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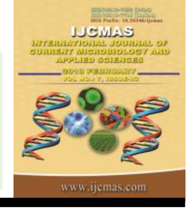

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Effect of Plant Architecture on Seed Yield and Quality of Okra [*Abelmoschus esculentus* (L.) Moench]-A Review

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A B S T R A C T

In today's context of shrinking arable land and exploding human population, productivity of any commercial crop plays a major role. Though India is the largest producer of okra in the world, its productivity (11.9 MT/ha) is too low when compared to other countries. Several factors contribute towards high productivity *viz*. seed quality, management practices, fertiliser use, temperature, rainfall etc. but good quality seed is of prime importance. Only good quality seed can achieve true genetic potential of an improved cultivar. So an improved variety should reach the farmers in a short span of time. To achieve this, seed multiplication rate has to be increased, keeping quality of seed intact. Hence the present study was framed to achieve this objective by altering architecture of plant for high seed yield and quality.

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] is widely cultivated in tropical and sub-tropical parts of the world and is amongst one of the most important vegetable crops grown in India. Okra belongs to family Malvaceae and is native to tropical Africa (Thomson and Kelly, 1979).

It is a good source of vitamin A, B, C, protein, carbohydrate, fats and minerals (Jha and Dubey, 1998). India has largest area and production followed by Nigeria. In India, it is widely cultivated in Andhra Pradesh, West Bengal, Bihar, Maharashtra and Karnataka (APEDA, 2014).

Okra is cultivated in an area of 532.66 thousand hectare, with the production of 6346.37 thousand metric tonne in India. In Himachal Pradesh, crop is grown during summer and rainy seasons in low and mid hills occupying an area of 2.76 thousand hectares and annual production of 34.03 thousand metric tonne (NHB, 2014).

Plant architecture refers to the three dimensional organisation of a plant body. Architecture of plant depends on relative arrangement of each of its parts; including branching pattern, size and number of leaves, inter-nodal distance, flowering pattern, fruiting pattern etc. Plant architecture has been the basis of systematic and taxonomic classification of plant species for a long time. "Green Revolution" was also based on modification of key architectural factors; such as short and sturdy stems which reduced lodging and significantly increased yield of major cereal crops. Plant architecture can also play a significant role in reducing crop losses due to insects and diseases. Altered plant canopy like modified branching, altered leaf size and number, inter-nodal length etc. can modify micro climatic conditions of temperature and humidity that influence pathogen and pest growth. Optimum spacing and pinching of terminal bud, which directly influence the plant architecture, are helpful in achieving twin objectives of proper plant spread and maximising podding for higher seed yield.

Spacing is one of the very basic management practice prescribed for almost all the commercial crops. It is defined as row to row and plant to plant distance which defines the planting density. Plant density has a profound influence on plant development, growth, architecture and yield of many crops (Stoffella and Bryan, 1988). Proper spacing leads to optimum canopy exposure to light and also it provides uniform area for water and mineral uptake by roots.

Pinching is defined as the removal of apex part of a plant. In most plant species, the axillary buds remain dormant due to inhibitory effect of growth of primary shoot apex, a phenomenon called Apical Dominance (Cline, 1991).

Apical bud pinching breaks apical dominance and induces development of lateral branches, thereby altering the plant architecture for increased potential poding area. When cytokinin concentration increases in axillary buds, it breaks their dormancy (Wang and Li, 2008) but auxins exported from apical meristem may limit cytokinin concentration in these lateral buds and maintain apical control through hormonal interaction. Therefore, auxin level in the buds determine the radial position and the size of lateral organs (Reinhardt *et al.,* 2000). So, if the terminal bud is pinched off, the sink for all the energy and hormones produced in the plant shifts from terminal bud to lateral buds thereby leading to thicker and wider canopy as well as shorter plant height which leads to increase in poding area and reduction in lodging.

