Sex Manipulation in Cucurbitaceous Vegetables

K.C. Megharaj¹*, P.S. Ajjappalavara¹, Revanappa¹, D.C. Manjunathagowda² and J.C. Bommesh³

¹Department of Vegetable Science, UHS, Bagalkot-587 104, Karnataka, India
²ICAR-DOGR, Rajgurunagar, Pune, Maharashtra–410505, India
³Department of Vegetable Science, IIHR, Hesaraghatta, Bengaluru-560065, Karnataka, India

*Corresponding author

A B S T R A C T

Sex manipulation is attributed to alter the ratio of male to female flowers within the individuals. A wide range of variation in sex forms ranging from primitive hermaphrodite to gynoecious advanced sex form is observed in cucurbitaceous vegetable crops. Sex expression in cucurbitaceae family is regulated by environmental, genetic and hormonal factors. In general, female sex expression is promoted by low temperature and short photoperiod, which may influence the level of endogeneous hormones (ethylene, auxin and GA) which in turn influence the sex expression. Sex inheritance plays an important role in breeding programme. The reduction in sex ratio, stabilizing the gynoecious character and development of stable gynoecious inbred parents is the main objective of cucurbit breeding programs. Identification of sex expression in the initial stage of the crop with the help of biotechnological tools like marker assisted selection (MAS) may be employed. The molecular breeding will also be helpful for studying the mechanism affecting sex expression and to identify the genes governing the sex character in cucurbits.

Introduction

The cucbit vegetables are the largest and diverse group comprised of 900 species classified under 130 genera (Jeffrey, 1964; 1980) belongs to the family Cucurbitaceae. The members of Cucurbitaceae family exhibit a fascinating range of sex (Table 1) namely staminate, pistillate and hermaphrodite flowers resulted in evolution of several types of sex forms like monoeocious (stamate and pistillate flowers produces in the same plant), gynoeocious (pistillate flowers producing plants), andromonoecious (stamate and hermaphrodite flowers in the same plant), gynomonoecious (pistillate and hermaphrodite flowers produces in the same plant), androecious (plant with stamate flowers only), trimonoecious (stamate, pistillate and hermaphrodite flowers produces in the same plant), gynodioceous (pistillate and hermaphrodite plants segregate separately from base population), dioecious (stamate and pistillate flowers are produced in separate plant). A wide range of variation in sex forms owed to evolve from primitive sex form hermaphrodite could lead to evolution of predominant sex form i.e. monoeocious and advanced sex form i.e. gynoeocious (Robinson and Decker-Walters, 1999). Sex manipulation

https://doi.org/10.20546/ijcmas.2017.609.227
is the process of altering male and female flower ratio within the individuals of a species, the sex modification leads to alteration in the sequence of flowering phenology by modifying beneficial sex ratio in order to enhance the economic yield. Sex inheritance plays an important role in cucurbit breeding, sex expression mainly influenced by genetical and environmental factors. The monoecious plants are characterized by three phases of flowering, *i.e.* an initial period where only male flowers are produced, secondly equal proportionate of male and female flowers are produced for maximum period and finally predominate in female flowers production.

**Evolution of sex expression in cucurbitaceae**

The original and primitive sex form of cucurbits are assumed to be hermaphrodite nature, and evolutionary changes had been occurred in later generations might be due to the vagaries of environmental factors, the dominant mutation effect may lead to the modification of sex from hermaphrodite to the intermediate sex forms like andromonoecious, trimonoecious and gynomoecious (Fig. 1), furthermore advancement in the evolutionary genetic and environmental changes might cause for modification of androecious, monoecious and gynoecious (Robinson and Decker-Walters, 1999). Sex expression in cucurbits is easily manipulated by controlling the environmental conditions as well as genetic factors, hence these two factors are major effect on sex manipulation. The non-genetic factors like environmental effect, cultural practices, plant growth regulators, and genetic factors like breeding behaviour and genetic constitution plays a significant role in altering the sex expression of cucurbits with the aid of conventional breeding methods and intervention of biotechnological approaches.

