GROWTH REGULATOR STUDIES IN MOP-HEAD HYDRANGEA (*Hydrangea macrophylla*) FOR IMPROVED VIGOUR AND FLOWERING

Thesis

by

RUPALI THAKUR
(H-2020-23-M)

submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY SOLAN (NAUNI) HP- 173 230 INDIA

in

partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (HORTICULTURE) FLORICULTURE AND LANDSCAPE ARCHITECTURE

DEPARTMENT OF FLORICULTURE AND LANDSCAPE ARCHITECTURE
COLLEGE OF HORTICULTURE

2022

Dr. Rajesh Thakur
Major Advisor

HRTS and KVK, Kandaghat, Solan
Department of Floriculture and Landscape Architecture
Dr. Yashwant Singh Parmar University of Horticulture and Forestry,
(Nauni) Solan (HP) -173 230 India

CERTIFICATE- I

This is to certify that the thesis titled, **"Growth regulator studies in mop-head hydrangea (*Hydrangea macrophylla)* for improved vigour and flowering",** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Horticulture) Floriculture and Landscape Architecture** in the discipline of **Horticultural Sciences** to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 India is a bonafide research work carried out by **Ms. Rupali Thakur (H-2020-23-M)** daughter of Shri Neelamjeet Thakur under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Nauni, Solan
Dated:

(Dr. Rajesh Thakur)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis titled, **"Growth regulator studies in mop-head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering"**, submitted by **Ms. Rupali Thakur (H-2020-23-M)** daughter of Shri Neelamjeet Thakur to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173230 India in partial fulfilment of the requirements for the degree of **Master of Science (Horticulture) Floriculture and Landscape Architecture** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with the External Examiner.

14/11/2022

Dr. Rajesh Thakur
(Major Advisor)

Dr. Ramesh Kumar
External Examinar

Members of the Advisory committee

1. **Dr. Jasbir Singh Wazir**
(Principle Extension Specialist, Retd) _____

2. **Dr. Pardeep Kumar**
(Senior Scientist) _____

3. **Mr. Nitin Sharma**
(Assistant Professor) _____

_____
Professor and Head
Department of Floriculture and Landscape Architecture

Countersigned

_____
Dean
College of Horticulture

ACKNOWLEDGEMENT

Happiness cannot be travelled to, owned, earned, worn or consumed. Happiness is the spiritual experience of living every minute with love, grace and gratitude. So, with limitless modesty, I would like to bow down my heartfelt gratitude to the almighty God for all his blessings, for giving me strength, opportunities and for all the things he bestowed upon me in this life.

No gift on earth is greater, no treasure field above, the joy that comes from knowing a parent's endless love. It warms and it protects us and guides us from afar, shedding light upon us like a bright and shining star. I would have never come to this proliferative stage and engaged myself in career building. It would be my bounded duty to put on record a line of utmost gratitude to my beloved father ***Mr. Neelamjeet Thakur*** *and my mother* ***Mrs. Champa Thakur****, who has shown me immense support, encouragement, sacrifice and love. They are in fact have been a real source to put me of the horizon of this success.*

I express my heartiest veneration and gratitude to my esteemed guide ***Dr. Rajesh Thakur****, Subject Matter Specialist HRTS & KVK, Kandaghat, Solan for his keen interest, valuable guidance, unflinching judgment and constant encouragement during the entire course of my study. I have paucity of words to express my obeisance before him. I am delightful to have this opportunity to express my deep sense of gratitude towards the esteemed members of my advisory committee* ***Dr. Jasbir Singh Wazir****,* ***Dr. Pardeep Kumar*** *and* ***Mr. Nitin Sharma*** *who provided their consistent support and suggestion during this programme.*

It is my profound privilege to express my heartfelt and sincere gratitude, veneration and earnest thanks to ***Dr. S R Dhiman*** *(Professor and Head, Department of Floriculture and Landscape Architecture),* ***Dr. Puja Sharma, Dr. Suman Bhatia*** *for their invaluable suggestions and every needful help rendered during my research and course work.*

Special thanks to ***Dr. Pramod Verma*** *and* ***Dr. Seema Thakur*** *for their encouraging words and help during the period of research work.*

I also felt like showing special gratitude toward my younger brother ***Ishant Thakur*** *whose positive, optimistic life approach have encouraged me during difficult times. His ecstatic soul, dedication, inspiration and patience rejuvenated my strength and sense of duty each time I saw or heard from him.*

Friendship is the pleasant experience most of all my warm and special thanks to my friends ***Nikhil Thakur, Arshia Prashar, Shivani Thakur, Aditika Sen*** *for always being there for me, for cheering me up during gloomy days, for giving me valuable suggestions, love and guidance.*

I also extend my deep sense of gratitude and affection towards ***Babita Kanwar*** *and my guide mate* ***Nandini Choudhary*** *who have helped me, motivated me during this entire course.*

With celestial smiles my heart shall always remember the wonderful company of ***Shikha, Sourav, Vikas, Sweta, Sushumna, Abhinav, Sunita, Vanlalnunhlui, Palieka, Mansi, Shagun, Priti, Nikhil, Nitish, Gaurav*** *who have added beautiful memories to this journey. I would also like to thank my seniors for their constant support and guidance throughout my research work* ***Shraddha Pundeer, Priyanka Rana, Vaishali Thakur, Rachna Kashyap Neha Thakur, Shabnam Pangtu, Neha Grace, Nidhi mam.*** *I would also like to express my thanks and love towards my juniors* ***Simrann*** *and* ***Priyanka.***

It's my fortune to gratefully acknowledge the support of field staff of KVK, Kandaghat, especially ***Mr Gopal, Mr Manoj, Mr Devinder, Mrs Bimla*** *for providing painstaking support during my research work.*

Last but not the least I am deeply indebted to all my well wishers who helped me directly or indirectly to complete this investigation. Each of them has my cordial thanks.

Needless to say, errors and omissions are solely mine

Place: Nauni, Solan (HP) **(Rupali Thakur)**
Date:

CONTENTS

LIST OF ABBREVIATIONS

Symbols	Abbreviations
%	Per cent
@	At
/	Per
˚C	Degree Celsius
ANOVA	Analysis of variance
BA	Benzyl adenine
C.D.	Critical difference
CRD	Completely Randomized Design
cm	Centimeter
cv.	cultivar
DAP	Days After Planting
df	Degree of freedom
et al.	"*et alia*" (And others)
EDTA	Ethylene Diamine Tetra Acetic acid
Fig.	Figure
FYM	Farm yard manure
GA_3 / GA_{4+7}	Gibberellic acid
HRTS	Horticulture Research and Training Station
g	Grams
K	Potassium
kg	Kilograms
KVK	Krishi Vigyan Kendra
L	Liter
mg	Milligrams
m	Meter
mm	Millimeter
ml	Milliliter
MOP	Murate of Potash
N	Nitrogen
P	Phosphorous
PGR	Plant Growth Regulator
ppm	Parts per million
S. Em.	Standard Error of mean
sp.	Species
SSP	Single Super Phosphate
var.	Variety
viz.	*videlice*t (As follows)
v/v	Volume per volume

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Chapter- 1

INTRODUCTION

Hydrangea a member of family Saxifragaceae is one of the most attractive and beautiful ornamental plant in the world. The word 'Hydrangea' was originated from the Greek word *'hydro'* and *'aggeion,'* which represents "water" and "vessel," respectively. The hydrangea flower represents grace, gratitude and beauty. It symbolizes "boastfulness" as it produces many beautiful gorgeous flowers. The family Saxifragaceae includes mostly woody plants with 17 genera and roughly 170 species (Duran,1999). There are at least 23 species under genus hydrangea which can be easily found in temperate regions of North America, subtropical Central and South America and in parts of Eastern Asia (McClintock 1957). The most extensively planted hydrangea species is *Hydrangea macrophylla* (Thunb.) Ser. which is commonly known as mop-head or bigleaf hydrangea. It is the only species that is mostly cultivated under different climates in many parts of the world (Jessica, 2008). It is used as a deciduous, attractive woody shrub in landscapes or as flowering potted plant for interior scape and residences (Bailey and Bailey, 1976). Many hydrangea species have variegated leaves that are highly prized for their leaf attractiveness.

In traditional flower-growing countries, hydrangeas are mostly grown for the spring pot plant market, but raising hydrangeas has become a financially viable enterprise in the same way that growing roses, chrysanthemums, and carnations has. As a flowering pot plant, these can be produced all year. These are valued for their huge, spherical flowerheads which are present in a variety of colors ranging from white to purple, pink, and red. The inflorescence of hydrangeas are terminal cymes which further have different axes for bearing individual flowers that are primary, secondary and tertiary (Litlere and Stromme, 1975). The cymose has sterile flowers with enormous sepals that are concealed beneath the sterile blooms, as well as inconspicuous fertile flowers.

Hydrangeas can be grown in semi-shade conditions. A cool moist temperature is considered good for its growth and development. It can withstand light conditions ranging from moderate sun to deep shade in the landscape, though it will not flower as profusely in the latter conditions (Gilman,1999; Van Gelderen and Van Gelderen, 2004). In India, hydrangeas are

mostly grown in hilly areas of Kashmir, Kalimpong, Darjeeling, Shillong, Himachal Pradesh, Uttarakhand, southern and northern hills as they have the potential to grow best quality hydrangea as pot plant or as cut flower (Bhattacharjee, 2006). The flowers can be produced from early spring to late autumn. Most of the mophead hydrangea blooms through early July but few may continue to produce flowers throughout the growing season. During winter months the flowers buds goes in resting stage and leaf defoliation occurs. The buds will start growing again after normal chilling temperature is present. When the winters are over the overwintered flower buds will flower in May to June. The flowers can be obtained all-round the year by flower forcing. Growers now days forced hydrangea for obtaining flowers during late January and February sales. It also generates good market potential during that time. Production schedules to meet demand for Christmas, Valentine's Day, Easter, and Mother's Day markets (Weiler, 1980).

Hydrangea have a tendency to show different colored flowers according to the pH of soil. The flower color of *Hydrangea macrophylla* also depends on the aluminium content in the soil and on the cultivar (Takeda *et al.*, 1985). It produces blue flowers in acidic soils as acidic soils are high in aluminium content and for pink-flowers a pH of 5.8-6.4, high P levels, and low K and Mo levels are required (Blom and Piott, 1992) whereas in neutral soil with low aluminium white color flowers are found.