All the relevant and important published work during 21st century on Okra has been reviewed and presented here under the following sub head:

Effect of spacing on plant growth, development and seed production in Okra

Effect of pinching on plant growth, development and seed production in Okra

Effect of spacing on plant growth, development and seed production in Okra

Talukder *et al.,* (2003) reported that one of the ways for obtaining the higher productivity of okra may be the maintenance of optimum plant population per unit area. Wider spacing in okra not only leads to higher number of pods/plant, length and weight of pod but also produces higher pod yield/plant and less jassid incidence.

Wu *et al.,* (2003) conducted a study to determine the response of okra plant architecture to various plant populations. Planting okra more densely than the control (90cm × 23cm) did not affect overall plant heights. The position of first bloom or fruit attachment and of first marketable fruit attachment tended to become higher on stem as plant population density increased, especially when plants from 15cm ×15cm spacing were compared to control plants.

Feleafel and Ghoneim (2005) studied effect of plant density on vegetative growth, seed yield and quality of plants in okra. Different plant densities were 9.5, 4.8 and 3.2 plants per m^2. The results indicated that increasing plant density from 3.2 to 9.5 plant per m^2 was accompanied with reduction in number of branches, number of leaves and leaf area per plant. On the contrary, plant height increased with high density (9.5 plant per m^2). Seed yield per plant showed a successive increment with decrease in plant density from 9.5 to 3.2 plant per m^2. Number of pods per plant, number of seeds per pod and germination percentage were not affected by different plant denisties.

Monirruzaman *et al.,* (2008) conducted a field experiment on okra with four spacings (60×30cm, 60×40cm, 60×50cm and 60×60cm). Plant spacing of 60×40cm produced the highest fruit yield of okra (2.86 T/ha) followed by 60×30cm spacing (2.80 T/ha). The germination percentage and seed vigour index were unaffected due to different plant spacings.

Paththinige *et al.,* (2008) conducted a field experiment to investigate the effect of different plant spacings on yield and fruit characteristics of okra. Treatments consisted of four plant spacings (90×60 cm, 60×45 cm, 45×45 cm and 45×30 cm) among which 90×60 cm spacing served as control. When compared to the control, total fruit yield increased by 35% and 160% at 45×45 cm and 45×30 cm spacing, respectively. In contrast fruit length decreased by 11.6% at 45×45 cm spacing and by 11.3% in 45×30 cm spacing as compared to control. Similarly single fruit weight also decreased by 16% at 45×45 cm and by 16.5% at 45×30 cm when compared to control.

The effect of plant spacing on the growth and yield of okra was evaluated by Ekwu *et al.,* (2010). Treatments were three plant spacings (30x50 cm, 40x50 cm and 50x50 cm). The number of leaves, leaf area, days to 50% anthesis, number of fruits per plant; weight, length, and width of fruits were highest at widest spacing of 50x50 cm. The closest plant spacing (30x50 cm) produced least values for all the above mentioned parameters.

Ijoyah *et al.,* (2010) conducted a study in okra on different intra-row plant spacings. The treatments consisted of three intra-row spacings (30 cm, 25 cm and 20 cm). Results of the study showed that the tallest okra plants were produced from the intra-row spacing of 25 cm. However, number of branches per plant, leaf area, pod length, pod diameter, number of pods per plant, pod weight and yield per plant decreased as intra-row spacings were reduced. The maximum fruit yield per plant was obtained from the intra-row spacing of 30 cm.

An experiment was conducted by Jana *et al.,* (2010) with four different spacings *viz*. 30x15 cm, 30x30 cm, 45x30 cm and 60x30 cm in okra variety Arka Anamika. Among different treatments, 45x 30 cm spacing recorded the highest number of fruits per plant (13.7), individual fruit weight (18.5 g), fruit yield per plant (195.0 g), fruit yield per ha (12.2 T) and Vitamin C content in fruits (25.3 mg/100 g).

An experiment conducted by Philip *et al.,* (2010) showed that spacing of 90x30 cm gave the highest fruit yield per plant of okra among all the treatments. Treatments consisted of four spacing (60x30 cm, 90x30 cm, 60x60 cm and 75x45 cm).

