and AB-1.2-3-21 (24.20 mm) had scored minimum and maximum width of the fruits respectively. The average estimate of this trait in the mutant population was 17.60 mm with that of the parent Arka Abhay (17.10 mm). The genotypic (11.03 %), phenotypic (13.21 %) coefficients of variation were observed as moderate, with high heritability (69.65 %) and low estimate of per cent mean genetic advance (1.87).

4.3.1.3.7 Number of internodes on the main stem

The number of internodes on the main stem of the mutant lines of Arka Anamika has ranged from 1.00 to 26.00 (AN-0.4-5-4 and AN-1.2-5-8) with an average number of 11.12 internodes. The parent Arka Anamika had an average value of 8.50 for this trait. High GCV (22.35 %) and PCV (32.90 %) with high estimates of heritability (67.97 %) and genetic advance as per cent of mean (24.73) was recorded among the population.

The Arka Abhay mutants exhibited a mean number of 12.96, whereas its parent showed average number of 8.60 internodes. Among the mutants, the lines AB-12-5-3 and AB-1.2-3-28 has recorded minimum and maximum (1.00 and 30.00) number of internodes indicating a wide range of variations. High estimates of GCV and PCV (47.60 and 47.98 per cent), high heritability of 98.42 per cent with moderate (20.29) per cent mean genetic advance were also exhibited by this trait.

4.3.1.3.8 Number of ridges per fruit

The trait has ranged from 5.00 to 8.00 among Arka Anamika mutants and Arka Abhay mutants. The parents scored a mean value of 5.00 against Arka Anamika mutants (5.41) and Arka Abhay mutants (5.50). Maximum number of ridges was scored by AN-0.4-5-9 (8.00) and AB-1.2-3-26 (8.00) in the respective population. Moderate estimates of GCV (13.78) and PCV (13.78) with high heritability (99.99) coupled with high GAM (28.46) was observed for TS_1 mutants of Arka Anamika. Similarly, Arka Abhay mutants also exhibited moderate estimates of GCV (15.58), PCV (15.60) and high heritability (99.90 %) with high GAM (32.18).

4.3.1.3.9 Number of locules per fruit

Both the check varieties had a mean value of 5.00 compared to mutants of Arka Anamika (5.34) and Arka Abhay (5.50). The trait had range of 5.00 to 8.00 (AN-0.4-5-9) in Arka Anamika mutants and Arka Abhay mutants (AB-1.2-3-26). Moderate estimates of GCV (12.88) and PCV (12.88), high heritability (99.99 %) coupled with high GAM (26.59) were noticed for the mutants of Arka Anamika. Similarly, moderate estimates of GCV (16.08) and PCV (16.09) coupled with high estimates of heritability (99.90 %) and genetic advance as per cent of mean (33.09) were observed among Arka Abhay mutants.

4.3.1.3.10 Single fruit weight (g)

Significant variation among the mutant lines of Arka Anamika for the weight of single fruit was noticed. The average weight of single fruit has ranged from 7.91 g in the mutant line AN-0.4-5-10 to 25.37 g in AN-1.2-3-43. The overall mean of 14.40g was scored among the population compared to parent Arka Anamika (16.25 g). The estimates of genetic parameters such as GCV and PCV (20.88 and 22.38 respectively), heritability (91.61 %) and per cent mean genetic advance (44.16) were very high for this trait.

Similarly, Arka Abhay mutants also had a larger variation for the character with a range of 8.76 to 44.88 g. The Parent Arka Abhay has scored an overall mean value of 17.95 g compared to the mutant mean of 16.34 g. The line AB-1.2-3-15 had maximum weight of single fruit (44.88 g) whereas the line AB-0.4-5-9 recorded minimum weight (8.76 g). Moderate GCV (17.17), PCV (19.43) and high heritability (87.72 %) with high genetic advance of as per cent of mean (28.15) were exhibited by the character among the population.

4.3.1.3.11 Number of seeds per fruit

The overall mean obtained for total number of seeds per fruit in case of Arka Anamika mutants was 40.77 ranging from 10.00 (AN-0.4-3-15) to 73.00 (AN-0.4-5-30), whereas the parent had an average of 49.00 seeds per fruit. High estimates of genotypic (30.69), phenotypic (33.98) coefficients of variability, heritability (90.19 %) and genetic advance as per cent of mean (47.41) were noticed for this character.

Alternatively in Arka Abhay mutant lines, the line AB-0.4-5-2 (10.00) and AB-1.2-3-2 (101.00) has recorded the minimum and maximum number of seeds per fruit respectively. The mean value for the trait among the mutant population was 31.88 compared to the parent Arka Abhay (50.00). The GCV (10.98) and PCV (17.21) values obtained were moderate coupled with moderate heritability of 60.38% and high GAM (42.00).

Table 40: Mean, range and genetic variability parameters for growth and yield traits in mutant families (TS_1) of Arka Anamika

Trait	Arka Anamika Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	46.50	56.11	39.00	83.00	15.23	26.28	56.75	11.35	20.22
PH	62.54	49.45	13.66	86.99	30.11	34.89	86.29	22.48	45.46
NB	4.88	2.78	1.00	7.00	35.27	46.73	75.60	1.02	36.69
NF	10.25	5.05	1.00	15.00	16.66	17.83	93.43	2.38	47.12
FL	16.11	13.36	8.75	18.75	13.05	15.40	71.85	3.05	22.82
FW	15.10	16.90	10.50	24.40	12.60	16.61	57.32	0.45	2.66
INT	8.50	11.12	1.00	26.00	22.35	32.90	67.97	2.75	24.73
NR	5.00	5.41	5.00	8.00	13.78	13.78	99.90	1.54	28.46
NL	5.00	5.34	5.00	8.00	12.88	12.88	99.90	1.42	26.59
SFW	16.25	14.40	7.91	25.37	20.88	22.38	91.61	6.36	44.16
NS	49.00	40.77	10.00	73.00	30.69	33.98	90.19	19.33	47.41
SWT	3.71	2.49	0.59	4.17	31.57	35.59	82.35	1.16	46.58
TWT	11.35	6.15	2.89	8.82	16.77	18.22	84.71	1.07	17.39
YLD	105.50	68.93	10.89	331.07	15.02	24.98	58.10	11.30	16.39

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

Table 41: Mean, range and genetic variability parameters for growth and yield traits in mutant families (TS_1) of Arka Abhay

Trait	Arka Abhay Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	49.20	55.10	39.00	79.00	17.16	27.92	58.79	12.84	23.30
PH	65.41	45.73	15.32	82.66	28.40	38.49	73.61	16.14	35.29
NB	3.74	3.51	0.00	8.00	27.06	33.36	81.20	1.94	55.27
NF	9.26	3.41	1.00	11.00	22.41	25.90	88.60	2.19	64.22
FL	15.19	13.14	9.04	17.91	13.21	15.58	71.93	3.04	23.13
FW	17.10	17.60	10.80	24.20	11.03	13.21	69.65	0.33	1.87
INT	8.60	12.96	1.00	30.00	47.60	47.98	98.42	2.63	20.29
NR	5.00	5.50	5.00	8.00	15.58	15.60	99.90	1.77	32.18
NL	5.00	5.50	5.00	8.00	16.08	16.09	99.90	1.82	33.09
SFW	17.95	16.34	8.76	44.88	17.17	19.43	87.72	4.60	28.15
NS	50.00	31.88	10.00	101.00	10.98	17.21	60.38	13.39	42.00
SWT	3.85	1.89	1.07	4.23	35.02	48.29	71.52	0.64	33.86
TWT	7.65	6.16	2.30	12.75	24.51	28.06	83.25	1.18	19.15
YLD	101.95	54.66	12.15	196.94	16.60	27.53	54.11	6.85	12.53

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

4.3.1.3.12 Weight of seeds per fruit (g)

The average weight of seeds per fruit in the parent Arka Anamika was 3.71 g, whereas its mutant population had an average of 2.49 g seed weight. The minimum (0.59 g) and maximum (4.17 g) weight of seeds per fruit was recorded in the lines AN-0.4-5-15and AN-1.2-3-15respectively, indicating range of 0.59 to 4.17 g. The high range of coefficient of variations at phenotypic and genotypic level were 31.57 and 35.59 per cent respectively. The trait scored high heritability of 82.35 per cent coupled with high genetic advance (46.58) as per cent of mean.

In case of Arka Abhay mutant population, the mean performance for weight of seeds per fruit was 1.89 g and its parent had 3.85 g per fruit. The mutant line AB-0.4-5-2 has recorded lowest seed weight per fruit (1.07 g) and highest was in line AB-1.2-3-15 (4.23 g). High GCV (35.02) and PCV (48.29) combined with high estimates of heritability (71.52 %) and genetic advance as per cent of mean (33.86) were also observed for this trait.

4.3.1.3.13 Test weight (g)

The range of test weight in mutants of Arka Anamika was 2.89 to 8.82g with an overall mean of 6.15 g, compared to its parent Arka Anamika (11.33 g). Maximum test weight of seeds was observed in the line, AN-0.4-3-15 (2.89 g) and minimum was in AN-1.2-3-13(8.82 g). The genotypic and phenotypic coefficients of variations noticed were moderate (16.77 and 18.22, respectively). The trait recorded high heritability (84.71 %) associated with moderate per cent of mean genetic advance (17.39 %).

The average weight of hundred seeds in Arka Abhay mutants was 6.16 g, ranging from 2.30 g in AB-1.2-5-4 to 12.75 g in the line AB-1.2-3-26. The parent Arka Abhay scored a mean value of 7.65 g for the trait. The genotypic and phenotypic coefficients of variation observed were high and values were 24.51 and 28.06 per cent, respectively. High heritability (83.25 %) coupled with the moderate genetic advance as per cent mean (19.15) were also exhibited by the trait in the mutant population.