Plant growth regulators are the chemical substances that regulates and modifies the physiological processes of the plants. They can be natural or synthetic. Mostly the plants hormones and phytohormones which are released by the plants in very low concentration are considered as natural growth regulators. The synthetic plant growth regulators are most commonly used by the people as they are stable and readily available in the market (Patil, 2000). PGRs are now being used by the commercial growers of ornamental plants and flower crops as a part of cultural practice to manipulate the plant according to the grower or as per the demand of the consumer, this helps in improving economic value of the plant (Yawale *et al.*, 1998). Plant growth regulators are easily absorbed by the plants and have fast movement through the plant tissues when application is done on different parts of plant. Also, a single PGR is capable of influencing various processes in the plant but they should be used in proper way to improve plant quality and yield. Plant growth regulators include auxins, gibberellins, cytokinin, ethylene, abscisic acid growth retardants and growth inhibitors.

Today these PGRs are used to influence various growth and developmental processes like initiating rooting in cuttings, propagation methods, controlling height of plant (stem elongation), regulating flowering and other physiological functions of plant. There use in improving crop quality and productivity is becoming more popular. These compounds show different responses in different crops according to the concentration and composition used. Hernandez (1997) reported that plant growth regulators have positively enhanced the growth and yield of plant. However, the performance of these PGRs varies with different species and cultivars **(**Latimer *et al*., 1998). Therefore, the concentration and efficacy must be according to species.

In 1926, a Japanese scientist named Eiichi Kurosawa discovered gibberellin while investigating bakanae, or "foolish seedling" sickness in rice (Salisbury and Ross, 1992). The possible use of gibberellic acid on floriculture crops for the first time were believed to be done by Kohl and Kofranek (1957). It promotes stem elongation, germination, breaking dormancy, flowering and fruit setting in some plants (hibiscus, pansy, petunia, phlox, cineraria and many more). Cytokinin are another important group of plant growth regulators that regulate various process of plant growth and development with cell division and cell differentiation, enhancement of leaf extensions and nutrient mobilization (Shudo, 1994). Ornamental plants growers sometimes need to encourage plant branching in certain crops like English Ivy, Verbena or in stock plants where cutting production is main the goal, there benzyl adenine can be used as a branching agent. Cytokinin have been used in laboratory work, turf management, cut flower industry, tissue culture, woody plant production and also in commercial pot plant production too. Cytokinin have also been reported to substitute manual pinching (Richards and Wilkinson, 1984) thus can save growers money. Their exogenous application helps to improve the different economically important and market desirable characteristics of ornamental plants. The concentration and efficacy of PGRs must be evaluated according to species and their uses.

Thus, keeping in view the above facts in mind the present investigation entitled "**Growth regulator studies in mop head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering**" was carried with the following objective:

- Standardization of Gibberellic acid, Benzyl adenine and GA_{4+7} + BA dose for the best growth and flowering of mop-head hydrangea.

Chapter- 2

REVIEW OF LITERATURE

The global horticultural industry places a high value on ornamental plants. A large range of organic substances that are either created synthetically or organically include plant growth regulators, which are used as a potential resource in the modern ornamental production system. Exogenous applications of PGRs as a cultural practice contributes in enhancing the various economically significant and marketable characteristics of ornamental plants.

Hydrangea macrophylla, valued for their large puffball type blooms are a perfect fit in landscape. They have a unique position as potted plants. These are facultative short day plants. The optimum temperature of 20˚C promotes flower initiation and a temperature between 15-20˚C is required for flower bud development. For production of potted plants of *H. macrophylla* extra lighting and heating is necessary, it is profitable for very early market. Growth-promoting agents are used to modify the physiology of plants in order to improve plant growth, flowering, uniformity, higher quality and pot presentation, which will increase the market demand for flowers. Thus, in this chapter, an attempt has been made to review the appropriate and updated literature related to the different aspects of this research work titled "**Growth regulator studies in mop head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering**" has been reviewed under the title:

2.1 Effect of gibberellic acid

2.2 Effect of Benzyl adenine

2.3 Effect of GA_{4+7} + BA

2.1 Effect of Gibberellins

Gibberellic acid (GA_3) is considered one of the most beneficial growth promoters and has been used to affect various developmental process of plants like increase the length or height of plants, to increase the number of flowers and induce early flowering, sex expression, breaking dormancy (Brian, 2008). According to some reports, it is possible to note the efficiency of application of GA_3 in the field of growing quality flowers. Spraying GA_3 recorded maximum plant height, maximum number of leaves and branches in chrysanthemum and many other

ornamental flowering crops (Sujatha *et al.*, 2002; Rana *et al*., 2005). Also, many have reported there was an increase in flower stalk length, number of flowers opening at time, flower weight and yield (Kumar *et al*., 2012; Dhaduk *et al*., 2007).

Sebanek (1973) evaluated the effect of exogenously application of gibberellin (GA_3) and cytokinin (benzyladenine) to one node segment of hydrangea to detect association between the mature leaf and its axillary bud. Both GA_3 and BA were able to detect the dominance between axillary buds when both leaves were left on the segments. This suggests that the bud treated with the appropriate growth regulator grew more aggressively. When one of the leaves was removed, the bud on that leaf developed more aggressively, but when GA_3 was applied to the axillary bud on the remaining leaf, the correlation was reversed; the bud on the remaining leaf expanded more furiously.

Jana and Biswas (1979) conducted an experiment on effect of various concentration of gibberellins on tuberose plants. They reported that when tuberose was sprayed with GA_3 at 10 ppm at 4-5 leaf stage and after 30 days after first spray, resulted in maximum number of leaves, spikes and flowers per plant.

Banker and Mukopadhya (1982) observed that when rose cultivar 'Queen Elizabeth' was treated with GA_3 at concentration 10, 25, 50, 100, 250 and 500 ppm there was significant effect on vegetative and flowering parameters of the crop. It was noticed that there was an increase in the stem length at concentration 100 and 250 ppm, increase in length of peduncle at 100 and 500 ppm, at 100 ppm there was maximum number of branches, maximum number of flowers were obtained between concentration 10-100 ppm. Thus, it was concluded that GA_3 at 100 ppm caused maximum increase in branching and high number of flowers at 10, 25, 50 and 500 ppm in rose.

Daheb *et al*. (1987) reported that an increase in plant height and diameter, number of shoots per plant and shoot length with application of GA_3 @ 500 and 1000 ppm when sprayed three times during the early growth stages; Also, GA_3 hastened flowering but reduced the numbers of inflorescence per plant in *Chrysanthemum frutescens.*

Nagarjuna *et al*. (1988) recorded that spraying of GA_3 initiated early flowering, large flowers, increased fresh and dry weight of chrysanthemum flowers.

Talukdar and Paswan (1996) reported that when GA_3 @ 10, 20 and 40 ppm concentration when applied as spray at 35 days interval after planting to potted chrysanthemum there was an increase in the plant height tallest at 20 ppm and with 40 ppm application produced leaves with large leaf area and flowers with greater diameter.

Dutta and Ramadas (1998) observed the effect of various plant growth regulators *viz*., NAA (50, 75 and 100 ppm), GA_3 (50, 100 and 150 ppm), maleic hydrazide (250, 500 and 1000 ppm) and CCC (2000, 3000 and 4000 ppm) on the growth and flowering of chrysanthemum (*Dendranthema grandiflora*). Plant height, internodal length, number of laterals, nodes and leaves per plant were markedly increased by all treatments compared with control. It was also observed that GA_3 treatment was the most effective among all the PGRs treatments. Plant height was greatest, internodes longest, number of buds and the number of laterals per plant greatest with GA_3 at 150 ppm.

Prakash and Jha (1998) reported that application of 150 ppm of GA_3 decreased the flowering time, increased length of inflorescence, length of spike, length of floret and number of florets per spike in gladiolus as compared to the reduced dose of 100 ppm.

Choudhari (2001) studied the effect of plant growth regulators on growth, flowering and quality of rose cv. 'Gladiator'. The results showed that the plants treated with GA_3 @ 250 ppm showed an increase in plant height, plant spread and number of flowers. Also stalk length, flower diameter, number of petals, vase life was maximum.

Gupta and Dutta (2001) investigated the effects of plant growth regulators (gibberellic acid at 50, 100 and 200 ppm) on chrysanthemum cv. 'Jayanti' for growth and flowering. GA_3 @ 100 ppm was most effective in boosting plant height.

Patil (2001) studied the effect of various PGRs on 'Sangria' cultivar of *Gerbera jamesonii* at Ornamental Plant Nursery at Gujrat Agricultural University. He reported that out of all the PGRs used in the experiment, GA_3 at 150 ppm produced the maximum plant height, plant spread and leaf area. Also, all treatments of GA_3 (50, 100 and 150 ppm) gave early flowering.

Dicks *et al* (2003) reported that gibberellic acid had a significant effect on the length of pedicel of lily as it increased with the increase in concentration of GA_3. Further, Verma and Parmar (2003) reported that when two application of GA_3 @ 100 ppm was done on carnation the results showed that treated plants had maximum plant height, maximum number of flowers and maximum stem length. However, maximum size of both flowers and buds were observed with GA_3 @ 50 ppm.

Rakesh and Beniwal (2003) studied the effect of GA_3 (0, 50, 100, 150, and 200 ppm) and pinching (35 or 45 days after transplanting) on growth and yield of chrysanthemum. Plant height, spread and number of branches per plant, all increased as the rate of gibberellic acid increased. With 200 ppm gibberellic acid at 35 and 45 DAT, the maximum plant height (48.00 and 70.54 cm), plant spread (32.05 and 37.55 cm), and number of branches per plant (13.57 and 16.16) were recorded respectively.

Dhaduk *et al*. (2007) reported that there was an increase in number of flowers, stalk length and spathe length of anthurium when foliar application of GA_3 was done. Further, in 2009 Parmar *et al.* reported that GA_3 200 ppm showed superiority over other concentration of GA_3 (100 ppm and 150 ppm) when applied at 15 days interval between two sprays on spider lily. All the vegetative (plant height, number of leaves per plant, dry weight of plant), floral (flower diameter, spike length, number of flowers per spike, days taken for first flower emergence, days taken for first spike emergence, fresh and dry flower weight) and yield characters were found superior in treatment with GA_3 200 ppm.

Anuradha *et al*. (2010) found that increasing levels of nitrogen and gibberellins resulted in greater vegetative growth of gerbera as indicated by measuring the plant height, stalk length

and leaf count per plant. Maximum growth was obtained by applying 30 g of nitrogen per square meter and with 100 ppm of gibberellic acid.

Shinde *et al.* (2010) studied that when GA_3 @ 200 ppm was sprayed over *Chrysanthemum morifolium* cv. IIHR-6, there was a significant increase in plant spread, number of branches, number of flowers, high suckers per plant and also in the yield of flower per plant. While, concentration of GA_3 @ 150 ppm showed minimum days for flower initiation, maximum flower duration and inflorescence diameter with maximum shelf and vase life.