Agba *et al.,* (2011) conducted a study on optimum planting density of okra. Treatments were five Okra plant populations i.e. 1,11,111 plants per ha; 55,555 plants per ha; 35,714 plants per ha, 27,777 plants per ha and 23,810 plants per ha. It wasfound that high density cultivation (1,11,111 plants/ha) reduced number of branches per plant and also reduced the dry matter production per plant. The least plant population of 23,810 plants/ha produced more fresh pods per plant and weight per pod and seeds per plant as compared to other higher plant populations. The maximum plant height was obtained from plant population of 1,11,111 plants/ha and this was significantly higher than values obtained from others. The highest fresh pod yield of 7.36 T/ha was obtained from plots having plant density of 1,11,111 plants/ha. The lowest yield values of 3.45 T/ha were obtained from plant density of 23,810 plants/ha.

Studies were conducted by Wenyonu *et al.*, (2011) to determine the influence of heading back and intra row spacing on growth of okra. Spacing treatments were 60x40 cm and 60x60 cm with heading back after 35, 40 and 45 days after germination. The results revealed that heading back significantly enhanced the production of more branches, increased leaf number, enhanced dry shoot weight, increased total leaf area and leaf area index and enhanced canopy size but reduced final plant height. The best results were recorded in 60x40 cm spacing and heading back 35 days after germination.

Chaudhary *et al.,* (2012)observed that higher yield attributes in okra *viz.*, number of pods/plant (18.9), length of pod (11.9 cm), weight of pod (9.4 g), pod yield/plant (147.3 g) and minimum jassid incidence (3.2 jassids/three leaves) were observed in plants spaced at 75 x 40 cm whereas, number of pickings (10.7) and pod yield/ha (159.9 q/ha) were observed more in plants spaced at 40 x 20 cm.

Pandey *et al.,* (2012) while conducting a study on optimum spacing and optimum nitrogen dose in okra, the highest seed yield per plot was recorded at closer spacing of 60x25cm and at the nitrogen dose of 125 kg/ha.

This investigation was conducted by Ganjare *et al.,* (2013) in okra with four different planting distances viz., 50x45 cm (S_1), 50x55 cm (S_2), 50x 65 (S_3) cm and 50x75 cm (S_4). The experimental findings revealed that vegetative growth characters namely; plant height, number of branches per plant, stem diameter and leaf area significantly increased with the increase in planting distance. Number of fruits per plant and fruit yield per plant were also found to be maximum with the wider plant spacing treatment (S_4). However, fruit yield per hectare was significantly higher in closest plant spacing of 50x45 cm (S_1).

Maurya *et al.*, (2013)reported thickest (2.50 cm) stem diameter, greatest (41.86 cm) leaf diameter, maximum (11.72) number of branches per plant and the highest (415.60 g) fruit yield per plant at the widest (60cm x 45 cm) spacing in okra as compared to other spacing treatments of 30cm × 45cm and 60cm × 30cm.

Ram *et al.*, (2013) carried out an investigation on four varieties of okra with 3 different spacings. Among three spacings (30 x 15, 30 x 30 and 30 x 45 cm), spacing of 30 x 15 cm was found best and optimum for growing V.R.O-6 variety that showed best yield attributes.

Firoz *et al.,* (2014) conducted an experiment to find the effect of planting time (1st week of June, July, August and September) and plant spacing (60 x 30, 60 x 40 and 60 x 50 cm) on the yield and yield components of okra.

Highest fruit yield per hectare was obtained by planting in July at close spacing of 60 x 30 cm.

Makinde (2014) conducted an experiment with plant populations from 33,333 to 1,11,111 plants per ha to assess plant development, fruit size, and seed yield in okra. Plant stem height and diameter were not affected by different plant densities. The population of 33,333 plants per ha had more leaves/plant and higher average leaf area. Fresh fruit yield per ha kept increasing from 6.4 to 7.6 MT per ha with increase in plant populations. The lowest population had greater fruit size while the high population had more small-sized fruits. Average seed yield was linearly related to plant population.