4.3.1.3.14 Total fruit yield per plant (g)

In the mutants of Arka Anamika, total fruit yield per plant was in a range of 10.89 to 331.07 g with an overall mean of 68.93 g compared to its parent (105.50 g). The mutant line AN-0.4-3-15 had minimum fruit yield per plant (10.89 g), contrary to this, the line AN-1.2-3-13 (331.07 g) has scored maximum for this trait. Moderate GCV (15.02 %), high PCV (24.98 %) and moderate estimate of heritability (58.10 %) coupled with moderate genetic advance as per cent of mean (16.39) were noticed for this character.

Similarly, in case of Arka Abhay mutants, the overall mean for the total yield of fruits per plant was 54.66 g with a range of 12.15 to 196.94 g, whereas its parental mean was 101.95 g. The maximum and minimum fruit yield per plant was recorded in lines, AB-1.2-3-26 and AB-1.2-5-1 respectively. The phenotypic (27.53 %) and genotypic (16.60%) coefficient of variations were found high and moderate respectively for the trait, accompanied with moderate heritability of 54.11 per cent and moderate genetic advance of 12.53 as per cent of mean.

4.3.2 Observation in TS_2 generation

4.3.2.1 Analysis of variance (ANOVA) for characters in TS_2 generation

The analysis of variance among 100 mutant lines of both Arka Anamika and Arka Abhay was performed for 14 quantitative traits and presented in Tables 42 and 43 respectively. The results revealed that values of mean sum of squares within the blocks (eliminating treatments), within the treatments (eliminating blocks) and checks vs mutants were significant for yield and its thirteen contributing traits suggesting significant differences among 100 TS_2 mutant lines of the both the varieties.

4.3.2.2 Genetic parameters of variability

The parameters of genetic variability such as, mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance as per cent of mean (GAM) of yield and its 13 attributing traits among the TS_2 mutant populations of Arka Anamika and Arka Abhay are furnished in the Tables 44 and 45, respectively.

4.3.2.2.1 Days to first flowering

The number of days to first flowering of the mutant lines of Arka Anamika has ranged from 41.00 days to 83.00 days with general mean value of 53.03 days and its control flowered in a mean days of 47.25. The GCV and PCV values were moderate (10.84 and 15.88, respectively) and the heritability in broad sense were also moderate (53.63 %) coupled with a low genetic advance as per cent of mean (8.16). In case of Arka Abhay mutants the values ranged between 39.00 and 79.00 with an average value of 51.85 days, whereas the parent had a mean value of 48.50 days. The GCV (11.50), PCV (19.58) and heritability (58.73%) were found moderate, associated with low genetic advance as per cent of mean (4.26).

4.3.2.2.2 Plant height

The range of plant height varied from 20.92 cm to 86.92 cm with an average value of 54.20 cm in case of Arka Anamika mutants compared to their parent (67.85 cm). The genotypic (20.39) and phenotypic (31.52) coefficient of variation were high, together with high heritability (61.18 %) and moderate per cent genetic

Table 42: Analysis of variance for growth and yield parameters in mutant families (TS_2) of Arka Anamika variety

Source	Df	DFF	PH	NB	NF	FL	FW	INT	NL	NR	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	4	1066.58 **	757.27 **	22.43 **	7.22 **	13.28 **	0.61 **	142.04 **	0.10 **	0.15 **	29.95 **	653.17 **	0.42 **	4.45 **	3096.69 **
Treatment (eliminating Blocks)	103	111.5 **	162.67 **	2.54 **	6.42 **	4.43 **	0.06 **	22.21 **	0.38 **	0.41 **	11.48 **	113.56 **	1.25 **	1.75 **	3121.38 **
Checks	3	11.64 **	15.28 **	3.04 **	10.18 **	11.56 **	0.17 **	0.63	0.001	0.001	1.60 *	3.11	0.34 **	2.26 **	1281.88 **
Mutants	99	152.84 **	194.04 **	3.29 **	6.38 **	4.16 **	0.08 **	27.62 **	0.38 **	0.41 **	11.67 **	121.49 **	0.63 **	1.12 **	3411.51 **
Mutants vs Check	1	579.87 **	521.27 **	16.83 **	32.84 **	56.58 **	0.04**	118.88 **	1.71 **	1.93 **	138.19 **	2255.7 **	42.47 **	80.39 **	6543.11 **
Residuals	12	0.57	1.59	0.04	0.20	1.01	0.01	0.48	0.001	0.001	0.42	1.90	0.05	0.12	61.55
CV		1.42	2.81	6.55	13.43	7.65	5.45	6.34	0.001	0.001	4.62	3.50	8.28	5.58	14.59
CD (5%) (Mutant v/s Control)		0.92	1.55	0.25	1.14	1.23	0.11	0.85	0.001	0.001	0.79	1.69	0.58	0.42	4.35
CD (5%) Two Mutants (Different Blocks)		1.19	1.99	0.32	1.50	1.59	0.14	1.10	0.001	0.001	1.02	2.18	0.77	0.54	5.62

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering NF: No. of Fruits INT: No. of Internodes NS: No. of Seeds YLD: Total yield
PH: Plant height FL: Fruit Length NR: No. of Ridges SWT: Seed weight NL: No. of Locules
NB: Number of branches FW: Fruit Width SFW: Single Fruit Weight TWT: Test Weight

Table 43: Analysis of variance for growth and yield parameters in mutant families (TS_2) of Arka Abhay variety

Source	Df	DFF	PH	NB	NF	FL	FW	NL	NR	INT	SFW	NS	SWT	TWT	YLD
Block (eliminating Treatment)	4	308.78 **	412.25 **	12.12 **	5.77 **	5.43**	0.04**	0.4 **	0.34 **	106.73 **	106.63 **	505.19 **	1.83 **	2.30**	620.91 *
Treatment (eliminating Blocks)	103	112.56 **	262.13 **	3.37 **	5.77 **	4.81 **	0.05 *	0.73 **	0.70 **	31.39 **	30.12 **	251.39 **	1.34 **	3.39 **	1404.44 **
Checks	3	9.81 **	17.09 **	3.20 **	10.41 **	6.78 **	0.08 *	0.001	0.001	0.58	1.49	3.95	0.43	2.73 *	1506.8 **
Mutants	99	119.52 **	284.43 **	3.83 **	5.69 **	4.54 **	0.05 *	0.74 **	0.7 **	33.76 **	32.27 **	232.26 **	0.77 **	2.82 **	1358.81 **
Mutants vs Check	1	961.27 **	435.54 **	6.01 **	21.49 **	34.15 **	0.23 **	4.00 **	4.00 **	315.25 **	326.13 **	4891.76 **	67.59 **	61.72 **	7926.92 **
Residuals	12	0.90	1.53	0.04	0.28	1.11	0.02	0.001	0.001	0.54	0.49	1.92	0.15	0.47	167.35
CV		1.73	2.74	5.94	5.52	8.06	7.27	0.001	0.001	6.00	4.47	3.98	7.52	10.72	13.37
CD (5%) (Mutant v/s Control)		2.00	3.30	0.55	1.42	2.81	0.34	0.001	0.001	1.96	1.86	3.70	1.04	1.84	5.52
CD (5%) Two Mutants (Different Blocks)		3.28	4.26	0.71	1.83	3.62	0.43	0.001	0.001	2.53	2.41	4.77	1.34	2.37	7.57

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total yield
NL: No. of Locules

advance (19.22). However the range of this trait was 15.45 cm to 82.45 cm with an average of 58.54 cm in case of Arka Abhay mutants and 70.12 cm in the parent. Moderate estimates of GCV (15.77), high PCV (27.87), moderate estimate of heritability (53.46 %) coupled with high genetic advance as per cent of mean (22.80) were observed for this trait.

4.3.2.2.3 Number of branches per plant

The values with regard to number of branches per plant ranged from 1.00 to 8.00 and the average value was 3.96. The parent had a mean value of 4.82 for this trait. Moderate GCV (19.89) and high PCV (25.36) coupled with high heritability (78.43 %) and high GAM (42.67) were noticed among mutants of Arka Anamika. Similarly, the number ranged from 1.00 to 8.00 with an average of 3.40 in Arka Abhay mutants and 4.00 in Arka Abhay parent. High estimates of GCV (27.22), PCV (35.54) and heritability (76.58 %) coupled with high genetic advance as per cent of mean (29.11) were calculated for this trait.

4.3.2.2.4 Number of fruits per plant

The trait number of fruits per plant has an overall mean of 11.50 in parent and 9.08 in the mutants, ranging from 1.00 to 17.00 in Arka Anamika mutants. The genotypic (17.19) and phenotypic (18.26) coefficients of variation were moderate, heritability (94.14 %) and genetic advance as per cent mean (40.52) were recorded high among the population. Similarly, in case of mutants of Arka Abhay, the trait scored a mean value of 6.27 in comparison to Arka Abhay parent (10.12). The trait had ranged from 1.00 to 14.00 among the mutants. The GCV (11.07) and PCV (18.89) were moderate with high heritability (67.60 %) together with high GAM (35.40) were observed among the mutants for this character.

4.3.2.2.5 Fruit length

The mutants of Arka Anamika recorded an average value of 13.89 cm with a range of 7.22 to 18.93 cm whereas, the parent had 14.56 cm of fruit length. Moderate estimates of GCV (13.78) and PCV (15.83) coupled with high heritability (75.80 %) and high genetic advance as per cent mean (24.76) were scored. The fruit length varied between 8.76 cm and 18.18 cm with an average of 14.87 cm in case of Arka Abhay mutants and 14.96 cm in the parent. The variability parameters such as GCV (14.41) and PCV (16.56) were moderate, heritability (75.66 %) and genetic advance as per cent of mean (25.82) were high for the trait.