Sharifuzzaman *et al*. (2011) conducted an experiment to study the effect of different concentration of gibberellic acid (GA_3 @ 50, 100, 150 ppm), cycocel (CCC @ 400, 600, 800 ppm) and maleic hydrazide (MH @ 50, 500, 750 ppm) on floral and vegetative characters of chrysanthemum. The results revealed that GA_3 @ 150 ppm treated plants showed an increase in plant spread, number of leaves, maximum number of cut blooms and large size of flowers with long stalk. GA_3 also caused early flower initiation as compared to CCC and MH as they delayed flowering.

Cardoso *et al.* (2012) reported that when gibberellic acid application was done on *Phalaenopsis* there was significant increase in length of leaves whereas decrease in width of leaves at lower concentrations.

Dogra *et al.* (2012) investigated the impact of growth regulators on gerbera. Different concentration of gibberellic acid (0, 100, 200 and 300 ppm) was evaluated. The results revealed that application of 200 ppm GA_3 showed the maximum plant height, leaf length-breadth, number of leaves and stalk length as compared to other treatments.

Sudhakar and Kumar (2012) revealed that plant growth regulators improved the growth and yield of gladiolus cv. 'White Friendship'. With GA_3 @ 100 ppm, they recorded the maximum number of florets per spike, spike length and bloom length as compared to other treatments.

Kanwar *et al*. (2013) reported that when a single spray GA_3 at 150 ppm was done on African marigold the plant showed increased plant height (83.30 cm), maximum number of flowers per plant (78.5), maximum leaf area (1188.58 cm^2), flower daimeter and higher yield of flowers per plant.

Baskaran *et al*. (2014) observed the effect of various concentration of gibberellic acid on growth, flowering and corm parameters of gladiolus cv. 'Chandini'. From this study it was revealed that GA_3 at concentration 750 ppm showed maximum plant height, number of leaves per plant, number of florets per spike, spike length and rachis length while GA_3 @ 500 ppm there was early corm sprouting, maximum spike duration and emergence.

Aier *et al*. (2015) reported the effect of different concentration of GA_3 (50, 100, 150, 200 and 150 ppm) on vegetative and floral characters of gladiolus cv. 'Red Candyman'. From the results it was revealed that maximum plant height, leaf area, highest number leaves per plant and minimum days for flower emergence was observed at GA_3 with concentration 200 ppm. Another investigation by Patra *et al*. (2015) reported that when concentration of GA_3 was increased from 25-150 ppm in gladiolus the plant height and plant spread also increased.

Muhammad *et al*. (2016) studied the effect of gibberellic acid on different parameters of chrysanthemum. The parameters observed were height of plant, leaf number, number of branches, leaf area, days to flowering, blooming period and size of flower and different concentration were 0, 50, 100, 150, 200 and 250 ppm. The results showed that maximum height of plant, number of leaves per plant, number of branches and leaf area were observed in GA_3 @ 250 ppm.

Palie *et al*. (2016) studied the effect of various plant growth regulators, on growth, flowering and yield attributes of African marigold. Among all PGRs GA_3 @ 100 ppm increased plant height, plant girth, number of branches per plant, number of leaves per plant, early flower bud initiation, opening of first flower, weight of flower per plant, stalk length, number of flowers per plant and flower yield.

Kalaimani *et al*. (2017) reported that GA_3 at a concentration of 150 ppm showed the maximum number of flowers per plant, flower yield per plant, flower yield per hectares and minimum days for flower bud initiation in African marigold (*Tagetes serrata* L.).

Sumalatha (2017) investigated the effect of gibberellic acid on vegetative, floral and bulb characters of Asiatic lilium (*Lilium longifolium*) cv. 'Menorca'. The plants were sprayed with four different concentrations of GA_3 @ 50, 100, 150 and 200 ppm 30 days after planting. It was found that GA_3 @ 100ppm gave most promising results over other treatments. Parameters like plant height, number of flower buds per plant, spike length, weight of bulbs, number of bulblets and weight of bulblets were significantly better than control.

Farag *et al.* (2018) found that GA_3 at 200 ppm concentration gave maximum plant height, maximum number of axillary buds per plant, maximum leaf area per plant of *Chrysanthemum morifolium* cv. 'Zambla White' compared with their other concentrations (50, 100 ppm). They also observed that there was a significant increase in number of leaves at any concentration of GA_3. Also, GA_3 at a concentration of 200 ppm gave the shortest period from showing color bud stage of the inflorescence to reach its full opening stage, compared with its other concentrations.

Holkar *et al.* (2018) studied the effect of BA and GA_3 on flowering and flower quality attributes of gladiolus cv. 'Summer Shine'. Different concentration of BA (100, 200 and 300 ppm) and GA_3 (150, 200 and 250 ppm) were used alone or with their combinations. The results revealed that gibberellic acid at concentration 150 ppm had minimum days for spike initiation, for first floret opening, 50% flowering, maximum spike girth, floret diameter, floret length. While GA_3 at 250 ppm showed maximum flowering duration, length of spike, more florets per spike and vase life. Whereas, BA at 200 ppm concentration took maximum days for initiation of spike, first floret opening, 50% flowering and highest yield of spike/ plant.

Kumari *et al*. (2018) reported that preharvest foliar spray of GA_3 @ 250 ppm resulted in maximum height of plant, maximum flower bud length, stem diameter and with maximum vase life as compared with control where no application of PGR was done.

Alshakhaly and Qrunfleh (2019) reported that foliar application of GA_3 at 5, 10, 25, 50 and 100 ppm at all concentration hasten flower growth, increases peduncle length and increases the number of flowers that open at a time in *Cyclamen persicum* in both first and second year of development as compared to control.

Mishra *et al.* (2019) reported that GA_3 @ 250 ppm when used on amaryllis lily (*Amaryllis belladonna*) had significant effect on growth and yield parameters. This treatment showed maximum plant height (45 cm), maximum length of flower stalk (44.03 cm) minimum days for initiation of buds (143.83). However, the maximum shelf life was recorded with BA @ 200 ppm.

Jayshree *et al.* (2020) concluded from their study on effect of different concentration of gibberellic acid (@ 50, 100 and 150 ppm) on morphological behaviour of Asiatic lily. Application of GA_3 @ 200 ppm exhibited maximum plant height (83.13 cm), leaf number (67.25), leaf length (10.27 cm), leaf width (2.52 cm) and early sprouting (6.00 days).

Patel *et al.* (2020) studied the effects of foliar application plant growth regulators on the growth and flowering of potted hibiscus plants. Application of gibberellic acid, benzyl adenine, and salicylic acid at various concentrations had a substantial impact on vegetative development, blooming parameters, and plant pigments of *Hibiscus rosa-sinensis* plants during both years (2017-2019) (control). At 30, 60, and 90 days after spraying, plants sprayed with 100 ppm gibberellic acid reached their maximum plant height, plant spread, shoots length and leaf area. Also, produced more number of flowers per plant, flowers per branch, flower diameter, blooming period, and *in situ* flower longevity. At 30, 60, and 90 days after spraying (DAS), the plants receiving the same treatments increased chlorophyll content in leaves (19.50, 20.37, and 20.85 mg/g) and anthocyanin content in flowers (17.03, 18.65, and 20.20 mg/g), respectively.

Sijo *et al*. (2020) investigated the effect of gibberellic acid and benzyl adenine both at 200 ppm and 250 ppm concentrations on rose. The result of the study revealed that plants which were treated with 250 ppm GA_3 had maximum plant height and maximum stalk length.

Srestha *et al*. (2020) observed that varied concentrations of GA_3 had a significant effect on the quality flower production of calendula. With foliar treatment of GA_3 @ 200 ppm, they noticed early initiation of the first bud and flowering. However, with GA_3 @ 250ppm, the maximum bloom diameter and flower weight were recorded. They concluded that for enhancing the floral quality of calendula GA_3 at concentration 200-250 ppm was most effective.

Yogendra (2021) carried out an experiment on *Calendula officinalis* cv. 'Bon Bon Yellow' to find the effect of different PGRs (GA_3 @ 200 ppm, 300 ppm and 400 ppm, MH @ 250 ppm, 500 ppm and 750 ppm, and CCC@ 250 ppm, 500 ppm and 750ppm). The results revealed that plant spread, number of branches per plant, number of leaves per plant, number of flowers per plant, early flowering, and seed production all increased significantly with the application of GA_3. Also, GA_3 was found to be more effective in hastening blooming for commercial purpose.

2.2 Effect of Benzyl adenine:

Cytokinins are a broad set of plant hormones and one of the most active cytokinins is benzyl adenine (Buban, 2000). For many years, cytokinin has been employed in research labs, tissue culture, turf management, the development of woody plants, the cut flower business, and potted plants. Different aesthetic plants have distinct useful application concentrations, which is often unknown (Werbrouk *et al*., 1996). BA are also reported to prevent bud blasting in tulips (Munk and Gijvenberg, 1977) and delay senescence of flowers in lilies (Ranwala and Miller, 1998). Some evidences also shows that there was an increase in flower size of some plants like in petunia (Nishijima *et al.,* 2006). Grossman *et al*. (2014) reported an increase in branching in of herbaceous perennials *viz. Agastache* 'Tutti Frutti' and *Verbena bonariensis* 'Lollipop' treated with BA before transplanting.

Treder *et al.* (1989) studied the effect of BA on growth of potted miniature roses. BA at concentration 100, 200 and 400 ppm were used in single and double spraying combination with manual pinching practice. It was observed that BA stimulated branching and pinched plants

branched better, also the number of shoots was higher with foliar application of BA @ 50, 100 and 200 ppm on pinched plants.

Fujii and Sasaki (2000) studied that BA @ 150 ppm induces high number of branches in chrysanthemum cultivars with non-branching habit. An investigation was carried by Chandrappa (2002) where he examined the effect of media, biofertilizers, and growth regulators on anthurium growth and flowering. They discovered that BA 1500 ppm produced the greatest number of lateral shoots, while GA_3 @ 750 ppm and control produced the least number of shoots.

Blanchard and Runkle (2008) conducted an experiment to study the effect of cytokinin on flowering of orchids (*Doritaenopsis* and *Phalaenopsis*). In this, foliar application of different concentration of BA (@ 100, 200, or 400 mg L^{-1}) and GA $_{4+7}$ + BA (25, 50, or 100 mg L^{-1}) was applied on weekly interval. The results showed that BA @ 200 ppm had maximum number of blooms (3-8 more blooms per plant) as compared to untreated plants. While, GA $_{4+7}$+ BA showed non-significant effect on inflorescence number and total flower number at the concentrations tested.