Brar and Singh (2016) studied impact of spacing on the growth and yield of okra. Treatments were plant to plant spacing of 10cm, 15cm and 20cm. The pod weight, pod length, number of pods per plant, pod yield per plant and total pod yield per ha was highest with optimum plant to plant spacing of 15 cm.

Effect of pinching on plant growth, development and seed production in Okra

Sajjan *et al.,* (2004) studied the effects of pinching [apical pinching at 20 and 30 days after sowing (DAS)] on the seed yield and quality of okra (cv. Arka Anamika) at Bagalkot, Karnataka, India. During the Kharif and Rabi seasons, pinching at 20 DAS resulted in the highest seed yields (951.9 and 782.8 kg/ha, respectively), 100-seed weight (6.25 and 4.90 g), seed germination (81.83 and 85.13%), root length (6.42 and 7.25 cm), shoot length (18.27 and 18.08 cm), seedling dry weight (66.87 and 66.13 mg), and seedling vigour index (2027 and 2160). They concluded that apical pinching at 20 DAS was most suitable for enhancing the yield and quality of seeds in okra.

Marie *et al.,* (2007) undertook a field trial to determine the effect of two sowing dates, topping and different growth regulators on growth, pod and seed yield in okra. Topping of plants resulted in higher number of pods than the untopped ones. Topping actively increased the dry weight of plant, number of branches, number of seeds per plant, pods and seed yield per plant and per hectare.

Dilta *et al.,* (2010) studied the effects of planting dates and pinching methods on flower production of eleven cultivars of carnation. Maximum flowering stems/plant (6.58) were recorded in cv. Lavender Lace when it was subjected to single pinching as against pinch and a half method.

A field experiment was conducted to study the effect of time of apical pinching, on plant growth, flowering time and yield of Jatropha by Islam *et al.,* (2010) and it was found that plant height was significantly reduced by pinching the plant 30 days after transplanting (72.4 cm) compared to pinching during transplanting (80.00 cm) and no pinching (95.5 cm). The maximum number of primary branches per plant (3.1) with more leaves per plant (113.2) were recorded when pinching was done 30 days after transplanting. Highest number of fruits and seeds per plant were also recorded in plants pinched 30 days after transplanting as compared to no pinching and pinching during transplanting.

An investigation on effect of nitrogen and pinching on growth and yield of African marigold was carried out by Maharnor *et al.,* (2011) and it was reported that maximum number of flowering branches were obtained in plants pinched at 30 days after transplanting as compared to not pinched ones.

Wenyonu *et al.,* (2011) conducted an experiment in okra to study the influence of heading back and intra-row spacing on its growth, flowering and harvesting. Heading back was done 35 days after germination (DAG), 40 DAG and 45 DAG. Spacing treatments were 60x40 cm and 60x60 cm. In all, pruning at 35 DAG enhanced better vegetative growth compared to the subsequent prunings. The results revealed that heading back enhanced the production of more number of pods per plant, enhanced weight of pods per plant and increased total and marketable yield and reduced pod length, pod diameter and pod weight. In all, pruning at 35 DAG enhanced yield compared to the control and the subsequent prunings by 2.2 to 53.4%.

An experiment was conducted to study the effect of planting distance and pinching on growth, flowering and yield of China aster by Khobragade *et al.,* (2012). The experiment consisted of six spacings (20×10cm, 30×10cm, 40×10cm, 30×20cm, 30×30cm and 40×20cm) and with unpinched and pinched plots. The closer spacing of 20x10 cm produced taller plants (86.74 cm). Pinching reduced the plant height and delayed flowering but pinched plants yielded more than unpinched ones. The interaction of spacing and pinching found that closer spacing (20cm × 10cm) with pinching gave higher yield (56.75 kg/plot) and economically best than wider spacing with unpinched plants. Wider spacing of 40×20cm with pinched plants gave more number of flowers per plant; weight and diameter of flowers.