4.3.2.2.6 Fruit width

The overall mean of Arka Anamika for the fruit width was 15.12 mm and that of the mutants was 16.60 mm with a range of 10.40 to 24.40 mm. The genotypic (16.48) and phenotypic (17.36) coefficients of variation were moderate. The

Table 44: Mean, range and genetic variability parameters for growth and yield traits in mutant families (TS_2) of Arka Anamika

Trait	Arka Anamika Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	47.25	53.03	41.00	83.00	10.84	15.88	53.63	4.33	8.16
PH	67.85	54.20	20.92	86.92	20.39	31.52	61.18	10.42	19.22
NB	4.82	3.96	1.00	8.00	19.89	25.36	78.43	1.69	42.67
NF	11.50	9.08	1.00	17.00	17.19	18.26	94.14	3.68	40.52
FL	14.56	13.89	7.22	18.93	13.78	15.83	75.80	3.44	24.76
FW	15.12	16.60	10.40	24.40	16.48	17.36	90.13	5.36	32.28
INT	8.82	11.32	2.00	22.00	32.60	36.44	89.46	2.65	23.41
NR	5.00	5.33	5.00	8.00	12.00	12.10	99.91	1.32	24.76
NL	5.00	5.31	5.00	8.00	11.61	11.64	99.90	1.27	23.91
SFW	16.20	14.77	7.29	25.26	13.34	23.77	51.12	2.66	18.00
NS	51.00	52.82	21.00	73.00	28.92	35.15	82.27	17.29	32.73
SWT	3.65	3.22	0.42	4.48	25.74	29.19	77.74	0.63	19.56
TWT	10.22	8.87	2.89	8.80	16.28	27.02	58.37	2.95	33.25
YLD	113.60	88.81	30.19	330.37	22.17	43.51	48.51	9.72	10.94

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total yield
NL: No. of Locules

Table 45: Mean, range and genetic variability parameters for growth and yield traits in mutant families (TS_2) of Arka Abhay

Trait	Arka Abhay Mean	Mean	Range		Coefficient of variability		h^2 (BS)	GA	Genetic advance as % mean
			Min	Max	GCV	PCV			
DFF	48.50	51.85	39.00	79.00	11.50	19.58	58.73	2.21	4.26
PH	70.12	58.54	15.45	82.45	15.77	27.87	53.46	13.35	22.80
NB	4.00	3.40	1.00	8.00	27.22	35.54	76.58	0.99	29.11
NF	10.12	6.27	1.00	14.00	11.07	18.89	67.60	2.22	35.40
FL	14.96	14.87	8.76	18.18	14.41	16.56	75.66	3.84	25.82
FW	16.62	17.50	11.10	24.00	11.01	13.16	84.60	3.33	19.02
INT	10.22	12.81	1.00	24.00	24.98	35.35	70.66	5.79	45.19
NR	5.00	5.47	5.00	8.00	15.26	15.28	99.95	1.72	31.44
NL	5.00	5.47	5.00	8.00	15.62	15.69	99.90	1.77	32.35
SFW	14.25	16.42	7.98	35.07	22.77	35.03	58.17	2.60	15.83
NS	49.22	42.57	10.00	100.00	26.56	40.79	63.20	13.30	31.24
SWT	3.52	2.96	0.50	4.27	9.02	14.67	59.88	0.68	22.97
TWT	9.68	7.17	2.28	12.60	24.83	27.22	83.23	1.19	16.59
YLD	95.40	72.55	10.99	194.99	6.69	20.15	33.20	9.22	12.70

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total yield
NL: No. of Locules

heritability (90.13 %) and GAM (32.28) were high for this trait. Likewise, the value of fruit width ranged from 11.10 mm to 24.00 mm with an average of 17.50 mm in case of mutants and 16.62 mm in the parent, Arka Abhay. The phenotypic coefficient of variation (11.01), GCV (13.16) were moderate, whereas, high heritability (84.60 %) and moderate genetic advance as per cent of mean (19.02) were observed.

4.3.2.2.7 Number of internodes on the main stem

Number of internodes on the main stem ranged from 2.00 to 22.00 with a mean value of 11.32 in Arka Anamika mutants and 8.82 in the parent. The variability parameters such as GCV (32.60), PCV (36.44), and heritability (89.46 %) and GAM (23.41) were recorded high for the trait. Similarly, the number of internodes had an average value of 12.81 with a range of 1.00 to 24.00 in mutants of Arka Abhay. The trait had an average value of 10.22 in the parent, Arka Abhay. High estimates of genotypic (24.98) and phenotypic (35.35) coefficients of variation, high heritability (70.66 %) coupled with high genetic advance (45.19) as per cent of mean were noticed.

4.3.2.2.8 Number of ridges per fruit

The overall mean of number of ridges per fruit in Arka Anamika was 5.00 and in the mutant was 5.33 with a range of 5.00 to 8.00. Moderate range of GCV (12.00), PCV (12.10) with high heritability (99.91 %) coupled with high range of GAM (24.76) were observed for this trait. In case of Arka Abhay mutants, the mean was 5.47 and 5.00 in case of the parent. The trait ranged from 5.00 to 8.00 in the mutants. Moderate GCV (15.26) and PCV (15.28) with high heritability (99.95 %) coupled with high range of GAM (31.44) were recorded for the trait.

4.3.2.2.9 Number of locules per fruit

Both the check varieties had a mean value of 5.00 compared to mutants of Arka Anamika (5.31) and Arka Abhay (5.47). The trait had range of 5.00 to 8.00 in Arka Anamika mutants and in Arka Abhay mutants. Moderate estimates of GCV (11.61) and PCV (11.64), high heritability (99.90 %) coupled with moderate GAM (23.91) were noticed for the mutants of Arka Anamika. Moderate estimates of GCV (15.62) and PCV (15.69) coupled with high estimates of heritability (99.90 %) and genetic advance as per cent of mean (32.35) were observed among Arka Abhay mutants.

4.3.2.2.10 Single fruit weight

Average weight of single fruits in the mutants of Arka Anamika was 14.77 g that of parent (16.20), which ranged from 7.29 g and 25.26 g. The values of GCV (13.34) and PCV (23.77) were moderate and high respectively, associated with moderate heritability (51.12 %) and moderate value of GAM (18.00). Similarly, the

trait ranged from 7.98 to 35.07 g with a mean of 16.42 g among the mutants and 14.25 g in the parent Arka Abhay. The parameters such as genotypic (22.77) and phenotypic (35.03) coefficients of variation were high, whereas the heritability (58.17 per cent) and genetic advance as per cent of mean (15.83) were noticed as moderate.

4.3.2.2.11 Number of seeds per fruit

The Arka Anamika mutants had an average number of 52.82 seeds per fruit with a range of 21.00 to 73.00 seeds. The average number of seeds in the Arka Anamika control plants was 51.00. High phenotypic and genotypic coefficients of variations were 28.92 and 35.15 per cent, respectively. Heritability of 82.27 per cent with an expected genetic advance of 32.73 per cent was observed for the trait. In respect to Arka Abhay mutants, the trait ranged from 10.00 to 100.00 with a mean value of 42.57 whereas, the parent scored a mean value of 49.22. The GCV (26.56), PCV (40.79), heritability (63.20 %) and genetic advance as per cent of mean (31.24) observed were high among the population.

4.1.2.2.11 Weight of seeds per fruit

Weight of seeds per individual fruits among Arka Anamika ranged from 0.42 to 4.48 g with an overall mean of 3.22 g as compared to the control (3.65 g). High estimates of GCV (25.74) and PCV (29.19) were recorded. This trait exhibited high heritability (77.74%) with moderate per cent mean genetic advance (19.56). With respect to mutants of Arka Abhay, the trait had an average of 2.96 g with a range of 0.50 to 4.27 g. The parameters such as GCV (9.02), PCV (14.67) were low and moderate respectively, heritability (59.88 %) was moderate and GAM (22.97) was scored high.

4.1.2.2.12 Test weight

The overall mean of the trait was 10.22 g in the control and the mutants had an average value of 8.87 g, ranging from 2.89 to 8.80 g. The GCV (16.28) recorded was moderate and PCV (27.02) was high. Moderate heritability (58.37 %) together with high genetic advance as per cent of mean (33.25) was noticed for the trait. Similarly, the range of this trait was 2.28 g to 12.60 g with a mean of 7.17 g among the mutants and 9.68 g among the control, Arka Abhay. The genetic parameters computed such as GCV (24.83), PCV (27.22) and heritability (83.23 %) were high and the genetic advance as per cent of mean (16.59) noticed was moderate.

4.1.2.2.13 Fruit yield per plant

Significant variation among the mutants of Arka Anamika for the total fruit yield per plant was observed. The total yield ranged between 30.19 g to 330.37 g with a mean value of 88.81 g among the mutants and 113.60 g for the control. High

estimate of GCV (22.17) and estimate of PCV (43.51) coupled with high heritability (48.51%) and moderate genetic advance as per cent of mean (10.94) were observed for this trait. Among the mutants of Arka Abhay the trait ranged from 10.99 g to 194.99 g with an overall mean of 72.55 g and the control had an average yield of 95.40 g. The GCV value was low and PCV estimate was high (6.69 and 20.15 respectively), whereas the heritability (33.20 %) was moderate combined with moderate GAM (12.70).