**Non-genetic factors**

**Influence of environmental effect on sex expression**

Sex expression mainly influenced by environmental factors, attributing female sex expression is promoted by low temperature, short photoperiod and high moisture availability, (Atsmon and Galun, 1962; Atsmon, 1968), which intern encourages the buildup of carbohydrates. The high temperature and long photoperiod results in male flower production (Cantliffe, 1981). The phenomenon of sex expression is influenced by environmental factors on production of endogenous hormones especially ethylene, auxin, gibberellic acid and chemical composition, may cause for different expression of sex forms, the ratio of staminate to pistillate flowers greatly varies when the monoecious plants are grown under different environmental conditions (Robinson and Decker-Walters, 1997; Achakzai; Kayani, 2002; Achakzai, 2012). Positive correlation between ethylene release and percentage of nodes and number of female flowers were recorded highest at 28°C/ (6h 18°C+6h 12°C) day/night temperatures. The enhanced female flowers in monoecious cucurbits is not directly regulated by low temperature or low night temperature, but these conditions lead to accumulation of the glucose and sucrose in the shoot apex under certain temperatures, through hexokinase-mediated sugar signalling pathway (Miao et al., 2011). The female flower producing nodes increased over sevenfold in monoecious cucumber and three-folds in andromonoecious cucumber for the production of bisexual flowers due to endogenous ethylene production under short-day (8 h photoperiod). Ethylene evolution from the shoot apices of monoecious and andromonoecious plants at the four-leaf stage indicated the maximum ethylene peak in monoecious and andromonoecious cucumber.
plants grown under 8h photoperiod approximately 1.5 times higher than the 16h photoperiod (Yamasaki et al., 2003).

**Influence of cultural practice on sex expression**

Cultural practices like irrigation, nutrient application and season of planting plays a minor role in sex manipulation, unfavourable growing conditions such as lack of water can cause a slowdown in flower production, higher application of nitrogen results in more vegetative growth intern reduces reproductive stage and lead to the delayed flowering. Mineral nutrients might alter sex expression in plants through effects on hormonal balance (Salisbury and Ross, 1969). The season of planting during higher rainfall results in lesser flower production, whereas planting during hot seasons produces more male flowers and less female flower production. Sub-optimal application of nitrogen, phosphorus, potassium nutrients has been reported to depress flowers and encourage male flowers rather than female flowers (Kraup et al., 2002). The modification of sex ratio in favour of female flowers using different factors such as mineral nutrients, most especially high levels of nitrogen has been most clearly demonstrated in monoecious cucurbits (Lau et al., 1993; 1995). Mineral nutrients like boron also influence sex expression in many cucurbits (Table 2).

Application of potassium fertilizers in potassium deficit soils increased the female flowers and subsequently enhanced fruit yield in squash (Abduljabbar and Ghurbat, 2010), application of bio-fertilizers significantly enhanced the induction of female flowers and reduced male flowers in squash plant (Abd El-Fattah and Sorial, 2000). The application of 100 kg/ha of NPK 15:15:15 induced the increased male to female flowers in pumpkin (Agbaje et al., 2012).

**Role of growth regulators on sex expression**

Growth regulators have tremendous effects on sex expression and flowering in various cucurbits lead to suppression of male flowers or an increased number of female flowers (Al-Masoum and Al-Masri, 1999), without imposing any deleterious effect on environment and human health. Growth regulators can alter the sex ratio and sequence if applied at the two- or four-leaf stage, which is the critical stage at which the suppression or promotion of either sex is possible (Hossain et al., 2006). The male to female flower ratio of cucumber plants is also regulated by plant hormones, ethylene and auxin promote the formation of female flowers, whereas gibberellins promote the formation of male flowers (Table 3). The first report in any plant species of alteration of sex expression via exogeneous chemicals was done by the application of auxin shifted sex expression in cucumber towards femaleness (Laibach et al., 1949). The foliar application of gibberlic acid promoted male flowers in a monoecious cultivars at nodes where female flowers would have normally occurred (Wittwer and Bukovac, 1958).

Gynoecious lines are obtained with the use of chemicals to induce staminate flower for genetically selfing in a cucumber population, cucumber variety ‘Bingo’ expressed gynoecious sex of 5%, Whereas Seminis-1, Seminis-3, Micro-c and long green were found predominantly gynoecious sex form and are stabalized gynoecious sex form in cucumber (Cucumis sativus L.) performed upon repeated selfing, further cent per cent gynoecious populations in S3 generation were obtained as SE1-G and SE3-G lines, gynoecious plants of these lines were maintained by selfing, bulked seeds of each S3 line used for the experiment on gynoecious line maintenance (Chaudhary et al., 2001).
Yin and Quinin, (1995) elaborated mechanistic model of hormone regulation of sexes in cucurbits. Ethylene plays a major role for inducing female flowers by suppressing gibberellin, a hormone for male flower production (Fig. 2). The internal ethylene level influences on expression of sex phenotypes i.e., gynoecious lines produce two to threefold higher ethylene level than monoecious or andromonoecious ones.