Eid *et al*. (2010) indicated that in *Polianthus tuberosa*, all parameters of flowering characteristics, number of bulblets per plant and fresh weight of bulb and bulblets per plant were significantly increased by foliar application of benzyl adenine. He also reported that when the concentration was increased from 50 ppm to 150 ppm there was significant increase in floral characters.

Ibrahim *et al.* (2010) studied the effect of foliar application of benzyladenine (BA @ 50, 100 and 150 ppm) on vegetative growth of croton plant. It was recorded that BA @ 150 ppm gave maximum number of branches and highest stem diameter as compared with other concentration.

Soad *et al.* (2010) studied the effect of different concentrations of benzyl adenine applied to the leaves of croton plants on several growth parameters. Plant height, number of branches

and leaves per plant, root length and leaf area, stem diameter and fresh weights of stem, leaves, and roots (g) per plant were all found to be higher in the plants treated with BA @150 ppm.

Asil *et al.* (2011) reported that when *Polianthes tuberose* L. (cv. 'Goldorosht Mahallat') plants were sprayed with benzyl adenine @ 50 ppm and 100 ppm after 40-54 days after planting there was a significant increase in the floret diameter and in the vase life of flower when compared with other treatments GA_3 (@ 0, 50, and 100 ppm) and BA (@ 0, 50, and 100 ppm). While with GA_3 @ 100 ppm there was early flower initiation and more stem length.

Bhatt and Chauhan (2012) studied the effect of growth regulators *viz*. GA_3 (@ 5, 10 and 15 ppm) and BA (@ 5, 10 and 15 ppm). They observed that BA @ 15 ppm was bound beneficial for increasing the number of leaves per plant in Dendrobium cv. 'Sonia-17'. Further, Nambier *et al.* (2012) examined the effect of BA on the induction of inflorescence formation in Dendrobium cv. 'Angel White'. BA application enhanced the percentage of inflorescence production, triggered early flowering, and contributed to changes in inflorescence length, leaf number and flower number generated.

Carey *et al.* (2013) studied the effect of different concentration of benzyl adenine on *Salvia nemorosa* L. cv. 'Caradonna'. According to the results it was revealed that foliar application of BA @ 100 to 1600 ppm (28 DAP) increased the branching and flowering significantly. It was also reported that BA@ 400 ppm delayed flowering by 2-3 weeks, however the compactness of the plants was more with high number of flower inflorescence.

Diana and Fulcher. (2013) studied the influence of rate of plant growth regulator on vegetative, floral growth and quality of hydrangea plants. The single foliar application of three different PGRs *viz.* Dikegulac sodium (800 ppm and 1600 ppm), Benzyladenine (300 ppm and 600 ppm) and Ethephon (500 ppm and 1000 ppm). The results reported that BA significantly increased the number of flowers and growth index of the plants.

Baghele *et al*. (2014) reported that BA @ 100 ppm when applied on rose cv. 'Poison' showed maximum number of leaves per plant, flower longevity and bud length as compared to control.

Attiya *et al.* (2015) observed that benzyl adenine @ 50 ppm when sprayed on lily plants significantly increase the time taken for flowering as compared to control. Further, Vasudevan and Kannan (2015) studied that when BA @ 200 ppm was applied on rose the plants treated with BA showed improved plant height, length of shoots, plant spread, number of cut stems per m^2. Also, there was improvement in vase life of the flower.

Newton and Runkle (2015) studied the effect of BA on potted *Miltoniopsis* Orchids. They conducted two experiments to record the effect on vegetative and flowering of plants. In first experiment 5 times application of BA @ 0, 200, 400 or 800 mg/L was applied every six weeks and in second experiment BA was applied @ 0 or 4000 mg/ L at five times in every two weeks to young plant and once at 0, 1000, 2000 or 4000 mg/L to larger plants. It was recorded that BA has no effect on flowering of *Miltoniopsis*, but BA @ 4000 mg/L spray application increased new number of vegetative shoots in young plants.

Ashwani and Chandrashekar (2017) observed that BA @ 150 ppm has significantly affected the vegetative growth of carnation by increasing the number of flower stem per plant. Further, Mondal and Sarkar (2017) studied the effect of benzyl adenine on growth, flowering, yield and quality of Hybrid Tea rose cv. 'Bugatti'. It was recorded that BA @ 100 ppm showed maximum spread, flower diameter (at cup stage) and maximum numbers of flowers per plant. BA @ 200 ppm gave maximum number of secondary shoots, stalk diameter, leaf area, flowering duration. Hence, they concluded that BA @ 200 ppm produced best quality blooms as compared with other treatments.

Bala and Singh (2018) reported the effect of foliar application of different PGRs on chrysanthemum. It was concluded from the results that BA @ 200 ppm recorded the highest flower diameter (5.75cm) and increased flower life up to 24.78 days followed by BA @ 150 ppm.

Farag *et al*. (2018) studied the effect of various concentration of BA on vegetative and flowering characters of chrysanthemum (*Chrysanthemum morifolium* cv. 'Zambla White'). Among BA concentrations 200ppm significantly increased the plant height, branch dry weight. Also found that the time taken for the color bud to reach its full opening stage was significantly reduced at BA concentration more than 50 ppm treatment.

Kapri *et al.* (2018) conducted an experiment to study the influence of GA_3 and BA on flowering and post-harvest parameters in lily. The plants were treated with different concentrations of GA_3 and BA (100 ppm, 150 ppm and 200 ppm). The results revealed that maximum diameter, minimum days to buds color appearance and maximum vase life was recorded in single dose of BA @ 100 ppm. While early flowering was observed in GA_3 @ 200 ppm.

Zhang *et al***.** (2018) studied the effect of different concentration of 6-BA on adult tea (cv. Longijng 43) plants. The foliar application of BA @ 50, 100, 200 or 400 mg/L were applied after heavy pruning. The effect on growth of new shoots and lateral branches were observed after five months. All treatments suppressed the plant height from minimum to maximum concentration by 11%, 18%, 21% and 22% respectively; BA @ 100, 200 or 400 mg/L reduced the number of lateral branches; 6-BA at 50 & 200 ppm increased the number of lateral branches by 38, 79 or 81 per cent respectively; BA @ 200 mg/L, increased diameter of lateral branches by 8%. It was concluded that all the four concentrations increased the formation of productive lateral branches and promoted dwarfism and among all concentrations 200 mg/L had best comprehensive effect. They also reported that 400 mg/L inhibited shoot growth and excessively finer branches were produced after five months. Thus, they concluded that BA @ 200 mg/L was most effective in production of lateral branches, promoting dwarfing and yield.

Sijo *et al*. (2020) studied the effect of GA_3 and BA on morphological and floral characters of rose. The plants were treated with GA_3 (@ 200 ppm and 250 ppm) and BA (200 ppm and 250 ppm). The results revealed that vegetative parameters like plant spread, number of branches per plant and leaves produced per branch were maximum in plants where foliar application of BA @ 200 ppm was done.

Jayshree *et al*. (2020) studied the influence of benzyl adenine and gibberellic acid on morphological behaviour of Asiatic lily. In this investigation total 16 treatments were given with different concentrations of BA (@ 50, 100 and 150 ppm) and gibberellic acid (@ 100, 150 and 200 ppm). The study affirmed that the plants treated with BA @ 150 ppm took maximum days for bulb sprouting (12.12), had maximum basal stem diameter (18.06), maximum total chlorophyll content and minimum plant height (36.72cm), leaf length (7.11cm), number of leaves (29.33).

2.3 Effect of GA_{4+7} + BA:

GA_{4+7} is a plant growth regulator which promotes growth of plants primarily by cell enlargement which is uniform in all plant tissues. Gibberellin activity in the cell cause cell wall flexibility when it hydrolyzes starch into sugar, which in turn provides energy and stimulates uptake of water by cells. The increased plant growth due to GA_{4+7} is attributed in increasing the rate of photosynthesis by influencing the leaf area. However, in case of BA it is associated with higher net assimilation rate and N content. (Moore, 1984). A variety of treatments that contain a combination of cytokinins and gibberellins are used to stop leaf yellowing and enhance bud blasting in tulips and Easter lilies. The combination of both hormones has also been reported to induce flowering in some crops. However, most of the interaction mechanism between these two hormones are still unknown (Jasinski *et al.,* 2005).

Ohkawa (1979) conducted an experiment to study the effects of gibberellins and benzyladenine on dormancy and flowering of *Lilium speciosum*. He reported that when lilium bulbs were treated with GA_{4+7}+BA there was early shoot emergence and flowering in dormant bulbs, while GA_3 and BA alone had no effect. The combination of GA_{4+7}+BA also reported to increase the number of flowers.

Grzesik and Rudnicki (1982) studied the effect of various growth regulators (Alar, Ethrel, BA, GA_3, GA_{4+7} +BA, MH, CCC, Stimulin, Atrinal) on branching of different woody ornamental plants (*Forsythia x intermedia* 'Spectabilis', *Weigela florida* 'Styriaca', *Rosa multiflora, Salix alba* 'Tristis' and *Spirea japonica* 'Macrophylla'). The results revealed that all the treatment promoted branching of *Forsythia x intermedia* plants. The maximum increase in branching was

observed in treatment with GA_{4+7} + BA in Rose, GA_3 in *Weigela florida* and BA in *Spirea japonica.* Also, early flowering was observed in *Forsythia x intermedia* with one spray of GA_{4+7} +BA.

Cody *et al*. (1985) reported that application of GA_{4+7} + BA at 250 and 500 ppm on 1 year old nursery trees of Pear cv. 'Bartlett', Cherry cv. 'Bing' and Apple cv. 'Oregon Spur II Delicious' significantly increased branching as compared with untreated control.

Koen *et al*. (1989) studied that when one-year-old spur-bearing and non-spur-bearing apple cv. 'Red Delicious' were treated with GA_{4+7} + BA with different concentrations of 0, 100, 200, 300, 400 and 500 ppm. It was found to have no effect on non-spur-bearing trees. The results showed that there was an increase in branching percentage in spur-bearing trees. Also, at 100 ppm GA_{4+7} + BA, the average branch angle increased substantially, and decreased with higher GA_{4+7} + BA concentrations.