Treatments of Trichostatin-A exhibited inferior mean performances for majority of the yield contributing traits. Variety independent delay in the first flowering was recorded in all the treatments, recording higher mean value in the mutant plants compared to their respective controls. In a comparison of mean performance of mutants in the first and second generations, significant difference could not observe for many traits. The range of many characters has narrowed in the second generation without much change in the average value. Tian and Chen (2000), Probst *et al.* (2004) and Forestan, (2018) also found increased number of days for flower induction in the HDAC mutants. Bossdorf *et al.* (2010) in *Arabidopsis thaliana* identified that the experimental demethylation using 5-azaC has strongly reduced the growth and fitness of plants and delayed their flowering, and the degree of response to this has varied significantly among genotypes. More than 40 per cent higher rate of mortality of plants, reduced flower size, dwarf plant stature, reduced number of branches and fruits, reduction of total biomass of the crop *etc.* were recorded following the treatment. Alternatively, Chang and Pikaard, 2005 and Yang *et al.* (2010) hypothesized that, TSA leads to an increase in histone acetylation and a corresponding decrease in DNA methylation which can lead to a change in gene expression on a global level. These inferences indicate that, a treatment with HDAC inhibitors such as sodium butyrate or TSA is associated with enhanced acetylation of histones and decreased DNA methylation, which subsequently produces transient phenotypes in the targeted organisms.

The study using Trichostatin-A among the Arka Anamika and Arka Abhay varieties has showed that, traits such as plant height, number of branches per plant, number of internodes on the main stem, number of seeds per fruit, and total yield in Arka Anamika mutants and characters such as plant height, number of branches per plant, number of internodes on the main stem, number of seeds per fruit, single fruit weight and test weight among Arka Abhay mutants recorded high estimates of GCV and PCV. Days to first flowering, number of fruits per plant, fruit length and width, number of ridges and locules per fruit had exhibited moderate values of GCV and PCV in TS_2 population of both the varieties. There are traits such as which has low or moderate values of GCV and high value for PCV such as average fruit weight, weight of seeds per fruit and total fruit weight. The two possible reasons for

this observation might be either due to effect of environment or due to phenotypic plasticity of the character (Bashar *et al.*, 2014).

Characters such as number of branches per plant, number of fruits per plant, fruit length, fruit width, number of internodes on the main stem, number of ridges and locules per fruit and number of seeds per fruit has recorded high heritability coupled with high genetic advance indicating the selective advantage of the traits for the crop improvement. On the other hand, days to first flowering, plant height, seed yield, average fruit weight and total fruit yield were identified as controlled by non- additive gene action as the traits exhibited low or moderate estimates of heritability and genetic advance. Johnson *et al.*, (1955) suggested that heritability estimates along with genetic advance are more valuable than the heritability value alone in predicting the response to selection.

4.3.2.3 Character association studies for yield and yield contributing characters in the TS_2 mutant population

Correlation studies are of considerable importance in plant breeding. The coefficient of correlation describes the degree and amount of association between two different variables. The correlation between yield and its component traits gives an idea for opting optimum selection pressure, which could profitably be exercised to achieve an increase in yield. The phenotypic correlations between total fruit yield and its thirteen contributing characters among the TS_2 mutant lines of Arka Anamika and Arka Abhay were worked out to understand the degree and direction of association existing among them. The results are presented in Tables 46 and 47 respectively.

4.3.2.3.1 Fruit yield

Fruit yield per plant in the TS_2 mutant populations of both Arka Anamika and Arka Abhay showed significant positive association with almost all the traits except for days to first flowering (-0.3266), number of ridges per fruit (0.0948), number of locules per fruit (0.0238) and number of seeds per fruit (0.0656) in Arka Anamika mutants, and for days to first flowering (-0.2128), number of locules per fruit (0.1087) and number of seeds per fruit (0.0843) in Arka Abhay mutant population. The days to first flowering exhibited significant negative correlation with the yield in Arka Anamika and in Arka Abhay mutants whereas, other trait such as number of ridges per fruit, number of locules per fruit and number of fruits recorded a positive but non- significant correlation in the mutant populations of both the varieties.

Number of fruits per plant, plant height, fruit length, single fruit weight, number of internodes on the main stem and plant height are the traits exhibited highest positive correlation with the yield in the TS_2 populations of Arka Anamika and Arka Abhay. Traits such as number of ridges and locules per fruit recorded

Table 46: Phenotypic correlation for yield and yield attributing characters in TS_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
DFF	1	-0.2527*	0.2561*	-0.3142*	-0.2237**	-0.0735	-0.0500	-0.0812	-0.1017	0.0470	-0.1252	-0.2136**	-0.1694**	-0.3266*
PH		1	0.2020**	0.2075**	0.4335*	0.3539*	0.1769**	0.0075	0.0851	0.2002**	0.0784	0.0723	0.0405	0.2646*
NB			1	0.5474*	0.3473*	0.1635**	0.5305*	0.2377*	0.1824**	-0.2976*	0.1645**	0.3186*	0.3388*	0.4864*
NF				1	0.3828*	0.3026*	0.4977*	0.0074	0.0022	0.1888**	0.0870	0.1597**	0.1702**	0.9726*
FL					1	0.4428*	0.2356*	0.0975	0.0519	0.0482	-0.0907	0.0554	0.2297*	0.3758*
FW						1	0.2553*	0.3724*	0.2529*	0.1978**	0.0862	0.0203	0.0035	0.4138*
INT							1	0.4448*	0.2905*	0.1444**	0.1846**	0.1747**	-0.0086	0.4957*
NR								1	0.8550*	0.1009	-0.0972	-0.0895	0.0570	0.0948
NL									1	0.0157	0.0004	-0.0105	0.0394	0.0238
SFW										1	0.3985*	0.5038*	0.3549*	0.4271**
NS											1	0.8502*	0.2534*	0.0656
SWT												1	0.7002*	0.1478**
TWT													1	0.1836**
YLD														1

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 47: Phenotypic correlation for yield and yield attributing characters in TS_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT	YLD
DFF	1	-0.1733**	0.1202**	-0.1162	-0.1200**	-0.1238**	0.1984**	-0.0609	-0.0383	-0.2074**	-0.1821**	-0.2608*	-0.1676**	-0.2128**
PH		1	0.5414*	0.5734*	0.3405*	0.3726*	0.5749*	0.0028	0.0423	0.3143**	0.2218**	0.3141*	0.1714**	0.5665*
NB			1	0.6606*	0.4161*	0.2718*	0.6869*	0.2055**	0.1996**	-0.0982	0.2003**	0.3065*	0.2510*	0.5675*
NF				1	0.4317*	0.3335*	0.5228*	0.0541	0.1085	0.1555**	0.0847	0.1928**	0.2050**	0.8791*
FL					1	0.4256*	0.1918**	0.1671**	0.0676	0.1311**	0.0896	0.2598*	0.3063*	0.5123*
FW						1	0.3844*	0.3825*	0.3653*	0.3426*	0.1994**	0.2149**	-0.0236	0.3763*
INT							1	0.3311*	0.3373*	0.1261**	-0.0696	-0.0625	-0.0029	0.4638*
NR								1	0.8985*	0.0021	0.3567*	0.0213	-0.0070	0.2137**
NL									1	-0.0454	0.3277*	0.3181*	-0.0766	0.1087
SFW										1	0.2033**	0.3039*	0.1876**	0.2048**
NS											1	0.7900*	-0.0105	0.0843
SWT												1	0.5135*	0.2172**
TWT													1	0.2629**
YLD														1

**** at 1% level of significance, *at 5 % level of significance**

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

positive non- significant correlation with the yield on the other hand, days to first flowering indicated negative significant association. Yonas *et al.* (2014), Ashadevi *et al.* (2017) and Dixit *et al.* (2019) also reported a significant negative correlation of days to first flowering with the yield.

4.3.2.3.2 Days to first flowering

Days to first flowering showed positive significant correlation with number of branches per plant (0.2561) whereas a significant negative correlation was observed with plant height (-0.2527), number of fruits per plant (-0.3142), fruit length (-0.2237), weight of seeds per fruit (-0.2136) and test weight (-0.1694) among the TS_2 population of Arka Anamika. Similarly, in case of mutants of Arka Abhay, a positive significant correlation was observed for number of branches per plant (0.1202) and number of internodes on the main stem (0.1984) whereas, a significant negative correlation was exhibited by plant height (-0.1733), fruit length (-0.1200), fruit width (-0.1238), single fruit weight (-0.2074) number of seeds per fruit (-0.1821), weight of seeds per fruit (-0.2608) and test weight (-0.1676). The mutant population of Arka Anamika and Arka Abhay had negative and significant association with the fruit yield (-0.3266 and -0.2128, respectively).

4.3.2.3.3 Plant height

The trait had a significant positive correlation with various traits like fruit yield (0.2646), number of branches per plant (0.2020), number fruits per plant (0.2075), fruit length (0.4335) fruit width (0.3539), number of internodes on the main stem (0.1769) and single fruit weight (0.2002) in case of Arka Anamika mutants. Similarly, the mutants of Arka Abhay also recorded a positive significant correlation with fruit yield (0.5665), number of branches per plant (0.5414), number fruits per plant (0.5734), fruit length (0.3405), fruit width (0.3726), number of internodes on the main stem (0.5749), single fruit weight (0.3143), number of seeds per fruit (0.2218), weight of seeds per fruit (0.3141) and test weight (0.1714). Both the mutant population had a positive but non-significant correlation of plant height with number of ridges per fruit and number of locules per fruit.