GA$_3$ acts as an ethylene biosynthesis blocker which blocks the ethylene precursor due to which the ethylene production is hindered. Similarly, AgNO$_3$ acts as a ethylene action blocker avoids the ethylene action and increases male flower production (Fig. 3). CEPA 150 ppm and NAA 50 ppm increased the total number of female flowers by 40 and 29 %, respectively in bittergourd by first female flower at 10 to 12 days earlier than control at lower nodes (Baset et al., 2014). The AgNO$_3$ at rate of 500 mg/l induced highest hermaphrodite flowers (15) on female sweet gourd plants, proportionately hermaphrodite flower production sharply decline at 700 mg/l AgNO$_3$ (about 10) with plant senescence and wilting of vines. However, the maximum number of female flowers (39) found in untreated vines (Sanwal et al., 2011).

**Genetic factors**

**Breeding for sex manipulation traits**

A wide range of variation in sex forms ranging from hermaphrodite to monoecious forms is observed in cucurbitaceous vegetable crops (Robinson and Decker-Walters 1997). Among these the gynoecious sex (only female flowers) form has been commercially exploited worldwide for cucurbit breeding programme. Development of hybrids in any crop is expensive (Behera, 2004). However, the utilisation of gynoecy is economical and easier for exploiting hybrid vigour in many cucurbitaceous crops. Hybrid varieties of cucurbits are predominantly used in the production system, the proportion of hybrid varieties is continuously increasing and thus, gynoecious lines in cucurbits are important for economic production. Development of hybrids in cucurbits is expensive because of hand pollination. However, it can be made inexpensive by the utilisation of gynoecy which is economical and easier for exploiting hybrid vigour.

**Table.1 Different sex forms in cucurbits**

| Sex forms                     | Cucurbits                                      |
|-------------------------------|-----------------------------------------------|
| Monoecious (♀ and ♂)          | Cucumber, Musk melon, Pumpkin, Summer squash, |
|                               | Winter squash, Water melon, Sponge gourd, Round |
|                               | melon, Bottle gourd, Bitter gourd.             |
| Gynoecious (♀)                | Cucumber, Bitter gourd, Musk melon, Watermelon, |
|                               | Ridge gourd                                    |
| Androecious (♂)               | Cucumber, Musk melon                           |
| Dioecious (♀ and ♂ in separate plant) | Pointed gourd, Ivy gourd,                      |
| Andromonoecious (♂ and ♀ in same plant) | Muskmelon, Water melon, Cucumber               |
| Gynomonoecious (♀ and ♂ in same plant) | Cucumber, Musk melon, Ridge gourd             |
| Trimonoecious (♂, ♀ and ♂ in same plant) | Cucumber                                       |
| Hermaphrodite (♂)            | Ridge gourd (Satputia)                         |

1842
| Crop                     | Dosage | Effect                                                                 | Reference                  |
|-------------------------|--------|------------------------------------------------------------------------|----------------------------|
| Muskmelon               | 6 ppm  | Increased ratio of hermaphrodite: staminate flowers.                   | Randhawa and Singh, 1974   |
| Cucumber cv. Poona Khira| 3-4 ppm| Increased pistillate flowers.                                          | Verma and Choudhary, 1980  |
|                         | 2-4 ppm| Decreased number of days to first female flower, early node to first female flower, lower male: female flower ratio. | Singh and Choudhary, 1988  |
| Cucumber cv. MotiTionh  | 0.25%  | Low ratio of male:female flowers.                                      | Maurya, 1987               |
| Cucumber                | 4 ppm  | Reduces the number of days to first male and female flower production, number of nodes to first female flower appearance and increases total number of female flowers. | Singh and Chaudhury, 1988  |
| Watermelon cv. Sugar baby| 3 ppm | Increased the total number of female flowers per vine and decreased ratio of male: female flowers | Ali et al., 1985           |
|                         | 2-4 ppm| Decreased number of days to first female flower production and number of nodes to first female flower appearance, more number of female flowers. | Singh and Chaudhury, 1988  |
| Watermelon              | 0.56 kg/ha | Increased pollen germination percentage                          | Phatak et al., 1990       |
|                         | 4 g per plant | Decreased the days to first male and female flower appearance, reduced sex ratio in both kharif and rabi season. | Patel, 2008               |
| Bitter gourd            | 4 ppm  | Increased female flowers per plant                                    | Verma et al., 1984        |
|                         | 4 ppm  | Decreased number of days to first male flower production, reduced male: female flower ratio. | Gedam et al., 1998        |
Table.3 Effect of growth regulators on different crops