Fooley and Keever (1992) studied the effect of foliar applications of Promalin (BA + GA_{4+7}), Pro-Shear (BA), Accel (PBA) or Florel (ethephon) for their capacity to increase cutting production of geranium stock plants. After a first harvest of cuttings, the number of terminal cuttings was increased 19% by a single application of GA_{4+7} + BA (Promalin) application when compared to an untreated control. However, after a second harvest of cuttings following a second application of the foliar spray treatments, numbers of terminal cuttings did not differ among chemical treatments and single-node cuttings increased 60–73% with the application of Promalin when compared to the control. Thus, it was observed that Promalin was effective in giving high number of cuttings by producing maximum number of shoots.

Poneidzialek and Porebski (1992) reported that application of GA_{4+7} + BA at 12, 25 and 37.5 ml/ L during late June and early July increased the number of laterals shoot in apple cv. 'Melrose'. Further, Olwell and Andrew (1992) also reported that GA_{4+7} +BA application increased the number of branches of all lengths in apple cv. 'Fuji'.

Foley and Keever (1993) studied the effect of various PGR *viz.* BA(Pro-Shear), GA_{4+7} + BA (Promalin), PBA (Accel) and Dikegulac in inducing branching in periwinkle (*Vinca minor* L.) cv. 'Alba'. The foliar application of these plant growth regulators was done. The results showed that plants receiving GA_{4+7} + BA @ 250 or 500 ppm had high number of runners and length of secondary runners. The application of GA_{4+7} +BA also increased the primary runners more as compared to other treatments.

Gianfagna and Merritt (1998) conducted an experiment to study the effect of BA, GA_{4+7}+BA and GA_{4+7} on stem growth and flowering in 'Rose-White' a genetic line of *Aquilegia* x *hybrida*. Rate of application of these PGRs were 50 mg/L. The results revealed that GA_{4+7} + BA had significant effects on both vegetative and flowering characters of the plant as compared to other treatments. There was an increasing in the height of plant, number of flowers per plant, advanced flowering and increase in flower longevity.

Ranwala and Miller (1999) studied the effect of GA_{4+7} +BA sprays on foliar chlorosis and plant height in Easter lily. They reported that GA_{4+7} +BA @ 100 mg/L prevented the chances of leaf chlorosis and significantly increased the stem length (23% to 52% taller than control) when sprayed at early stage (36 or 55 DAP). When sprayed after 55 DAP it increased postharvest flower longevity.

Moe *et al*. (2001) studied the effect of GA_{4+7}+ BA on reducing the foliar chlorosis in *Lilium longiflorum.* In this experiment, the plants were sprayed with 0, 100, 200, 400 mg/L. The plants were harvested and stored for 0-3 weeks at 2.5˚C in the dark, and then moved to room with 21¤C. It was recorded that plants treated with GA_{4+7} + BA significantly reduced the leaf senescence. Also, the treated plants were much taller (6-14cm) than the untreated ones.

Whitman (2001) investigated the effect of GA_{4+7} + BA on reducing foliar chlorosis on Easter Lily. The concentration applied were 0, 100, 200 and 400 mg/l. from this it was revealed that GA_{4+7} + BA @ 100 and 400 mg/l was more effective than other concentration in preventing chlorosis.

Celikel *et al*. (2002) studied the efficacy of 1-MCP and GA_{4+7} + BA (Promalin) for extending the post-harvest life of Oriental lilies. From the results it was reported that GA_{4+7} + BA significantly had performance better than the control. It reduced leaf yellowing, delayed bud and flower senescence, increased vase life of flower.

Emongor *et al*. (2004) studies with kale (*Brassica oleracea* var. Acephala) have shown that GA_{4+7} + BA at 25, 50, 75 mg/L significantly increased total leaf area, plant height, leaf number and plant dry matter. Similarly, as the concentration of GA_{4+7} + BA was increased from 0 to 1200 ppm, dry matter and plant height of *Euphorbia lathyris* increased significantly (Preece, 1990).

Kim *et al*. (2005) conducted an experiment on *Lilium* Oriental hybrid 'Siberia' and *Lilium* Asiatic hybrid 'Dream Land' to study the effect of different growth regulators treatments on vase life and physiological characters of the plants. They used (0, 50 and 100 mg/ L) GA_3, $GA_{4+7,}$ BA and Promalin (GA_{4+7} +BA). From the results it was concluded that GA_{4+7} +BA treatments were more useful for extension of vase life and freshness in cut lilies.

Kim and Miller (2008) reported that when GA_{4+7}+BA sprayed on pot tulip (*Tulipa gesneriana* 'Seadov') at mature bud stage it significantly enhanced flower longevity to maximum and had less effectiveness when sprayed at immature buds (green). Also, the most effective concentration of GA_{4+7}+BA was 50 mg/ L, the concentration more than 50 mg L^{-1} cause unwanted early senescence of matured tulip flowers. Thus, the concentration below 50 mg L^{-1} would be more effective in achieving desired results.

Padhye *et al*. (2008) observed the influence on BA+ GA_{4+7} in improving the branching in poinsettia 'Freedom Red'. The plants were transplanted into 6-inch pots and after 3-4 weeks of transplanting a single foliar application of BA+ GA_{4+7} @ 50 ppm and 100 ppm was done. From the data collected at flowering it was observed that the plants treated with BA+ GA_{4+7} (50 or 100 ppm) had more numbers of shoots than untreated plants.

Henschke *et al.* (2015) concluded from his study on the effect of gibberellic acid and benzyl adenine on *Helloborus orientalis* 'Red Hyrids' that the use of growth regulators significantly affected the height of plants and leaves present per plant. They also reported that GA_{4+7} +BA treated plants had more number of leaves per plant with shorter plant height. The method of application also affected the growth pattern of plant as soil drenched plants had higher leaves than the plants where foliar application was done. There was an increase in the overall growth of the plant with application of GA_{4+7} +BA as compared to control.

Alshakhaly and Qrunfleh (2019) conducted an experiment to study the effect of foliar application of GA_{4+7} +BA at different concentration on flower development and quality of *Cyclamen persicum.* They reported that when compared to the control, GA_{4+7} +BA (@ 0.75, 1.0 and1.25 ml/L) significantly accelerated flower growth and elongated peduncles. In addition, GA_{4+7} +BA (@ 1.25, 2.0 and 3.0 ml/L) also increased peduncles length and increased number of flowers to open at a time.

Rufato *et al.* (2019) concluded with his study on lateral branch induction at nursey with growth regulators in 'Maxi Gala' apple trees grafted on four rootstocks that both BA and GA_{4+7} +BA are very effective and more reliable for inducing more lateral branches. He also reported that the higher the concentration, the greater is the effect of interrupting the trunk's apical dominance and stimulating narrower crotch angles of lateral branches.

Markovic and Klett (2021) studied the influence of plant growth regulators on stock plant production of Mojave sage (*Salvia pachyphylla*) and 'Avalanche' cape daisy (*Osteospermum* hybrid). Different concentration of PGRs were sprayed, 200 and 400 ppm of ethephon; 250 and 500 ppm benzyladenine and 50 and 100 ppm GA_{4+7} +BA. The results revealed that GA_{4+7} +BA significantly increased the overall growth of plant and produced maximum number of cuttings, while BA resulted in small increase in number of cuttings.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled "**Growth regulator studies in mop-head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering**" was carried out at Horticultural Research & Training Station and Krishi Vigyan Kendra, Kandaghat an aegis of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India during the year 2021-2022.

3.1 LOCATION AND CLIMATE

The experimental site, KVK Kandaghat, Solan is situated in the northern hemisphere at a latitude of 30.97˚ and longitude 77.10˚ at an elevation of 1425 m with sub temperate climate. The area falls under zone 2 (sub humid mid hills) of agroclimatic zones of Himachal Pradesh. In summers, the place has a good rainfall while in winters face very little. The average annual temperature is 16˚C, experiences about 1262 mm annual precipitation. The driest month is November with minimum level or no rainfall at all. The month with most precipitation is July averaging about 325 mm of rainfall. (APPENDIX I)

3.2 PLANTING MATERIAL

One year old healthy, disease free and uniform size stock plants of *Hydrangea macrophylla* were selected for the present studies. These mophead hydrangeas have pink coloured (63B Red Purple group as per Royal Horticultural Society colour chart, London) compact blooms with dark green foliage. Plants having lengthy branches were pruned off to maintain uniformity. These plants were prepared from softwood terminal cuttings taken from healthy and vigorous mother plant in the month of July, 2020. The terminal cuttings were made 8-10 cm long of pencil thickness with 4-5 nodes, the lower 1-2 pair of leaves were removed and slant cut was given at the basal node. The cuttings were dipped in Dithane M-45 (0.25%) and Bavistin (0.1%) for 4-5 minutes. These cuttings were planted at proper (4-5 cm) distance from each other in beds of propagation chamber filled with cocopeat: vermiculite: perlite: sand (3:1:1:0.5 v/v). For enhancing rooting, these cuttings were dipped in IBA @ 1000 ppm solution for 5-10 seconds just before planting in propagation beds. The cuttings were than lightly watered. After establishment

of the cuttings, they were then transplanted in black polybags (20x10x7 cm), where they were kept for a long period of one year.

3.3 MEDIA USED FOR POTTING OF PLANTS

The stock plants of hydrangea were planted in 8 inches plastic pots containing a sterilized potting media during the first week of November, 2021. The media consisted of pine wood soil, FYM, sand, pine needle leaf mould and shredded pine tree bark (2:1:1:1:1 v/v). The uniformly mixed media was filled in the pots. The hydrangea plants were handled carefully so that the earth ball was not disturbed. After planting the plant in the media, gentle pressure was given with hands around the stem. The transplanting was done in evening hours as the temperature was low at that time.

3.4 INTERCULTURAL PRACTICES

After planting the pots were lightly watered and kept inside naturally ventilated, lowcost polyhouse and were arranged in such a way that they would receive proper sunlight. Irrigation was given with the help of plastic pipes in evening hours. The rate of watering the plants depends on the season i.e., winter or summer. During summer when the temperature was quite high irrigation was done frequently with 2-3 days interval. Weeding and hoeing was done in the pots manually and regularly through the period of experiment. To maintain the health and pot presentability the standard plant protection measures were followed. For insect like aphids and whiteflies spray of Imidachlorprid @ 0.5 ml/L of water and for diseases like powdery mildew and anthracnose spray of Dithane M-45 @ 0.25% + Bavistin @ 0.1% can be done.

3.5 FERTILIZER APPLICATION

Basal application of NPK (2.5g N, 1g P and 1.5g K per pot) was done. Full dose of phosphorous and potassium and one fourth dose of nitrogen was given at the time of planting. These quantities of NPK were supplied through Calcium Nitrate, Single Super Phosphate and Murate of Potash. Apart from this, fertigation of plants was also done at fortnightly intervals @ 200 ppm through NPK- 19:19:19. To reduce chances of iron deficiency in hydrangea plants, foliar application of ferrous sulphate EDTA was done 2g/ L at fortnightly interval. The frequency of application depends on the severity of deficiency in the plant.