4.3.2.3.4 Number of branches per plant

Significant positive correlation was observed in number of branches per plant with yield (0.4864), days to first flowering (0.2561), plant height (0.2020), number of fruits (0.5474), fruit length (0.3473), fruit width (0.1635), number of internodes on the main stem (0.5305), number of ridges per fruit (0.2377), number of locules per fruit (0.1824), number of seeds per fruit (0.1645), weight of seeds per fruit (0.3186) and test weight (0.3384) in case of Arka Anamika mutant lines. The trait, single fruit weight (-0.2976) had negative and significant correlation with the trait. In case of Arka Abhay mutants, fruit yield (0.5675), days to first flowering (0.1202), plant

height (0.5414), number fruits per plant (0.6606), fruit length (0.4161), fruit width (0.2718), number of internodes on the main stem (0.6869), number of ridges per fruit (0.2055), number of locules per fruit (0.1996), number of seeds per fruit (0.2003), weight of seeds per fruit (0.3065) and test weight (0.2510) had showed significant and positive correlation.

4.3.2.3.5 Number of fruits per plant

The number of fruits per plant scored significant positive correlation in Arka Anamika mutants with fruit yield (0.9726), plant height (0.2075), number of branches per plant (0.5474), fruit length (0.3828), fruit width (0.3026), number of internodes on the main stem (0.4977), single fruit weight (0.1888), weight of seeds per fruit (0.1597) and test weight (0.1702). Similarly, in case of Arka Abhay mutants, the trait exhibited positive and significant association with fruit yield (0.8791), plant height (0.5734), number of branches per plant (0.6606), fruit length (0.4317), fruit width (0.3335), number of internodes on the main stem (0.5228), Single fruit weight (0.1555), weight of seeds per fruit (0.1928) and test weight (0.2050).

4.3.2.3.6 Fruit length

In Arka Anamika mutants, fruit length showed significant positive correlation with fruit yield (0.3758), plant height (0.4335), number of branches per plant (0.3473), number of fruits per plant (0.3828), fruit width (0.4428), number of internodes on the main stem (0.2356), and test weight (0.2297). Days to first flowering was significantly and negatively correlated (-0.2237) with the trait. Fruit yield (0.5123), plant height (0.3405), number of branches per plant (0.4161), number of fruits per plant (0.4317), fruit width (0.4256), number of internodes on the main stem (0.1918), number of ridges per fruit (0.1671), single fruit weight (0.1311), weight of seeds per fruit (0.2598) and test weight (0.3063) were the characters which showed significant positive correlation with fruit length in case of Arka Abhay mutants. On the other hand, days to first flowering recorded significant negative correlation (-0.1200).

4.3.2.3.7 Fruit width

Phenotypic correlation of Arka Anamika mutants for this trait was positively significant with fruit yield (0.4138), plant height (0.3539), number of branches per plant (0.1635), number of fruits per plant (0.3026), fruit length (0.4428), number of internodes on the main stem (0.2553), number of ridges (0.3724) and locules (0.2529) per fruit and single fruit weight (0.1978). Likewise, in Arka Abhay mutants, the traits, fruit yield (0.3763), plant height (0.3726), number of branches per plant (0.2718), number of fruit per plant (0.3335), fruit length (0.4256), number of internodes on the main stem (0.3844), number of ridges (0.3825) and locules (0.3653) per fruit, single fruit weight (0.3426), number of seeds per fruit (0.1994) and weight

of seeds per fruit (0.2149) recorded significant and positive correlation with fruit width. Days to first flowering (-0.1238) was significantly and negatively correlated to fruit width.

4.3.2.3.8 Number of internodes on the main stem

The number of internodes on the main stem recorded significant positive correlation in Arka Anamika mutants with fruit yield (0.4957), plant height (0.1769), number of branches per plant (0.5305), number of fruits per plant (0.4977), fruit length (0.2356), fruit width (0.2553), number of ridges (0.4448) and locules (0.2905) per fruit, and single fruit weight (0.1444), number of seeds per plant (0.1846) and weight of seeds per fruit (0.1747). In case of Arka Abhay mutant population, a positive and significant association was observed with fruit yield (0.4638), days to first flowering (0.1984), plant height (0.5749), number of branches per plant (0.6869), number of fruits per plant (0.5228), fruit length (0.1918), fruit width (0.3844), number of ridges (0.3311) and locules (0.3373) per fruit and weight of single fruit (0.1261).

4.3.2.3.9 Number of ridges per fruit

The trait had significant positive association with number of locules per fruit (0.8550), number of branches per plant (0.2377), fruit width (0.3724) and number of internodes on the main stem (0.4448) in Arka Anamika mutant population. Similarly, in case of Arka Abhay mutants, the trait had positive significant correlation with yield (0.2137), number of branches per plant (0.2055), fruit length (0.1617), fruit width (0.3825), number of internodes on the main stem (0.3311), number of locules per fruit (0.8985) and number of seeds per fruit (0.3567).

4.2.2.3.10 Number of locules per fruit

Number of locules per fruit positively and significantly associated with number of branches per plant (0.1824), fruit width (0.2529), number of internodes on the main stem (0.2905) and number of ridges per fruit (0.8550) in mutants of Arka Anamika. On the other hand, number of branches per plant (0.1996), fruit width (0.3653), number of internodes on the main stem (0.3373), number of ridges per fruit (0.8985), number of seeds per fruit (0.3277) and single fruit width (0.3181) showed positive and significant association with the trait in Arka Abhay mutant population.

4.2.2.3.11 Single fruit weight

Positive and significant phenotypic correlation among the mutants of Arka Anamika was noticed for fruit yield (0.4271), plant height (0.2002), number of fruits per plant (0.1888), fruit width (0.1978), number of internodes on the main stem (0.1444), number of seeds per fruit (0.3985), weight of seeds per fruit (0.5038) and test weight (0.3549). Significant but a negative correlation was observed for number of branches per plant (-0.2976) among the population.

Correspondingly in the mutant population of Arka Abhay positive and significant correlation was observed for fruit yield (0.2048), plant height (0.3143), number of fruits per plant (0.1555), fruit length (0.1311), fruit width (0.3426), number of internodes on the main stem (0.1261), number of seeds per fruit (0.2033), weight of seeds per fruit (0.3039) and test weight (0.1876) whereas, negative significant correlation was observed for days to first flowering (-0.2074).

4.2.2.3.12 Number of seeds per fruit

Number of seeds per fruit expressed significant and positive association with number of branches per plant (0.1645), number of internodes on the main stem (0.1846), single fruit weight (0.3985), weight of seeds per fruit (0.8502) and test weight (0.2534) in case of mutants of Arka Anamika. Likewise, mutants of Arka Abhay has exhibited positive significant correlation with plant height (0.2218), number of branches per plant (0.2003), fruit width (0.1994), number of ridges per fruit (0.3567), number of locules per fruit (0.3277), single fruit weight (0.2033) and weight of seeds per fruit (0.7900). A negative significant correlation for days to first flowering (-0.1821) also recorded for the trait.

4.2.2.3.13 Weight of seeds per fruit

A positive and significant correlation among the mutant population of Arka Anamika was recorded for fruit yield (0.1478), number of branches per plant (0.3186), number of fruits per plant (0.1597), number of internodes on the main stem (0.1747), single fruit weight (0.5038), number of seeds per fruit (0.8502) and test weight (0.7002), while days to first flowering exhibited significant negative correlation (-0.2136). Characters such as fruit yield (0.2172), plant height (0.3141), number of branches per plant (0.3065), number of fruits per plant (0.1928), length of the fruit (0.2598), fruit width (0.2149), number of locules per fruit (0.3181), single fruit weight (0.3039), number of seeds per fruit (0.7900) and test weight (0.5135) recorded significant positive correlation among mutants of Arka Abhay. Alternatively, negative significant correlation was noticed for days to first flowering (-0.2608).

4.2.2.3.14 Test weight

In Arka Anamika mutant population, weight of hundred seeds was found to have significant positive correlation with fruit yield (0.1836), number of branches per plant (0.3388), number of fruits per plant (0.1702), fruit length (0.2297), single fruit weight (0.3549), number of seeds per fruit (0.2534) and weight of seeds per fruit (0.7002). Identically, mutants of Arka Abhay also showed a positive and significant correlation (0.2629) with the yield. Plant height (0.1714), number of branches per plant (0.2510), number of fruits (0.2050), fruit length (0.3063), Single fruit weight

(0.1876) and weight of seeds per fruit (0.5135) were the traits exhibited positive association with the test weight.

4.3.2.4 Path coefficient analysis

As the number of factors involved in correlation studies increase, their association becomes more complex and confusing. Under such circumstances, path coefficient analysis helps in removing the complication by partitioning the total effect of the independent variable in to direct and indirect effects on dependent variable. It also indicates the real determinant of yield and helps in genetic improvement of crops. The results of path coefficient analysis for 13 independent characters with fruit yield are presented in Tables 48 and 49 for Arka Anamika and Arka Abhay mutant populations, respectively.

4.2.2.4.1 Direct effect of yield attributing traits on the fruit yield

Path coefficient analysis of the TS_2 mutant population of Arka Anamika revealed that the trait number of fruits per plant recorded the highest positive direct effect (0.4597) on fruit yield followed by single fruit weight (0.4245) and weight of seeds per fruit (0.3811). Plant height (0.0433), number of branches per plant (0.0896), fruit length (0.0113), number of internodes on the main stem (0.0532), number of ridges per fruit (0.0863), number of seeds per fruit (0.2335) and test weight (0.1226) were the traits which showed direct positive effect on yield. Alternatively, a negative direct effect was exhibited by days to first flowering (-0.0224), fruit width (-0.0132) and number of locules per fruit (-0.0617).