| Crop          | Growth regulator | Dosage       | Effect                                                                 | Reference                          |
|---------------|------------------|--------------|------------------------------------------------------------------------|------------------------------------|
| Muskmelon     | GA\(_3\)         | 10 mg/l      | Increased fruit yield per hectare                                      | Randhava and Kirtisingh, 1973      |
|               | GA\(_3\)         | 400 mg/l (Seed soaking) | Increased number of fruits and yield                                   | Ram et al., 2012                   |
| Cucumber      | Silver nitrate   | 400 ppm      | Increased total number of staminate flowers/plant, early days to flowering in main axis, early node of first male flowering in main axis. | Badri et al., 2001                 |
|               | Ethephon         | 100 and 200 mg/l | Increased yield                                                         | Thappa, 2011                       |
|               | MH + Ethephon    | 100 ppm each | Earliness, increased sex ratio and reduced plant expansion            | Thappa, 2011                       |
|               | Ethrel           | 500 ppm      | Increased female flowers and reduced male flowers                      | Bhandary et al., 1974              |
|               | Ethephon (ethrel) | 400 ppm     | Maximal suppression of staminate flowers                               | Mishra et al., 1976                |
| Watermelon    | GA\(_3\)         | 10 ppm       | Produced more number of female flowers                                  | Gopal Krishna and Choudhary, 1978  |
|               | TIBA             | 50-200 ppm   | Producing a favourable female to male ratio and increased number of fruits. | Gopal Krishna and Choudhary, 1978  |
| Bitter gourd  | GA\(_3\)         | 10 ppm       | Effective in improving the yield components                            | Islam, 1995                        |
|               | Ethrel (2-Chlorothyl phosphonic acid) | 200 to 600 ppm | Stunting growth and significant reduced production of male flowers. | Ravindran, 1971                   |
| Pumpkin       | Ethephon         | 300 mg/l     | Increased number of female flowers                                     | Sure et al., 2012                  |
| Pointed gourd | Ethrel           | 150 ppm.     | Pistillate flowers, fruit numbers/plants, fruit size and fruit weight were increased. | Ramaswamy et al., 1976             |
| Snake gourd   | Ethephon (ethrel) | 250 ppm     | Altered sex expression and increased fruit yield                       | Cantliffe, 1976                    |

Table.4 Report of different inheritance pattern for sex expression in cucurbits

| Crops           | Mode of inheritance | Gene symbol | Investigators                   |
|-----------------|---------------------|-------------|---------------------------------|
| Cucumber        | Three major genes   | F/f, M/m, A/a | Kubicki, 1969a; Galun, 1961     |
| Musk melon      | Two recessive genes | A-ggmm      | Kenigsbuch and Cohen, 1990       |
| Bitter gourd    | Single recessive gene | gy-1        | Ram et al., 2006                 |
| Water melon     | Single recessive gene | gy         | Jiang and Lin, 2007             |
| Ridge gourd     | Major recessive gene | -           | Singh et al., 2012              |
**Fig. 1** Evolution of sex forms in cucurbits (Whitaker, 1931)

- **Original form** (Primitive sex form)
- **Intermediate form**
- **End form**

- **Hermaphrodite**
  - **Andromonoecious**
  - **Trimonoecious**
  - **Gynomoecious**

- **Male receptor**
- **Female receptor**
- **Ethylene precursor**

**Fig. 2** Effect of ethylene on flower manipulation

- **Ethylene**
- **Inhibiting**
- **Inducing**
Fig. 3: Role of different hormones in flower modification

![Diagram showing the role of different hormones in flower modification.]

- **Ethylene precursor**
  - Ethylene
  - Male receptor
  - Inducing

- Female receptor

- **Ethylene action blocker**
  - Silver nitrate (AgNO₃)
  - Silver thiosulphate [Ag(S₂O₃)₂]

- **Biosynthesis blocker**
  - Gibberellic acid (GA)
  - Aminoethoxy vinyl Glycine (AVG)

Fig. 4: Schematic representation of development of gynoecious line in muskmelon (Yigal, 1993)

![Diagram showing the development of a gynoecious line in muskmelon.]

1846
Achievements of gynoecism development in cucurbitaceous vegetable crops

Gynoecious line was reported for the first time in cucumber cultivar ‘Shogoin’ (PI 220860) (Peterson and Anhder, 1960), gylan—a gynoecious muskmelon obtained (Fig. 4) in segregated F₇ population of GY-4 × 36 (Yigal, 1993), Gy263B gynoecious lines was reported in bitter gourd (Ram et al., 2006). Gynoecious gene (gy-1) in watermelon had been located (Jiang and Lin, 2007).