A field experiment was carried by Kumar *et al.,* (2012) at Faizabad to assess the effect of planting distance and pinching on growth and flowering behaviour of African marigold. Six treatment combinations comprising of two spacing (50x40 cm and 50x50 cm) and three pinching [30, 40 and 50 days after planting (DAP)] were assigned. Plant height and secondary branches per plant increased at closer spacing of 50x40 cm; however, spread and diameter of plant, primary branches per plant increased at wider spacing (50x50 cm). Opening of first flower was delayed in closer spacing, whereas duration of flowering and yield of flower increased with wider spacing. Pinching has reduced plant height but increased plant spread and yield of flowers per ha. Interaction between spacing and pinching were significant for number of secondary branches per plant, duration of flowering and flower yield. Flower yield was maximised (250 q ha^{-1}) significantly when marigold was planted at closer spacing of 50x40 cm along with pinching at 40 DAP.

Sharma *et al.,* (2012) gave different pinching and spacing treatments viz pinching after 20, 30 and 40 days after transplanting with different spacings at 30×30 cm, 30×45 cm, 45×45 cm, 45×60 cm and 60×60 cm in marigold. It was reported that highest flower yield (203.00 q/ha) was obtained with the combination of plant spacing at 45×60 cm and pinching after 30 days of transplanting. This combination was superior to the flower yield, plant growth and number of flowers per plant obtained under solo applications i.e. either spacing or pinching.

The effects of pinching and lowering on cucumber yield were studied by Higashide *et al.,* (2012). Plants were pinched at above 20 leaves on a main branch and at the second leaf on first lateral branch. Lowering plants were pinched at above 15-19 leaves on a main branch and not pinched on 4 lateral branches that were lowered with their growth. The fresh fruit yield of pinched plants was higher than in lowering plants. The high fresh fruit yield was caused by high dry weight yield which happened due to high dry matter production in pinched plants.

An experiment was conducted to standardise the time of pinching and spacing in marigold by Kour *et al.,* (2012). Three spacings (40×40 cm, 50×50 cm and 40×60 cm) and three stages of pinching [pinching at 20, 30 and 40 days after transplating (DAT)] were given. It was reported that delayed pinching i.e. 40 DAT along with close spacing of 40×40 cm produced more yield (248.12 q/ha) as compared to all other treatment combinations. This treatment also recorded increase in number of secondary branches per plant and flower number per plant. Olfati and Malakouti (2013) gave pinching treatments to study its impact on yield and development of fababean. Treatments were zero, one, two and three pinchings. First pinching was done when plants had four true leaves, second and third pinching were done when all lateral and sublateral branches had atleast four true leaves. Pinching two times produced more pods per plant and more pod and seed yields than not pinching. Although number of seeds per pod and mean pod weight remained unaffected.

Kumar *et al.,* (2014) gave pinching at 20, 30 and 40 days after transplanting (DAT) at 10 and 20 cm height (main branches only), one at 40 DAT (main + secondary branches) at 20 cm height and one control (no pinching) to Stevia (*Rebaudiana bertoni*). They concluded that stevia plants pinched at 40 DAT (main + secondary branches) at 20 cm height recorded best results with higher number of leaves per plant (213), fresh leaf weight (93.8 g per plant) at first harvest and 27.7 % higher total leaf dry biomass as compared with control. This treatment also recorded highest net returns (Rs. 1,86,998 per ha).

Lakshmi *et al.,* (2015) studied the effect of apical pinching on fenugreek. Treatments included pinching plants and not pinching. Higher seed yield with better seed quality attributes were obtained when plants were pinched. Germination (95.40%), SVI-I (2271), SVI-II (1584) and field emergence (87.20%) with lower electrical conductivity (126 dSm^{-1}) were superior in seeds obtained from pinched plants.

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