Similarly, in case of Arka Abhay mutant lines, number of fruits per plant had the highest positive effect on total fruit yield (0.3310) preceded by single fruit weight (0.2681) and fruit length (0.2618). Plant height (0.0553), number of branches per plant (0.0610), number of internodes on the main stem (0.0020), number of ridges per fruit (0.0831), number of seeds per fruit (0.0507), weight of seeds per fruit (0.1314) and test weight (0.0361) were the other traits recorded for positive direct effect. On the other hand, characters such as days to first flowering (-0.0716), fruit width (-0.0068) and number of locules per fruit (-0.0730) had displayed direct but negative effect on total yield of fruit. Similar observations for number of fruits per plant and single fruit weight was recorded by Rathava *et al.* (2019) and Prasath *et al.* (2017). Singh *et al.* (2017) observed a negative direct effect of days to first flowering on fruit yield of okra.

4.2.2.4.2 Indirect effect of yield attributing traits on the fruit yield

The highest indirect and positive effect on fruit yield per plant among the mutants of Arka Anamika was scored by number of branches per plant (0.4278), number of internodes on the main stem (0.3798), fruit width (0.3139) and fruit length (0.2647) *via* number of fruits per plant. However, the highest negative indirect effect

Table 48: Phenotypic path of different yield components on fruit yield in TS_2 mutant families of Arka Anamika

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT
DFF	**-0.0224**	-0.0108	0.0233	-0.4975	0.0025	0.0209	-0.0027	-0.0069	0.0062	-0.1062	0.0304	-0.0718	0.0208
PH	0.0056	**0.0433**	-0.0179	0.1215	-0.0049	-0.0046	0.2043	-0.0409	0.0055	0.0249	-0.0187	0.0267	-0.0049
NB	0.0058	0.0087	**0.0896**	0.4278	-0.0040	-0.1021	0.0565	0.0207	-0.0111	-0.0374	-0.0374	0.0239	-0.0417
NF	0.0069	0.0091	0.1893	**0.4597**	-0.0043	-0.0053	0.0956	-0.0728	-0.0142	-0.0112	-0.0210	0.0081	-0.0208
FL	-0.2269	0.0186	-0.0314	0.2647	**0.0113**	-0.0058	0.0378	0.0086	-0.0031	0.0062	0.0210	0.0029	-0.0282
FW	0.0016	0.0396	-0.0143	0.3139	-0.0050	**-0.0132**	0.0238	0.0021	-0.0154	0.0249	-0.0210	0.0076	0.0000
INT	0.0011	0.1435	0.1491	0.3798	-0.0027	-0.0034	**0.0532**	0.0268	-0.0179	0.0174	0.0420	-0.1528	0.0012
NR	0.0018	-0.0004	-0.0215	-0.0647	-0.0011	0.0949	0.0234	**0.0863**	-0.1339	0.0125	0.0233	-0.1043	-0.0074
NL	0.0022	-0.0039	-0.0161	-0.1007	-0.0006	0.0443	0.0154	0.0734	**-0.0617**	0.0025	0.0000	-0.0738	-0.0049
SFW	-0.1111	0.0087	0.0269	-0.1864	0.2006	0.1776	0.0074	0.0086	-0.0012	**0.4245**	0.0704	-0.0905	0.0429
NS	0.0029	0.0035	0.0543	0.0064	0.0758	-0.0012	-0.0096	-0.0086	0.0047	-0.0498	**0.2335**	0.1239	0.0181
SWT	0.0047	0.0030	0.0857	-0.1550	0.1107	-0.0003	-0.0090	-0.0078	0.0006	0.1623	-0.1985	**0.3811**	0.0858
TWT	0.0038	0.0017	-0.0305	0.0031	-0.0026	0.0078	-0.0005	0.0052	-0.0025	-0.0436	-0.0584	0.0668	**0.1226**
r value	-0.3260**	0.2646**	0.4865**	0.9726**	0.3757**	0.4138**	0.4956**	0.0948	0.0238	0.4270**	0.0656	0.1478**	0.1835**

RESIDUAL: 0.0348

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 49: Phenotypic path of different yield components on fruit yield in TS_2 mutant families of Arka Abhay

	DFF	PH	NB	NF	FL	FW	INT	NR	NL	SFW	NS	SWT	TWT
DFF	**-0.0716**	-0.0094	0.0073	-0.0997	-0.0083	0.0001	0.0002	-0.0050	0.0102	-0.2027	0.0091	-0.0342	-0.0061
PH	-0.0122	**0.0553**	0.0733	0.3137	0.0234	-0.0025	0.1512	0.0116	-0.0102	0.0027	-0.0112	0.0407	0.0061
NB	0.0086	0.1298	**0.0610**	0.3485	0.0289	-0.0018	0.0644	0.0175	-0.0146	-0.0268	-0.0101	0.0407	0.0090
NF	0.0086	0.0715	0.1903	**0.3310**	0.0296	0.0673	0.0851	0.0208	-0.0124	-0.0161	-0.0041	0.0250	0.0076
FL	0.0086	0.0188	0.0856	0.2973	**0.2618**	-0.0029	0.0404	0.0141	-0.0051	0.1349	-0.0046	0.0342	0.0112
FW	0.0007	0.0205	0.0565	0.1772	0.0296	**-0.0068**	0.0008	0.0316	-0.0270	0.0980	0.0101	-0.0276	-0.0007
INT	-0.0072	0.1875	0.0421	0.3021	0.0131	-0.0026	**0.0020**	0.0274	-0.0248	0.0349	0.0036	-0.0079	0.0319
NR	0.0043	0.0457	0.0128	-0.2008	0.0752	-0.0026	0.0197	**0.0831**	0.1657	0.0101	0.0183	-0.0420	-0.0004
NL	-0.0712	0.0077	-0.0122	-0.1413	0.0048	-0.0025	0.0087	0.0071	**-0.0730**	-0.0134	0.0167	-0.0420	-0.0029
SFW	0.0007	0.0006	0.0727	-0.0499	0.0089	0.1423	0.0503	0.0010	0.0167	**0.2681**	0.0451	-0.0394	-0.0069
NS	-0.0129	0.0122	0.0122	-0.0665	0.0062	0.0871	-0.0001	-0.0299	0.0541	-0.0536	**0.0507**	0.0713	-0.0004
SWT	-0.0486	0.0171	-0.0189	-0.1579	0.0179	0.0714	-0.0001	-0.0266	0.0234	-0.0804	-0.0401	**0.1314**	0.1784
TWT	-0.0206	0.0094	-0.0153	-0.1745	0.0213	0.0301	0.0411	-0.0008	0.0058	-0.0509	0.0005	0.0670	**0.0361**
r value	-0.2128**	0.5667**	0.5674**	0.8792**	0.5124**	0.3766**	0.4637**	0.2138**	0.1088	0.2048**	0.0840	0.2172**	0.2629**

RESIDUAL: 0.0126

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

on fruit yield was exhibited by days to first flowering *via* number of fruits per plant (-0.4975). Likewise, among the mutants of Arka Abhay, the positive indirect effects were indicated by number of branches per plant (0.3485), plant height (0.3137), number of internodes on the main stem (0.3021) and fruit length (0.2973) *via* number of fruits. Nevertheless, high but negative indirect effect of days to first flowering *via* weight of single fruits (-0.2027) was also observed among the population.

Residual effect values recorded were 0.0348 and 0.0126 (Arka Anamika and Arka Abhay, respectively), which is negligible and indicated that most of the important characters contributing towards fruit yield had been included in the study.

4.3.2.5 Identification of desirable mutants

Significant differences were visible for all the trait values among the TS_2 mutant population of Arka Anamika and Arka Abhay induced by the epigen, Trichostatin-A for various concentrations and different incubation periods. Characters such as days to first flowering, plant height, number of branches and internodes per plant, number of fruits per plant, fruit length, single fruit weight, the total fruit weight per plant and other traits were remarkably inferior in the treatments compared to their control. From among the 100 mutant lines of both the varieties, superior ones were selected and forwarded to the third generation (TS_3) based on the average performance of the lines for these traits.

Among the hundred mutant lines of Arka Anamika treated with Trichostatin-A, 13.00per cent of them showed higher performance compared to the average performance of parent (114.00 g) for the total fruit yield per plant. Twenty eight lines among the hundred mutant lines (28.00 per cent) were early flowering mutants in comparison to the check (48.00 days). Out of which three lines (AN-0.4-3-1, AN-1.2-3-12 and AN-1.2-3-13) were reasonably higher yielding compared to the Arka Anamika composing 3.00 per cent of the total population (Figure 3). In case of number of fruits per plant, 29.00 per cent of the total lines exhibited superior performance whereas, 20.00 per cent for fruit length and 31.00 per cent for single fruit weight.

On the other hand, 12.00 per cent of the total hundred lines of Arka Abhay displayed better yielding ability compared to their parent. 27 per cent of the population (27 lines) were early flowering, out of which four lines (AB-0.4-3-13, AB-0.4-5-12, AB-1.2-3-12 and AB-1.2-3-21) were yielding remarkably (Figure 3) composing 4.00 per cent of the total population. In the mutant population, 23.00 per cent of them were better performing in terms of number of fruits per plant, 11.00 per cent of them were satisfactory for the fruit length and 24.00 per cent of them were good in terms of weight of single fruits.