The development of gynoecious line is mainly due to the involvement of spontaneous or chance segregation of gynomonoecious lines lead to the isolation of gynoecious lines in the segregating population. Gynoecious lines are improved by repeated backcrossing and further maintained by selfing, it is possible by using growth regulators by induction of staminate flower for selfing as pollen source.

Hybrid seed production is more effective with the use of gynoecious lines and are mainly used as a female parental line, since gynoecious plants does not produce male flowers as pollen source, all nodes bears pistillate flowers lead to high yielding with addition of parthenocarpic traits. The cross of heterosexual (cross between female and male plant), homosexual (cross between two females by inducing bisexual flowers in any one of the female plants) revealed the highest number of fruits per plant of F₁ heterosexual (32.1) than F₁ homosexual (30.7).

The sex expression in progeny seeds of female homosexual crosses produced 100 % female plants in F₁, indicate the female: male sex ratio of 1:0 whereas in heterosexual cross, is 1:1 segregation of male and female plants indicated that the sex expression is controlled by xx/XY chromosomes. The gynoecious sex expression in sweet gourd is governed by a single homozygous recessive gene (Sanwal et al., 2011). Jiang and Lin (2007) discovered the gynoecious gene (gy) in watermelon, by crossing gynoecious line (Gynoecious 1) with monoecious line (A123) lead to production of normal monoecious F₁ hybrid. The ratio of monoecious to gynoecious sex form was 86:18 in F₂ and in the progeny backcrosses further lead to the segregation, results of ratio 59:43, could reveal gynoecism in watermelon is controlled by single recessive gene. The inheritance of gynoecism in bitter gourd had been studied with the use of GY263B gynoecious line and Pusa-Do-Mousami monoecious line were used as parents and the phenotype of F₁ revealed to be the monoecious and upon examine of F₂ population and testcross (3:1 and 1:1 ratio of monoecious to gynoecious respectively) revealed the gynoecious in bitter gourd is controlled by single recessive gene (Ram et al., 2006). ‘Gylan’- an improved gynoecious muskmelon variety with resistance to downy mildew disease had been developed (Fig. 4) by crossing with lines 124111F, governing two dominant downy mildew resistance genes Pcé and Pç2, the stable gynoecious muskmelon breeding line GY-4 isolated from a segregating population (gynoecious: gynomonoecious) of Wisconsin 998, carrying a pair of recessive genes for gynoecy sex, g and m (Yigal 1993).

Biotechnological intervention in sex manipulation

The monoecious (M-ff) cucumbers hypothesized to produce two types of flower buds namely one produces more ethylene and the other produces less ethylene (Yamasaki et al., 2001). This could be due to the 1-aminocyclopropane-1-carboxylic acid (ACC) is an immediate precursor of ethylene (Adams and Yang, 1979) and that the expression of ACC synthase genes (ACS) generally correlates with ethylene biosynthesis in plants.
Development of male and female specific markers at early identification of male and female plants and efficiency in improving of dioecious vegetables (Ivy gourd, Pointed gourd, Spine gourd and Asparagus etc.) as well as transferring the desirable gene governing sex character in to the required plants adapting tissue culture techniques for mass multiplication of gynoecious lines and biotechnological approaches import a crucial role in which RAPD marker associated with gynoecious trait (gy-1 gene) in bitter gourd had been revealed namely, OPZ 13 marker of 700 bp produced specific band in gynoecious lines makes easy identification of gynoecious lines in bitter gourd (Mishra et al., 2014). Male specific RAPD markers in pointed gourd isolated namely, OPC05₁₀₀₀ of 1000 bp produced specific banding pattern found only in males. Similarly, OPC14₄₀₀ was the female specific marker produces specific banding pattern only in females (Kumar et al., 2008). Ethylene regulation has been studied and revealed the sex expression genes in cucumber plants namely CS-ETR₂ and CS-ERS genes. CS-ETR₂, CS-ERS, CS-ETR₁ are ethylene receptor genes and CS-AC₂ is a female inducing gene. The effect of ethrel on gene expression of CS-ETR₁, CS-ETR₂, and CS-ERS in the shoot apices of cucumber var. Otone no. 1 at the 4-leaf stage is increased, however the effect of AVG (Amyl-Vinyl-Glycine) on gene expression of CS-ETR₁, CS-ETR₂, and CS-ERS in the shoot apices of Higan-fushinari at the 4-leaf stage found to be low. The results revealed the expression gene is influenced by exogenous or indigenous hormonal concentration (Yamasaki et al., 2001). Gynoecious lines acts as a male sterile line in cucurbitaceous vegetables and predominantly used in heterosis breeding, use of gynoecious lines complicated by isolation and maintenance, less stability due to the variation of gene depending upon environmental effects. Utilization of gynoecious lines has been commercially exploited in cucumber viz., Pusa Sanyog, Phule Prachi, Phule Champa, and DBGH 12 in bitter gourd.