3.6 GROWTH REGULATORS USED

In this study growth regulators used were gibberellic acid (GA_3), benzyl adenine (BA) and GA_{4+7} +BA in different concentrations. The solution of different concentration was prepared in distilled water just before foliar application. The foliar application of PGR was done at 15 days interval.

a) Gibberellic acid:

The required amount of GA_3 (25 mg, 50 mg and 100 mg) was weighed and first dissolved in 5 ml of 95 per cent ethanol and stirred till the powder gets dissolved completely. Then final volume was made up to 1000 ml (1L) each by adding distilled water to prepare required concentration of GA_3.

b) Benzyl adenine

The required amount of benzyl adenine is weighed and is first dissolved in 5 ml of 1N NaOH to dissolve the powder completely and the final volume made was up to 1000 ml (1L) by adding distilled water to prepare the required quantity of benzyl adenine (50 ppm, 100 ppm, 150 ppm).

c) **GA_{4+7} + BA**

The solution of GA_{4+7} + BA was prepared by making GA_{4+7} solution and BA solution separately. The required amount of GA_{4+7} was first dissolved in 5ml of 95 per cent ethanol and then making the final solution to one liter. Similarly, BA was prepared by adding required amount to 5ml of 1N NaOH and then final volume of solution made was one liter. Both the solutions were freshly prepared and mixed just before spraying.

The sprayer nozzle was set to the finest point to give an even mist. The plant growth regulators were sprayed uniformly over the plants till the leaves were wet and droplets of solution were trickling down and level of spray was kept constant for all treatments. The control plants were sprayed with distilled water. Spraying was done in evening hours. One liter of solution was required for each treatment. Three foliar application was done at 15 days interval at vegetative phase of plants.

3.7 EXPERIMENTAL DETAILS

The details of the experiment are as under:

- Control- Water (T_1)
- **Gibberellic acid** (GA_3)- Three concentrations (as given below)

  (Foliar application) - a) 25 ppm (T_2)

  b) 50 ppm (T_3)

  c) 100 ppm (T_4)
- **Benzyl adenine** (BA)- Three concentrations (as given below)

  (Foliar application) - a) 50 ppm (T_5)

  b) 100 ppm (T_6)

  c) 150 ppm (T_7)
- **GA_{4+7} + BA** - Three concentrations (as given below)

  (Foliar application) - a) 50 ppm (T_8)

  b) 150 ppm (T_9)

  c) 250 ppm (T_{10})

Experimental Design	:	Completely Randomized Design (CRD)
Total number of treatments	:	10
Number of replications	:	3
Number of pots per replication	:	10

3.8 OBSERVATION TO BE RECORDED:

The following observations were recorded at the time of peak flowering. The parameters include both vegetative and floral characters that were recorded during the investigation.

3.8.1 Plant height (cm):

It was recorded from the base of the plant i.e., just from the soil level up to the top of the inflorescence of the longest shoot with the help of meter scale.

3.8.2 Plant spread (cm):

Plant spread was recorded as the average distance between the outer most side shoot in East to West direction and the distance between outermost side shoot in North to South directions.

3.8.3 Number of shoots:

The total number of shoots produced per plant were counted.

3.8.4 Length of shoots (cm):

The length of individual shoots was measured from where it is attached to the main stem to the apical growing portion.

3.8.5 Number of days taken for visible bud formation:

Days were counted from the date of planting the hydrangea plants in the pots to the stage when first flower bud was visible.

3.8.6 Number of days taken for flowering:

Days were counted from the date of planting to flowering.

3.8.7 Number of inflorescences per plant:

This observation was recorded by counting the total number of inflorescences produced per plant.

3.8.8 Length of inflorescence stalk (cm):

It was recorded by measuring the stalk length from visible base of the stalk to the base of the inflorescence.

3.8.9 Inflorescence diameter (cm):

Inflorescence diameter was recorded at the time of flowering as average of the distance between apices of distal florets in East to West direction and in North to South direction.

3.8.10 Duration of flowering (days)

Number of days were counted from the stage of 50% inflorescence opening till at least single inflorescence in pot remained presentable.

3.8.11 Maximum number of inflorescences per plant open at a time:

In this maximum number of inflorescences fully open at a time per pot were counted.

3.8.12 Growth Index (cm):

It is calculated by using the following formula:

$$GI = \frac{\text{Plant height + Width of plant + Perpendicular width}}{3}$$

3.8.13 Pot presentability:

Quality of plants were evaluated on the basis of point system modified after Conover (1986). The parameters studied and points allotted were based on whole appearance of plant, flowering behavior, form and foliage of plant. Each pot was scored out of 100 based on these parameters. The pot presentability chart and distribution of points are as follows:

Presentability chart:

Parameters	**Description**	**Maximum Points**
1) Appearance as a whole plant	i) Fresh appearance (No damage, No indication of senescence on any part of the plant)	**20**
	ii) Fresh appearance (some indication of senescence)	**12**
2) Flowering	i) Number of inflorescence/ pot open at a time	
	• More than 8	**20**
	• < 8-4	**16**
	• < 4-2	**12**
	ii) Diameter of inflorescence (cm)	
	• Extra large (20 and above)	**8**
	• Large (16 to 20)	**16**
	• Medium (10 to 16)	**20**
	• Small ≤ 8	**12**
3) Foliage	i) Healthy foliage without any damage, deficiencies or insect attack	**20**
	ii)Unhealthy foliage with bruises, infestation or deficiencies	**12**
4) Form	i) Plant in balance with pot (neither too large nor too small, with optimum plant spread)	**20**
	ii) Plants too large or small, uneven spread	**12**

One and a half year old stock plants

Stock plants planted in pots

Plate 1. Vegetative phase of *Hydrangea macrophylla* during the trail

3.9 Susceptibility of pests and diseases and nutritional chlorosis:

It was recorded by observing the plants regularly for pests and diseases and for any nutritional chlorosis. When symptoms appeared proper control measures were adopted.

3.10 Cost Benefit ratio:

This index provides an estimate of the benefit derived for the expenditure incurred in adopting a particular practice. (APPENDIX- IV)

$$\text{Cost Benefit Ratio} = \frac{Gross\ return}{Total\ expenditure}$$

3.11 STATISTICAL ANALYSIS:

The data generated from present investigation on various vegetative and flowering parameters were subjected to analysis of variance (ANOVA) using completely randomized design at five per cent level of significance (Gomez and Gomez, 1984). The ANOVA tables for observations recorded were represented in Appendix III

The table of analysis of variance (ANOVA) will be calculated as follows:

Hypothesis to be tested

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$ or All treatments means are equal

Against

H_1 = At least two treatments are not equal

Source of variation	Degree of Freedom	Sum of Squares	Mean sum of Squares	F calculated	F table value
Treatments	t-1	TSS	$\frac{TSS}{(t-1)} = MST$	MST/MSE	
Error	t(r-1)	ESS	$\frac{ESS}{t(r-1)} = MSE$		
Total	(rt-1)	TSS			

Let the level of significance be 0.05

ANOVA

The calculated ‘F’ value was compared with ‘F’ table value at 5 per cent level of significance. If the calculated value is higher than the table value, it will be considered significant.

The standard error of mean i.e., SE and critical difference (CD) will be calculated for comparing the different treatment means.

Critical difference = SE (d) × t (5%) value at error degree of freedom

Chapter-4

RESULTS AND DISCUSSION

The data that was recorded during the investigation entitled "**Growth regulator studies in mop head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering**" is presented and discussed in this chapter. The analysis of variance for various characters studied have been presented in Appendix III.

4.1 Plant Height (cm)

The data pertaining to the effect of plant growth regulators on height of plant has been indicated in Table 4.1 and graphically in Fig.1. From the table, it is revealed that plant growth regulators had significant effect on plant height of hydrangea plants as compared to control. The maximum plant height (39.60 cm) was recorded in T_4 i.e., GA_3 @ 100 ppm which was followed by T_8 (36.67 cm) @ 50 ppm G_{4+7} + 50 ppm BA and T_3 (36.13 cm) GA_3 @ 50 ppm, whereas the minimum plant height (28.33 cm) was recorded in BA @ 150 ppm (T_7). From this it was found that T_4 (GA_3 @ 100 ppm) was superior over other treatments in increasing the plant height.

Table 4.1. Effect of plant growth regulators on plant height (cm) of *Hydrangea macrophylla*

Treatment	Treatments Details	Plant height (cm)
T_1	Control	29.60
T_2	GA_3 @ 25 ppm	35.53
T_3	GA_3 @ 50 ppm	36.13
T_4	GA_3 @ 100 ppm	39.60
T_5	BA @ 50 ppm	33.07
T_6	BA @ 100 ppm	30.53
T_7	BA @ 150 ppm	28.33
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	36.67
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	35.27
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	33.93
	$C.D_{0.05}$	1.15

Plant height is a fundamental agronomical factor for field research and is used to evaluate the above ground biomass and yield potential (Yasuda *et al*., 2020). From the data recorded it was clear that foliar application of GA_3 @ 100 ppm resulted in maximum plant height (39.60 cm). As it was also observed that with increase in concentration of GA_3, there was a significant increase in the height of the plant and with increasing concentration of BA the plant height decreased.

The increase of plant height with application of GA_3 is due to the cell multiplication and cell elongation property of gibberellins. As it enhances auxin activation by proliferating the site of auxin action i.e., shoot apex. Thus, due to cell elongation the internodal length and number increases which causes increase in plant height. The results were in accordance with findings of Aier *et al*. (2015) in gladiolus cv. 'Red Candyman', Farag *et al.* (2018) in *Chrysanthemum morifolium* cv. 'Zambla White' where maximum plant height was recorded when plants were treated with GA_3. Sumalatha (2017) also concluded that maximum plant height was recorded when lilium (*Lilium longifolium*) cv. 'Menorca' plants were sprayed with 100 ppm GA_3.

With increasing concentration of BA there was reduction in the height of the plant. This was due to the modification in the apical dominance. As BA lowers the endogenous level of auxin and gibberellins thus causing reduction in plant height. BA is also known to have inhibitory effects at higher concentrations. These results were in accordance to Parmar *et al*. (2009) in *Hyznecallis speciosa* and Kumari *et al.* (2018) in Asiatic lily cv. 'Tresor'.