Table 50: Top ten lines identified in TS_2 population of Arka Anamika variety

Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TWT	YLD
1	Control	48.00	70.25	4.90	11.50	14.12	8.82	16.29	50.00	4.55	10.20	114.00
2	AN-0.4-3-1	41.00	51.56	5.00	11.00	15.61	9.00	17.39	49.00	3.59	7.29	130.35
3	AN-0.4-3-8	71.00	50.00	4.00	12.00	15.70	12.00	18.50	43.00	4.51	9.84	142.00
4	AN-0.4-5-3	57.00	62.50	4.00	13.00	18.93	11.00	25.26	73.00	4.77	9.65	156.50
5	AN-0.4-5-5	52.00	60.00	3.00	15.00	15.15	22.00	16.80	29.00	2.24	7.74	181.00
6	AN-0.4-5-10	62.00	45.00	2.00	14.00	14.00	12.00	19.00	35.00	2.51	5.62	116.00
7	AN-1.2-3-12	41.00	58.00	3.00	15.00	18.00	13.00	24.00	42.00	2.95	6.55	122.00
8	AN-1.2-3-13	42.00	75.00	7.00	17.00	15.50	19.00	24.35	33.00	1.94	5.37	330.37
9	AN-1.2-3-15	50.00	78.50	8.00	15.00	17.25	22.00	17.60	34.00	1.087	3.19	127.60
10	AN-1.2-3-14	51.00	75.00	4.00	15.00	15.25	11.00	16.50	40.00	4.21	8.89	126.50
11	AN-1.2-5-14	55.00	66.50	6.00	13.00	17.50	15.00	19.00	51.00	3.65	6.21	131.55
CD		0.92	1.55	0.25	0.55	1.23	0.85	0.79	1.69	0.41	0.42	4.35

DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

Table 51: Top ten lines identified in TS_2 population of Arka Abhay variety

Sl. No	LINES	DFF	PH	NB	NF	FL	INT	SFW	NS	SWT	TWT	YLD
1	Control	48.00	66.45	4.00	9.00	15.12	9.45	14.50	50.00	3.58	7.85	95.62
2	AB-0.4-3-13	40.00	54.00	4.00	11.00	16.50	11.00	18.80	35.00	2.51	7.24	114.00
3	AB-0.4-5-2	56.00	61.00	6.00	12.00	17.00	14.00	19.25	36.00	3.26	8.36	157.00
4	AB-0.4-5-5	54.00	78.00	4.00	10.00	17.41	18.00	25.00	39.00	2.15	4.69	117.20
5	AB-0.4-5-12	46.00	63.00	4.00	11.00	14.00	12.00	21.00	68.00	3.22	6.55	135.50
6	AB-0.4-5-10	52.00	73.00	3.00	13.00	16.25	12.00	19.50	44.00	2.45	7.07	138.00
7	AB-1.2-3-6	48.00	65.25	4.00	12.00	12.50	16.00	15.50	49.00	3.35	6.84	108.50
8	AB-1.2-3-12	41.00	63.00	8.00	13.00	13.50	11.00	14.60	48.00	2.32	8.02	129.00
9	AB-1.2-3-13	50.00	78.00	7.00	11.00	15.00	16.00	19.67	51.00	3.76	7.38	121.24
10	AB-1.2-3-21	45.00	71.00	6.00	14.00	17.50	11.00	21.56	53.00	4.29	8.81	204.00
11	AB-1.2-3-23	49.00	83.00	5.00	11.00	16.60	16.00	16.43	48.00	3.10	6.37	125.20
CD		2.00	4.26	0.55	1.42	2.81	1.96	1.86	3.70	1.04	1.84	5.52

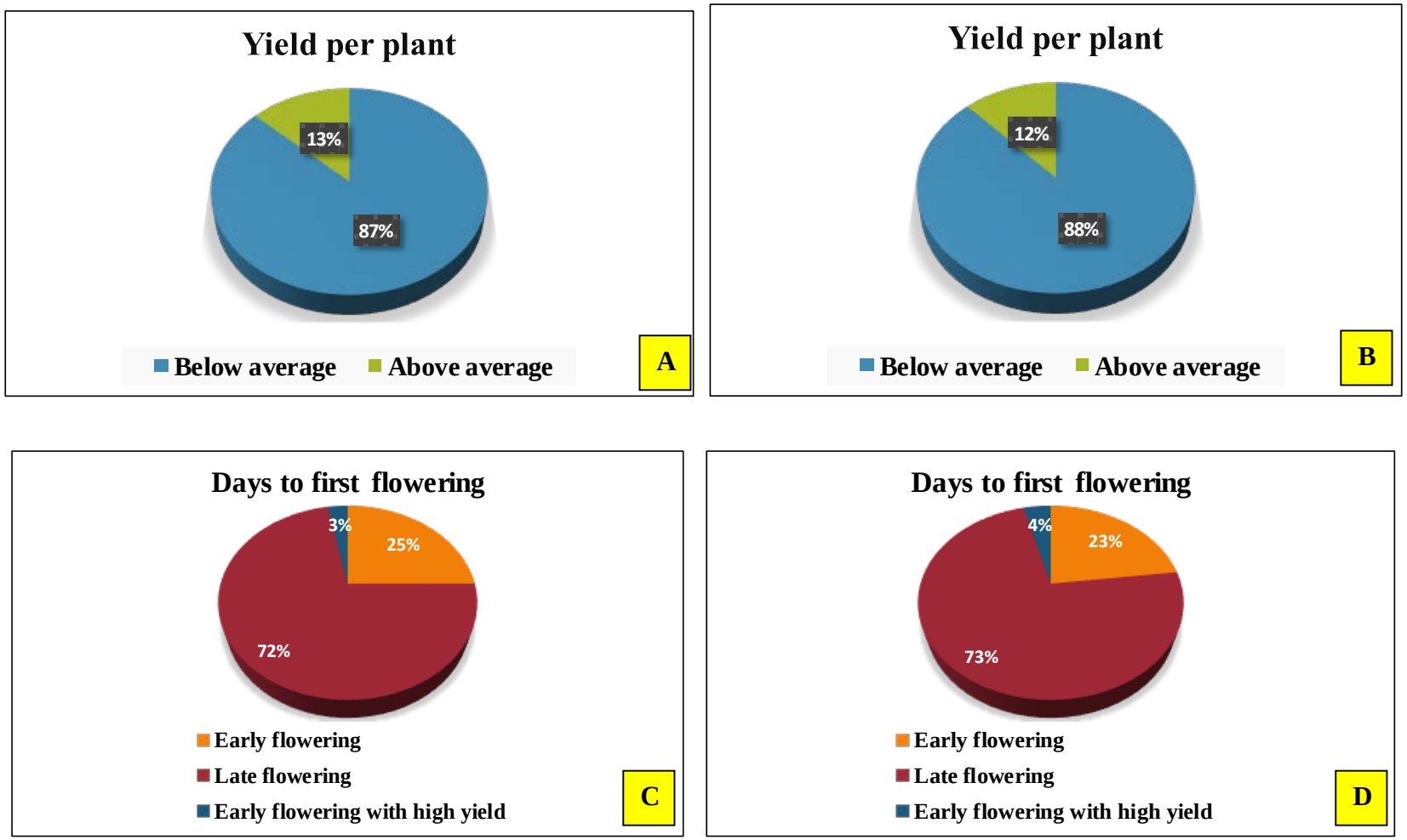
DFF: Days to first flowering
PH: Plant height
NB: Number of branches
NF: No. of Fruits
FL: Fruit Length
FW: Fruit Width
INT: No. of Internodes
NR: No. of Ridges
SFW: Single Fruit Weight
NS: No. of Seeds
SWT: Seed weight
TWT: Test Weight
YLD: Total Yield
NL: No. of Locules

From both the populations, accounting for other important traits as well, top ten superior mutant lines (10.00 per cent of the total population) each were selected and listed in Tables 50 and 51.

From the mutant lines of Arka Anamika, the lineAN-1.2-3-13 was the early flowering mutant (42 days) with highest yield performance (330.37 g) and also found good for other traits like number of fruits (17.00), fruit length (15.50 cm), single fruit weight (24.35 g), number of branches (7.00) and internodes (19.00). Three other lines, AN-0.4-3-1 and AN-1.2-3-12 (41 days each) were also early flowering types with remarkably higher fruit yield compared to the parent (114.00 g). The lines, AN-0.4-5-5 recorded the highest fruit yield among the late flowering types (181.00 g). The number of branches per plant (3.00), number of fruits per plant (15.00), fruit length (15.15 cm), number of internodes on the main stem (22.00), single fruit weight (16.80 g) and other yield contributing traits were also higher in this line. AN-0.4-5-3 and AN-0.4-3-8 are the other lines which exhibited higher fruit yield (156.50 g and 142.00 g respectively) and other yield determining characters suggesting to be other superior lines among the population.

In case of Arka Abhay mutant population, the line AB-1.2-3-21 was the highest fruit yielder (204.00 g) which is also identified as an early flowering type (45.00 days) compared to the control (48.00 days). The number of fruits (14.00), fruit length (17.50 cm), single fruit weight (21.56 g), number of branches (6.00) and internodes (11.00) were also recorded to be high in the line. The lines *viz*., AB-0.4-3-13 (40.00 days), AB-0.4-5-12 (46.00 days) and AB-1.2-3-12 (41.00 days) were the other early flowering mutants with higher fruit yield and other yield parameters. AB-0.4-5-2, AB-1.2-3-10 and AB-0.4-5-10 were the other potential lines.

Studies ranging across biological systems from yeast (Levy and Siegel 2008) to plants (Fieldes *et al.,* 2005; Salmon *et al.,* 2005, 2008, Keyte *et al.,* 2006; Molinier *et al.,* 2006), animal development (Ruden *et al*., 2005) and behavior (Crews *et al.,* 2007; Crews, 2008) and humans (Whitelaw and Whitelaw 2006) have found that epigenetic changes induced by hybridization or environmental stress may be inherited by future generations, and therefore could contribute to explaining adaptation to novel environments. These research studies ensure that epigenetically modified okra lines can be selected for desired traits in the early generations and can be stably inherited to the later generations.