Sex manipulation in cucurbits plays an important role in the reduction of sex ratio. Gynoecious lines acts as a male sterile line in cucurbitaceous vegetables. Henceforth, stabilization of gynoecious trait and development of stable gynoecious inbred parents will be helpful in hybrid development programs. The mechanism affecting sex expression and identification of the genes governing the sex character is possible through specific molecular markers. In dioecious crops, the molecular markers linked to gynoecious trait are useful in early identification of sex at earlier stage of the crop.

References

Abd El-Fattah, and Sorial, M. E., 2000. Sex expression and productivity responses of summer squash to biofertilizer application under different nitrogen levels. Zagzig J. Agric. Res. 27(2): 255-281.

Abduljabbar, I. M., and Ghurbat, H. M., 2010. Effect of foliar application of potassium and IAA on growth and yield of two cultivars of squash (Cucurbitia pepo L.). J. Tikrit Univ. Agric. Sci. 10(2): 222-232.

Achakzai, A. K. K., 2012. Effect of various levels of nitrogen fertilizer on some vegetative growth attributes of pea (Pisum sativum L.) cultivars. Pak. J. Bot. 44(2): 655-659.

Achakzai, A. K. K., and Kayani, S. A., 2002. Effect of fertilizer, inoculation and sowing time on the chemical composition of field grown soybean seeds. Asian J. Plant Sci. 6: 619-621.

Adams, D. O., and Yang, S. F., 1979. Ethylene biosynthesis: identification of 1-aminocyclopropane-1-carboxylic acid as an intermediate in the conversion of methionine to ethylene. Proceedings of
the National Academy of Sciences, USA 76. p. 170–174.
Agbaje, G. O., Oloyede, F. M. and Obisesan, I. O., 2012. Effect of NPK fertilizer and season on the flowering and sex expression of pumpkin (Cucurbita pepo L.). International Journal of Agricultural Sciences. 2(11): 291-295.
Ali, K. S., Reddy, N. T. and Reddy, E. N., 1985. Effect of plant nutrients and growth regulators on growth, flowering and sex ratio in watermelon (Citrullus lanatus (Thunb.) South Indian Hort. 33(5): 336-338.
Al-Masoum, A., and Al-Masri, A. A., 1999. Effect of ethephon on flowering and yield of monoecious cucumber. Egy. J. Hort. 26: 229–236.
Atsmon, D., 1968. The interaction of genetic, environment and hormonal factors in stem elongation and floral development of cucumber plants. Ann. Bot. 32: 877-882.
Atsmon, D., and Galun, E., 1962. Physiology of sex in Cucumis sativus L. leaf age patterns and sexual differentiation of floral buds. Ann. Bot. 26: 137-146.
Badri, N. C., Kasem, P., Thanya, T. and Chairerg, S., 2001. Development and maintenance of gynoecious lines of cucumber (Cucumis sativus L.). Kasetsart J. (Nat. Sci.). 35: 242 – 250.
Baset, M., Islam, M. S. and Shamsuddin, Z. H., 2014. Altered sex expression by plant growth regulators: An overview in medicinal vegetable bitter gourd (Momordica charantia L.). Journal of Medicinal Plant Research 8(8): 361-367.
Behera, T. K., 2004. Heterosis in bitter gourd. J New Seeds. 6: 217-221.
Bhandary, K. R., Shetty, K. P. V. and Sulikeri, G. S., 1974. Effect of ethrel (2-Chloro ethyl phosphonic acid) on the sex expression and yield of cucumber (Cucumis sativus L.). Progressive Hort. 6 (2/3):49-57.
Cantliffe, D. J., 1976. Improved fruit set on cucumber by plant growth regulator sprays. Proceedings of the Florida State Hort. Soc. 89: 94- 96.
Cantliffe, D. J., 1981. Alteration of sex expression in cucumber due to changes in temperature, light intensity and photoperiod. J. Amer. Soc. Hort.Sc. 106: 133-136.
Galun, E., 1961. Study of the inheritance of sex expression in cucumber, the interactions of major genes with modifying genetic and non-genetic factors. Genetica. 32: 134-163.
Gedam, V. M., Patil, R. B., Suryawanshi, Y. B. and Mate, S. N., 1998. Effect of plant growth regulators and boron on flowering, fruiting and seed yield in bitter gourd. Seed Res. 26 (1): 97-100.
Gopalkrishnan, P. K., and Choudhury, B., 1978. Effect of plant regulator sprays on modification of sex, fruit set and development in watermelon (Citrullus lanatus L.). Indian J. Hort. 35: 235-241.
Hossain, D., Karim, M. A., Pramanik, M. H. R. and Rahman, A. A. M., 2006. Effect of gibberellic acid (GA$_3$) on flowering and fruit development of bittergourd (Momordica charantia L.). International J. Bot. 2: 329–332.
Hossain, K. L., Rahman, M. M. Banu, M. A., Khan, T. R. and Ali, M. S., 2006. Nitrogen fertilizer effects on the agronomic aspects of asparagus racemosus. Asian J. Plant Sci. 5(6): 1012-1016.
Islam, M. S., 1995. Seed production studies on bitter gourd (Momordica charantia L.). Seed Sci. 33:121-123.
Jeffrey, C., 1964. Key to the cucurbitaceae of west tropical Africa with a guide to localities and little known species. J. W. African Sc. Assoc. 9: 79-97.
Jeffrey, C., 1980. A review of the Cucurbitaceae. Bot J Linn Soc. 81:233-247.
Jiang, X. T., and Lin, D., 2007. Discovery of watermelon gynoecious gene gy, Acta Horticulturae Sinica. 34 (1): 141 – 142.
Kenigsbuch, D., and Cohen, Y., 1990. The inheritance of gynoecy in muskmelon. Genome. 33: 317-320.
Kraup, C. A., Kraup, R. and Pertierra, U. A., 2002. Growth of Asparagus crowns with increasing nitrogen rates at three different sites. Acta Horticulturae. 589: 145-150.