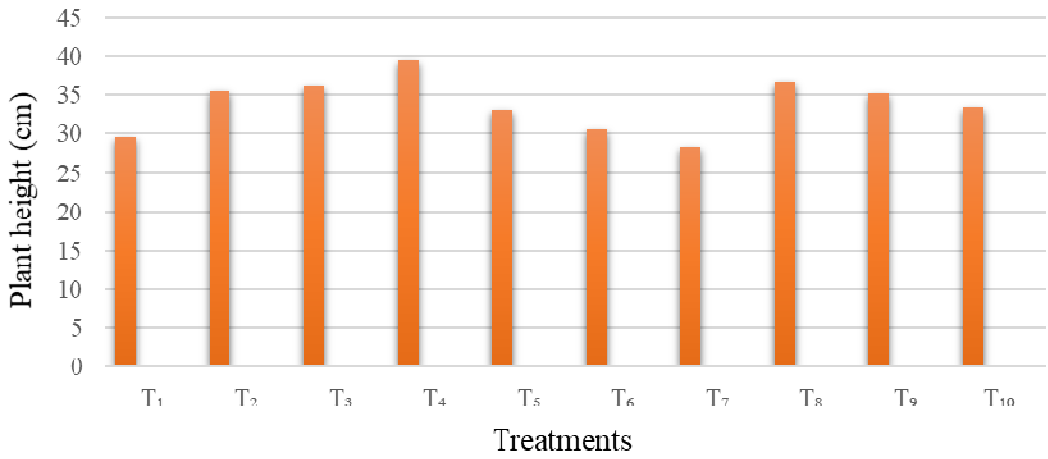

Fig.-1: Effect of plant growth regulators on plant height (cm) of *Hydrangea macrophylla*

T_4 (GA_3-100 ppm T_7 (BA-150 ppm)

(a)

T_4 (GA_3-100 ppm) T_7 (BA-150 ppm)

(b)

Plate 2. Plant height at vegetative (a) and flowering (b) stage of *Hydrangea macrophylla*

4.2 Plant Spread (cm)

The data depicting the effect of plant growth regulators on plant spread has been presented in Table 4.2 and graphically represented in Fig.2.

The maximum plant spread being 35.43 cm was recorded in T_7 i.e., BA @150 ppm as compared to other treatments. This data was at par (33.96) with plants in T_8 (GA_{4+7} @ 50 ppm + BA @ 50 ppm). This was closely followed by the other treatments i.e., T_9 (GA_{4+7} @ 150ppm + BA @ 150 ppm) and T_{10} (GA_{4+7} @ 250 ppm + BA @ 250 ppm) with plant spread of 33.11 cm and 33.23 cm respectively and these treatments were at par with each other. The minimum plant spread (27.09 cm) was recorded in T_2 i.e., GA_3 @ 25 ppm.

Table 4.2. Effect of plant growth regulators on plant spread (cm) of *Hydrangea macrophylla*

Treatment	**Treatments Details**	**Plant spread (cm)**
T_1	Control	28.51
T_2	GA_3 @ 25 ppm	27.09
T_3	GA_3 @ 50 ppm	27.74
T_4	GA_3 @ 100 ppm	29.39
T_5	BA @ 50 ppm	29.57
T_6	BA @ 100 ppm	31.17
T_7	BA @ 150 ppm	35.43
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	33.96
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	33.11
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	33.23
	$C.D_{0.05}$	1.80

Plant spread is a significant agronomical feature that determines plant morphology above ground. It is clear from Table 4.2 that the application of plant growth regulators had significantly affected the plant spread. The maximum plant spread was recorded in plants treated with BA @ 150 ppm. The increase in plant spread might be due to the physiological effect of BA, as BA are

known for cell enlargement not cell elongation as with auxin and GA_3. Another reason of increased plant spread can be stimulation in number of shoots of plants.

BA promotes cell growth in all directions (Preece and Read, 1993). There can be decrease of apical dominance if cytokinin levels in the plant are elevated (Hartmann *et al*., 2002). Thus, increase in lateral growth causes increased plant spread. These results are corroboratory with findings of Vasudevan and Kannan (2015) in rose and Mondal and Sarkar (2017) in Hybrid Tea rose cv. 'Bugatti' in both cases maximum plant spread was recorded with application of BA @ 200 ppm.

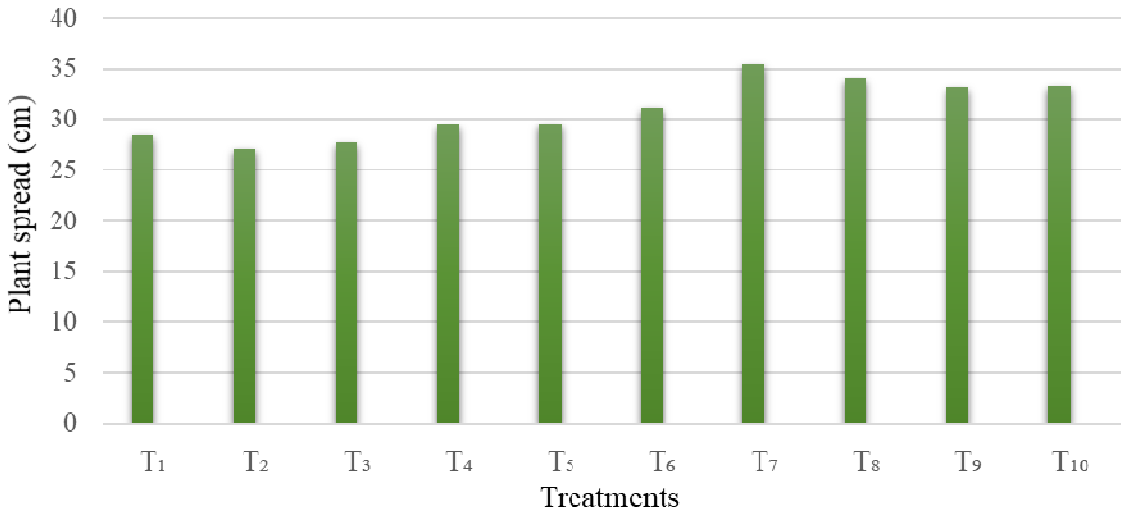

Fig.2: Effect of plant growth regulators on plant spread (cm) of *Hydrangea macrophylla*

4.3 Number of shoots

The data pertaining to the number of shoots of hydrangea plants as shown in Table 4.3 and graphically represented in Fig.3 were significantly affected by the application of plant growth regulators.

As per the observations recorded the maximum number of shoots per plant (12.15) were produced in plants treated with BA @ 150 ppm (T_7). This was followed by T_{10} (GA @ 250 ppm

+ BA @ 250 ppm) being 11.70 and T_6 (BA @ 100 ppm) being 11.28, these two treatments were at par with each other. The minimum number of shoots were recorded in T_1 (Control) i.e., 6.98.

Table 4.3. Effect of plant growth regulators on number of shoots of *Hydrangea macrophylla*

Treatment	Treatments Details	Number of shoots
T_1	Control	6.98
T_2	GA_3 @ 25 ppm	7.60
T_3	GA_3 @ 50 ppm	8.70
T_4	GA_3 @ 100 ppm	9.42
T_5	BA @ 50 ppm	10.06
T_6	BA @ 100 ppm	11.28
T_7	BA @ 150 ppm	12.15
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	10.57
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	11.07
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	11.70
	$C.D_{0.05}$	0.57

Data presented in Table 4.3 revealed that maximum number of shoots per plant (12.15) were produced in plants treated with BA @ 150 ppm. It was also recorded that the increasing concentration of BA significantly increased the number of shoots. The regulation of shoots or shoot branching is an important aspect in improvement of crop. BA are known to regulate cell division and plays important part in lateral bud outgrowth. Several findings reported that cytokinins synthesized in the stem nodes are responsible for axillary bud outgrowth (Chen *et al*., 2016). Dun *et al*. (2012) reported that external application of BA enhances growth of lateral buds and hence counter acts the effect of apical dominance giving rise to more shoots.

These results were in substantial agreement with findings of Ibrahim *et al.* (2010) who concluded that when foliar application of BA @ 150 ppm was done on Croton maximum number of shoots were produced. Similar results were recorded by Carey *et al.* (2013) in *Salvia*

nemorosa L. cv. 'Caradonna', Newton and Runkle (2015) in potted *Miltoniopsis* Orchids and Zhang *et al***.** (2018) tea cv. 'Longijng 43'.

Likewise, the number of shoots were seen increased with different concentration of GA_{4+7} +BA as compared to control. This might be due to the combine effect of both gibberellins and cytokinin on physiology of the plant.

4.4 Length of shoots (cm)

The data illustrated in Table 4.4 and graphically in Fig. 3 indicates that the length of shoots of plants treated with plant growth regulators showed significant difference between the treatments.

The maximum length of shoots was recorded in T_4 (27.51 cm) with application of GA_3 @ 100 ppm. This treatment was followed by T_3 (24.37cm) with application of GA_3 @ 50 ppm and then T_8 (23.81 cm) with application of GA_{4+7} @ 50 ppm + BA @ 50 ppm. The minimum length of shoots was recorded in T_7 (14.59 cm) i.e., BA @ 150 ppm.

Table 4.4. Effect of plant growth regulators on length of shoots (cm) of *Hydrangea macrophylla*

Treatment	**Treatments Details**	**Length of shoots (cm)**
T_1	Control	17.97
T_2	GA_3 @ 25 ppm	23.10
T_3	GA_3 @ 50 ppm	24.37
T_4	GA_3 @ 100 ppm	27.51
T_5	BA @ 50 ppm	17.05
T_6	BA @ 100 ppm	16.36
T_7	BA @ 150 ppm	14.59
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	23.81
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	22.70
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	22.33
	$C.D_{0.05}$	1.25

As the results of pre sent investigation revealed that maximum length of shoot was recorded in plants treated with GA_3 @ 100 ppm and minimum was recorded where BA @ 150 ppm was used. Also, the data presented in table 4.4 shows significant increase in length of shoots with increase in the concentration of GA_3 and decrease with increase in concentration of BA.

The emergence of longer shoots is due to the most pronounced effect of gibberellins on the plant growth i.e., cell enlargement or elongation of internodes. Significant increase in length of shoots were also observed by Verma and Parmar (2003) in Carnation where 100 ppm of GA_3 was applied. Similar results were recorded by Holkar *et al.* (2018) in gladiolus cv. 'Summer Shine' and Sijo *et al.* (2020) in rose.

With increasing concentration of BA there was decrease in length of shoots, this might be due to some moderations in apical dominance or may be reduction in endogenous level of gibberellins. The similar results were found in conformity with Chakardhar (2002) in Rose cv. 'Gladiator' and by Suresh (2008) also in rose.