A and B: Percentage of superior mutant lines for fruit yield in Arka Anamika and Arka Abhay respectively, C and D: Percentage of early flowering mutant lines in Arka Anamika and Arka Abhay respectively

Figure 3: Percentage of superior lines in the mutant population of Arka Anamika and Arka Abhay induced by Trichostatin-A

Outcome of research

- Variability was induced in two okra varieties using gamma radiation (genetic mutations) and two HDAC inhibitors *viz.*, Sodium butyrate and Trichostatin-A (epigenetic mutations).
- Superior lines from the gamma irradiated mutants of Arka Anamika and Arka Abhay with high yielding and early flowering habit were recovered.
- Epigenetically modified lines with high yield potential and early flowering types were identified and selected in the second generation.
- Experimental evidence for trans-generational inheritance of epigenetic mutations was obtained by identifying the transmission of a peculiar flower mutant lacking purple pigmentation on the backside of the petals.

Future line of work

- Promising mutant lines identified and selected in the M_2 generation can be advanced to next generations for further confirmation of their performance and stability.
- Screening of mutant lines for the resistance to important diseases such as Okra Yellow Vein Mosaic can be done.
- The epigenetic mutants of sodium butyrate and Trichostatin-A can be selfed to next generations to develop mapping population like epi-RILs.
- Screening, identification and selection of potential epi-mutants can be done for yield, resistance to biotic and abiotic stresses and fruit qualities.
- The flower mutant with lack of purple pigmentation on the backside of the petals identified can be used to study the inheritance pattern of the trait.
- Molecular techniques such as immuno- staining can be employed for the flower mutant and other lines to ascertain the histone modification induced by the epigens.

SUMMARY

VI SUMMARY

The present study, "**Assessment of Variability in Okra (*Abelmoschus esculentus* (L.) Moench) Generated through Mutations"**, was executed in two open-pollinated varieties of okra and was carried out at the College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga during 2019-2021. The experimental material was generated using gamma radiation of different doses and two different epi-mutagens such as sodium butyrate and Trichostatin-A.

6.1 Induction of variability through mutations and its assessment

The analysis of variance in the M_1 and M_2 generations of gamma induced mutants of Arka Anamika and Arka Abhay had revealed that the mean sum of squares within blocks (eliminating treatments) within treatment (eliminating blocks) and check vs varieties were significant for all the traits under consideration, which signifies the existence of remarkable differences within mutant lines. All the doses of gamma radiation had caused wide spectrum of visible mutations in both Arka Anamika and Arka Abhay mutants. Various chlorophyll mutants such as chlorina, xantha, albino, albina green and viridis were observed in the mutants along with leaf mutants such as rosette, round and lobed types. Various flower mutants and fruit mutants were also evident in the treatments.

Significant differences in the mean values of most of the traits were observed for mutant lines of both Arka Anamika and Arka Abhay in response to different doses of gamma radiation. Mean and range of major yield contributing traits such as number of branches per plant, number of fruits per plant, fruit length, single fruit weight, number of seeds per fruit, seed weight per fruit and test weight has increased in the M_2 generation compared to the M_1 generation for both the varieties. The treatment with 50 kR of gamma radiation enhanced some of the important traits governing yield among both the mutant population. Traits such as plant height, number of fruits per plant, fruit length, single fruit weight and total fruit yield per plant were observed to be significantly higher in 50 kR treatment compared to other treatments and control in both the varieties.

High GCV and PCV estimates were observed for traits such as number of branches per plant, number of fruits per plant, fruit length, number of internodes on the main stem and number of seeds per fruit. High heritability coupled with high GAM was observed for the traits *viz.,* number of branches per plant, number of fruits per plant, fruit length, number of seeds per fruit, weight of seeds per fruit and test weight in case of M_2 mutant populations, indicating the predominance of additive gene action. A higher response for simple selection of these characters are proposed as additive genes govern these traits.

6.2 Induction of variability to create epigenetic variations

The analysis of variance in the first and second generations of sodium butyrate (S_1 and S_2 generations respectively) and Trichostatin-A treated mutants (TS_1 and TS_2 generations respectively) of Arka Anamika and Arka Abhay had revealed that mean sum of squares within blocks (eliminating treatments) within treatment (eliminating blocks) and check vs varieties were significant for all the 14 traits suggesting the existence of substantial amount of variability among the mutant populations. Noticeable variations in flowers with respect to their number, sizes and shapes, delayed flowering, leaf and fruit mutants, and partial to full male and female sterility were observed among the treatments. A peculiar mutant with flowers lacking purple pigmentation on the backside of the petals, induced by sodium butyrate treatment was found to be inherited to the next generation, proving the trans-generational mode of epigenetic inheritance.

Significant differences for the range and mean performances of the fourteen traits were observed for varied doses and different incubation time of the chemicals in the present study. Mean performance of the major economic traits such as total fruit yield per plant, plant height, number of fruits, fruit length, single fruit weight, number of seeds, seed weight per fruit and test weight of the seeds were remarkably higher in the control compared to the treatments. Deleterious effects were found to be increased as the concentration of chemical and incubation period increased. The range of characters was higher, more importantly in case of fruit yield, plant height and days to first flowering. Among the different treatments, 150 µM of sodium butyrate incubated for three days had a selective advantage over the other treatments. Similarly, 1.2 µM of Trichostatin-A treatment (incubated for three days) was observed to be better performing for majority of the economic traits.

Traits such as number of branches per plant, number of fruits per plant, number of internodes on the main stem, single fruit weight, number of seeds per fruit and test weight exhibited higher values of GCV and PCV in the S_2 mutant of Arka Anamika and Arka Abhay. Similarly, in the TS_2 mutants of Arka Anamika and Arka Abhay, traits such as plant height, number of branches per plant, number of internodes on the main stem, number of seeds per fruit, and total yield had recorded high estimates of GCV and PCV. High heritability coupled with high genetic advance as per cent of mean was recorded for traits like number of branches per plant, number of fruits per plant, fruit width, number of ridges and locules per fruit and number of seeds per fruit among the S_2 populations and TS_2 populations of Arka Anamika and Arka Abhay. High estimates of heritability and genetic advance suggest a greater proportion of additive genetic variance and consequence a high genetic gain expected from the selection.

6.3 Assessment of genetic association and path analysis for yield and its contributing traits

The analysis of correlation coefficients among different characters in the M_2 population of gamma irradiated plants showed that fruit yield per plant in the populations of both Arka Anamika and Arka Abhay showed a significant positive association with almost all the traits except for days to first flowering and test weight. Traits such as number of fruits per plant, single fruit weight and number of internodes had exhibited highest positive significant correlation with the yield.

Out of fourteen characters studied in the S_2 and TS_2 population of Arka Anamika and Arka Abhay, all the traits exhibited positive and significant association with the total fruit yield, except days to first flowering, number of ridges and locules per fruit and test weight. Number of fruits per plant, fruit length, single fruit weight, number of internodes on the main stem and plant height were the traits exhibited the highest positive correlation with the yield, suggesting that these traits are the primary determinant of yield. Therefore, a direct selection for these traits might indirectly reward the total fruit yield of fruits in okra.

Path coefficient analysis revealed that the characters such as number of fruits per plant have highest positive direct effect on total fruit yield per plant, followed by single fruit weight and single fruit weight in the mutants generated through gamma radiation, sodium butyrate and Trichostatin-A. Thus it can be concluded that these characters should be relied upon and given prime importance for the selection of lines for better yield.

6.4 Identification of productive mutant lines

In the present study using gamma radiations and epigenetic mutagens, selection pressure was applied in M_2, S_2 and TS_2 populations on the basis of total fruit yield per plant, number of fruits per plant, single fruit weight and test weight. Lines with high yield and early flowering habit were also given importance during the selection process.

Among the 300 M_2 lines induced by gamma radiation, ten lines of Arka Anamika and twelve lines of Arka Abhay were identified which were reasonably higher yielding and early flowering compared to the control. Four lines out of 120 mutant lines generated using sodium butyrate (S_2 generation) in Arka Anamika and five lines of Arka Abhay were identified as outperforming and early flowering compared to their respective parents. Similarly, among the hundred mutant lines of the TS_2 population, three lines in Arka Anamika and four lines of Arka Abhay with superior performance and early flowering nature were identified and selected.

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VII REFERENCES

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APPENDICES

Appendix 1I. Monthly meteorological data for the year 2020 recorded at the meteorological observatory, Zonal Agricultural and Horticultural Research Station, Navile, Shivamogga, Karnataka.

Month	Rainfall (mm)	Mean temperature (°C)		Mean relative humidity (%)	Sunshine hours	Sunshine hours	Rainy days
		Maximum	Minimum				
January	0.00	31.8	16.3	67.3	8.8	4.0	0
February	0.00	32.7	16.6	59.1	9.2	4.5	0
March	13.40	35.0	19.4	56.5	9.2	4.9	1
April	49.40	35.7	21.1	58.3	8.6	5.3	4
May	88.00	34.7	21.9	63.9	7.8	6.8	6
June	116.6	29.8	20.9	80.9	3.1	7.8	11
July	154.40	28.5	20.5	83.5	2.4	6.3	17
August	265.80	27.4	20.1	85.9	2.3	7.5	16
September	191.6	29.1	20.2	88.0	4.1	5.7	14
October	148	29.8	19.3	85.2	5.4	4.4	8
November	0.00	30.7	17.4	77.7	7.1	4.8	0
December	16.20	30.2	15.7	75.9	7.8	4.8	1
Total	**1043.4**	**31.8**	**16.3**	**73.5**	**6.3**	**5.6**	**78**

Appendix 2. Monthly meteorological data for the year 2020 recorded at the meteorological observatory, Zonal Agricultural and Horticultural Research Station, Navile, Shivamogga, Karnataka.

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November	0.00	30.7	17.4	77.7	7.1	4.8	0
December	16.20	30.2	15.7	75.9	7.8	4.8	1
Total	**1043.4**	**31.8**	**16.3**	**73.5**	**6.3**	**5.6**	**78**