Kubicki, B., 1969a. Investigation on sex determination in cucumber (Cucumis sativus L.) III. Variability of sex expression in the monoecious and gynoecious lines. Genet Pol. 10: 5-22.

Kumar, S., Singh, B. D., Sinha, D. P. and Rai, M., 2008. Sex expression-associated RAPD markers in pointed gourd (Trichosanthes dioica). Proceedings of the IXth EUCARPIA meeting on genetics and breeding of cucurbitaceae. France. May 21-24th, 2008.

Laibach, F., and Kribben, F. A., 1949. The influence of growth regulators on the development of male and female blossoms in a monoecious plant (Cucumis sativus L.). Bot. Ges. 62: 53-55.

Lau, T. C., Lu, X., Koide, R. T. and Stephenson, A. G., 1995. Effects of soil fertility and mycorrhizal inflection on pollen production and pollen grain size of Cucubita pepo L. Plant Cell Environ. 18(2): 169-177.

Lau, T., and Stephenson, A. G., 1993. Effects of soil nitrogen on pollen production, pollen grain size and pollen performance in Cucurbita pepo. Am. J. Bot. 80(7): 763-768.

Maurya, K. R., 1987. Effect of nitrogen and boron on sex ratio, yield, protein and ascorbic acid content of cucumber (Cucumis sativus L.). Indian J. Hort. 44(3-4): 239-240.

Miao, M., Yang, X., Han, X. and Wang, K., 2011. Sugar signaling is involved in the sex expression response of monoecious cucumber to low temperature. J. Exp. Bot. 62: 797-804.

Mishra, R. S., Panigrahi, R. K. and Panda, S. C., 1976. Chemical regulation of sex expression in relation to growth and yield in cucumber. Orissa J. Hort. 4(1/2):57-61.

Mishra, S., Behera, T. K., Munshi, Gaikwad, K. and Mohapatra, T., 2014. Identification of RAPD marker associated with gynoecious trait (gy-1 gene) in bitter gourd (Momordica charantia L.). Aus. J. Crop. Sci. 8(5):706-710.

Patel, 2008. Effect of FYM, B and Zn on growth, yield and quality of watermelon (Citrullus lanatus (Thunb.) Matsum & Nakai cv. Sugar Baby” M.Sc. Thesis, Navsari Agricultural University, Navsari.

Peterson, C. E., and Anhder, L. D., 1960. Induction of staminate flowers on gynoecious cucumbers with GA₃. Science. 131: 1673-1674.

Phatak, S.C., Hall, M. R. and Gaines, T. P., 1993. Effect of boron and boron-calcium on limabean and watermelon. Proceedings of the International Congress of Plant Physiology, New Delhi, India, 15-20 February 1988, 2: 1178-1182.

Ram, A., Singh, G. N., Shukla, H. S, and Rajbir, S., 2001. Effect of seed soaking with gibberellic acid on growth and fruiting of muskmelon (Cucumis melo L.). Haryana J. Hort. Sci. 30: 277-278.

Ram, D., Kumar, S., Singh, M., Rai, M. and Kalloo, G., 2006. Inheritance of gynoecism in bitter gourd (Momordica charantia L.). Journal of Heredity, 97 (3):294–295.

Ramaswamy, N. C., Govindaswamy, V., and Ramanujam, C., 1976. Effect of ethrel and planofix on flowering and yield of snake gourd (Trichosanthes anguina L.). Annamalai Agric. Univ. Ann. Res. 6:187-189.

Randhawa, K. S., and Kirtisingh, 1973. Effect of maleic hydrazide, naphthalene acetic acid and gibberellic acid applications on vegetative growth and yield of muskmelon (Cucumis melo L.). Indian J. Hort. 27: 195-200.

Ravindran, D. N., 1971. Effect of photoperiod and growth substances on sex expression in snake gourd (Trichosanthes anguina L.). South Indian Hort. 15:1-21.

Robinson, R. W., and Decker-Walters, D. S., 1997. Cucurbits. Cab International Wallingford Oxon, UK. pp: 1-206.
Robinson, R. W., and Decker-Walters, D. S., 1999. Cucurbits. CAB International Wallingford, Oxon (GB). pp: 226.

Salisbury, F. B., and Ross, C., 1969. Plant physiology 1st ed pp: 444-480.

Sanwal, S. K., Marcin, K., Sanjeev, K., Singh, B. and Deka, B. C., 2011. Yield improvement through female homosexual hybrids and sex genetics of sweet gourd (Momordica cochinchinensis Spreng.). Acta Physiol Plant., 33: 1991–1996.

Singh, P. K., Choudhary, B. R., Singh, R., Bhardwaj, D. R. and Rai M., 2012. Developing sponge Gourd (Luffa cylindrica (Roem.) L.) populations with a very high proportion of pistillate flowers. Acta hort. pp: 938.

Singh, R. K., and Choudhury, B., 1988. Differential response of chemicals on sex modification of three genera of cucurbits. Indian J. Hort. 45(1-2): 89-99.

Sure, S., Arooie, H. and Azizi, M., 2013. Effect of GA3 and ethephon on sex expression and oil yield in medicinal pumpkin (Cucurbita pepo var. styriaca). International J. Farming and Allied Sciences. 2(9): 196-201

Thappa, M., Kumar, S. and Rafiq, R., 2011. Influence of plant growth regulators on morphological, floral and yield traits of cucumber (Cucumis sativus L.). Kasetsart J. (Nat. Sci.) 45: 177-188.

Verma, V. K., and Choudhury, B., 1980. Chemical sex modification through growth-regulators and chemicals and their effect on yield. Indian J. agric. Sci. 50(3): 231-235.

Verma, V. K., Sirohi, P. S. and Choudhury, B., 1984. Note on the response to chemical seed treatment on sex expression and fruiting in bitter gourd. Indian J. Hort. 41(1-2): 113-115.

Whitaker, T.W., 1931. Sex ratio and sex expression in the cultivated cucurbits. American Journal of Botany. 18(5): 359-366

Wittwer, S. H., and Bukovac, M. J., 1958. The effects of gibberellin on economic crops. Econ. Bot. 12:213-215.

Yamasaki, S., Fujii, N. and Takahashi, H., 2003b. Characterization of ethylene effects on sex determination in cucumber plants. Sexual Plant Reproduction, 16: 103–111.

Yamasaki, S., Fujii, N., Matsuura, S., Mizusawa, H. and Takahashi, H., 2001. The M locus and ethylene-controlled sex determination in andromonoecious cucumber plants. Plant and Cell Physiology, 42: 608–619.

Yigal, Cohen, Helena, Eyal. And Avraham, Cohen, 1993. ‘Gylan’—A Gynoecious Muskmelon. HortScience, 28(8):855.

Yin, T., and Quinn, J. A., 1995. Tests of a mechanistic model of one hormone regulating both sexes in Cucumis sativus L. Am. J. Bot. 82(12): 1537-1546.

Yongan, C., Bingkui, Z., Enhui, Z. and Zunlian, Z., 2002. Control of sex expression in summer squash (Cucurbita pepo L.). Cucurbit Genetics Cooperative Report, 25: 51-53.

How to cite this article:

Megharaj, K.C., P.S. Ajjappalavara, Revanappa, D.C. Manjunathagowda and Bommesh, J.C. 2017. Sex Manipulation in Cucurbitaceous Vegetables. Int.J.Curr.Microbiol.App.Sci. 6(9): 1839-1851. doi: https://doi.org/10.20546/ijemas.2017.609.227