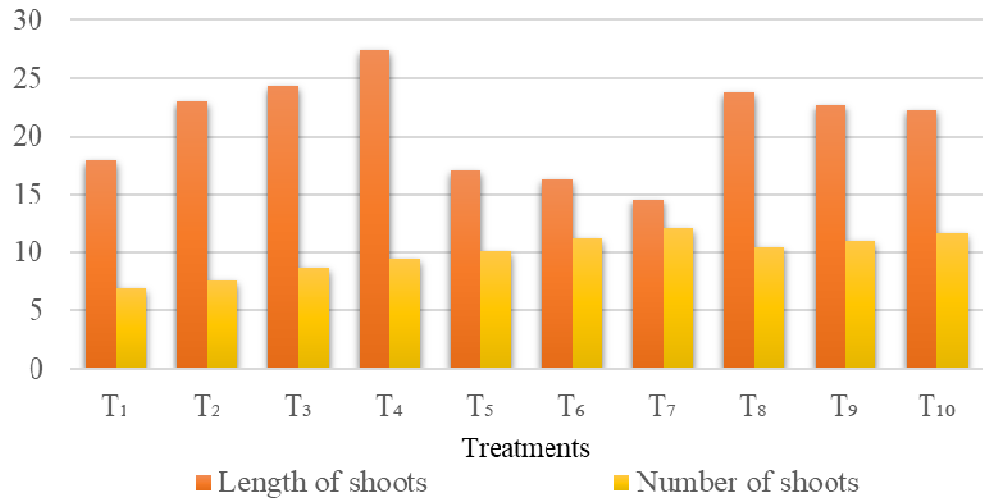

Fig.3: Effect of plant growth regulators on length and number of shoots of *Hydrangea macrophylla*

4.5 Growth Index (cm)

The data in respect to growth index of plants is presented in Table 4.5 and graphically in Fig. 4. The observations depicted in the table shows a significant difference in the growth index of plants as affected by the use of different plant growth regulators.

The maximum (35.81 cm) value of growth index was recorded in plants where application of GA_{4+7} @ 50 ppm + BA @ 50ppm (T_8) was done. Whereas the minimum (29.54 cm) growth index was recorded in control (T_1)

Table 4.5. Effect of plant growth regulators on growth index (cm) of *Hydrangea macrophylla*

Treatment	Treatments Details	Growth Index (cm)
T_1	Control	29.54
T_2	GA_3 @ 25 ppm	30.57
T_3	GA_3 @ 50 ppm	31.03
T_4	GA_3 @ 100 ppm	33.99
T_5	BA @ 50 ppm	30.91
T_6	BA @ 100 ppm	30.43
T_7	BA @ 150 ppm	32.08
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	35.81
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	34.16
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	33.64
	$C.D_{0.05}$	1.23

From the data presented in the Table 4.5 the maximum growth index was recorded in plants where application of 50 ppm GA_{4+7} + 50 ppm BA was done. There was a significant increase in the growth index as compared to control. This increase in overall plant growth might be due to combined effect of gibberellic acid and benzyl adenine. Gibberellins are involved in the regulation of axillary meristems, thus controlling the plant architecture (Eshed and Lippman, 2019). The combination of GA_{4+7} + BA increased the lateral growth and caused elongation of lateral branches, which ultimately enhanced the overall growth of the treated stock plants. Similar results were obtained by Markovic and Klett (2021) in *Salvia pachyphylla* and *Osteospermum* hybrid where there was a significant increase in the growth index at 50 ppm concentration of GA_{4+7} + BA as compared to other treatments.

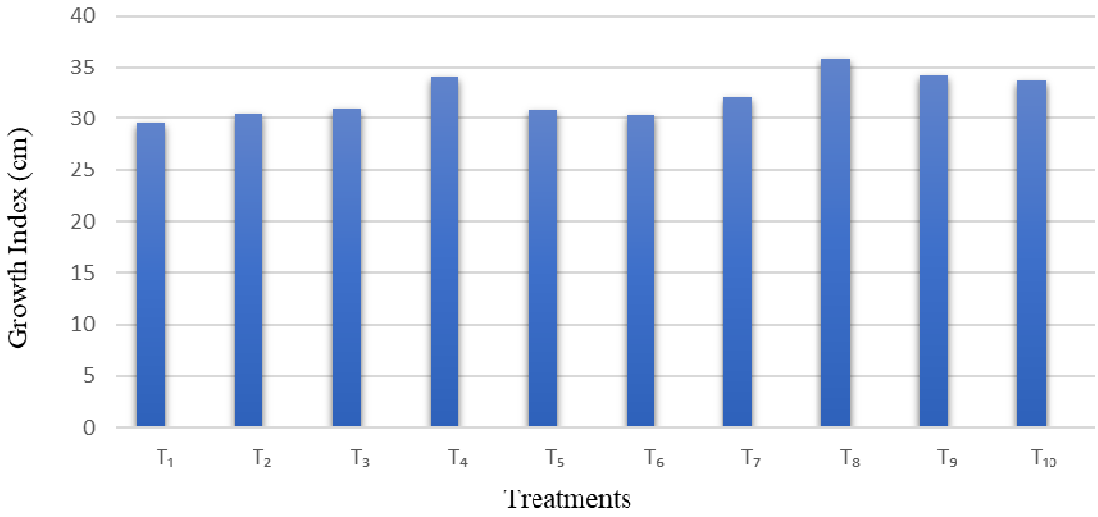

Fig.4: Effect of plant growth regulators on growth index (cm) of *Hydrangea macrophylla*

4.6 Number of days taken for visible bud formation

The data pertaining to the effect of plant growth regulators on number of days taken for visible bud formation from date of planting of hydrangea plants is depicted in Table 4.6 and graphically represented in Fig.5. The use of gibberellins and cytokinin at different concentrations showed significant differences among the treatments.

From the data recorded it was clear that the plants treated with GA_3 @ 100 ppm (T_4) took minimum days (151.47 days) for visible bud formation which was statistically at par with T_3 (GA_3 @ 50 ppm) with 153.47 days taken for visible bud formation. The maximum days (170.13 days) were observed in T_7 (BA @ 150 ppm). This treatment was statistically at par with T_{10} (169.10 days) with application of 250 ppm GA_{4+7} + 250 ppm BA.

The data presented in Table 4.6 shows significant variation in the number of days taken for visible flower bud formation due to application of various concentration of plant growth regulators. The plants where foliar application of GA_3 was done took minimum number of days for the formation of visible buds as compared with other treatments.

Table 4.6. Effect of plant growth regulators on number of days taken for visible bud formation of *Hydrangea macrophylla*

Treatment	Treatments Details	Number of days taken for visible bud formation
T_1	Control	161.96
T_2	GA_3 @ 25 ppm	158.53
T_3	GA_3 @ 50 ppm	153.47
T_4	GA_3 @ 100 ppm	151.86
T_5	BA @ 50 ppm	163.33
T_6	BA @ 100 ppm	165.60
T_7	BA @ 150 ppm	170.13
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	160.33
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	165.97
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	169.10
	$C.D_{0.05}$	2.41

Plants treated with GA_3 @ 100 ppm took minimum number of days (151.86) for visible bud formation. This is due to the fact that gibberellins promote juvenile to adult transition when endogenous level increases (Andres *et al*., 2014). Also, gibberellins are known to proliferate auxin synthesis and directs the transport of metabolites to stem apical meristem and promotes development of buds. GA_3 stimulated early bud formation also in the reports by Patil (2001) *Gerbera jamesonii* cv. 'Sangria' with GA_3 at 150 ppm, Parmar *et al*. (2009) in Spider lily with GA_3 at 200 ppm, Palie *et al*. (2016) in African marigold with GA_3 at 100 ppm and Mishra *et al*. (2019) in Amaryllis lily with GA_3 at 250 ppm.

Whereas the plants treated with BA took maximum days for formation of visible buds. This may be due to the fact that at higher concentration of BA, it was observed that slower cell division takes place which causes the cells to take more time for formation of photosynthates that are required for bud initiation. Similar results were reported by Asil *et al.* (2011) in *Polianthes tuberose* L. (cv. 'Goldorosht Mahallat'). Likewise, the increase in concentration of BA in T_7 (GA_{4+7} @ 150 ppm + BA @ 150 ppm) also caused late emergence of visible buds (170.13).

4.7 Number of days taken for flowering

The result presented in Table 4.7 and graphically in Fig. 5 shows the effect of plant growth regulators on flowering of hydrangea.

A perusal of data indicated the significant effect of GA_3, BA and GA_{4+7} +BA on number of days taken for flowering. The minimum number of days (184.53 days) taken for flowering were recorded in T_4 i.e., foliar application of GA_3 @ 100 ppm. This treatment was at par with T_3 (GA_3 @ 50 ppm) with 186.86 days taken for flowering. However, the maximum number of days (208.83) were recorded in T_7 with BA @ 150 ppm.

Table 4.7. Effect of plant growth regulators on number of days taken for flowering of *Hydrangea macrophylla*

Treatment	Treatments Details	Number of days taken for flowering
T_1	Control	201.67
T_2	GA_3 @ 25 ppm	189.13
T_3	GA_3 @ 50 ppm	186.86
T_4	GA_3 @ 100 ppm	184.53
T_5	BA @ 50 ppm	203.03
T_6	BA @ 100 ppm	206.37
T_7	BA @ 150 ppm	208.83
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	195.67
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	197.03
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	199.83
	$C.D_{0.05}$	3.07

From the results of the investigation as depicted in Table 4.6 it is clear that the minimum number of days taken for flowering were recorded in plants treated with GA_3 @ 100 ppm which was at par with plants treated with GA_3 @ 50 ppm. This can be due to the effect of gibberellins which reduces juvenile phase and also due to production of florigen flowering hormone. Thus, causes early development of flowering stage (reproductive stage) i.e., the shoot apical meristem

instead of producing branches and leaves starts producing flowers. These results are in concurrence with findings of Asil *et al.* (2011) in *Polianthes tuberose* L. (cv. 'Goldorosht Mahallat') with application of GA_3 @ 100 ppm and Yogendra (2021) in *Calendula officinalis*.

BA treated plants took maximum number of days for flowering, this is due to the property of BA which causes enhancement in multiple shooting or lateral branching and sometimes it also interferes in synthesis of endogenous auxin and gibberellins. Thus, taking more time for flowering. Carey *et al.* (2013) in *Salvia nemorosa* and Holkar *et al.* (2018) in gladiolus cv. 'Summer Shine' had recorded the same results where BA caused delay in flowering. Also, Attiya *et al.* (2015) observed that benzyl adenine when sprayed on lily plants significantly increase the time taken for flowering as compared to control.

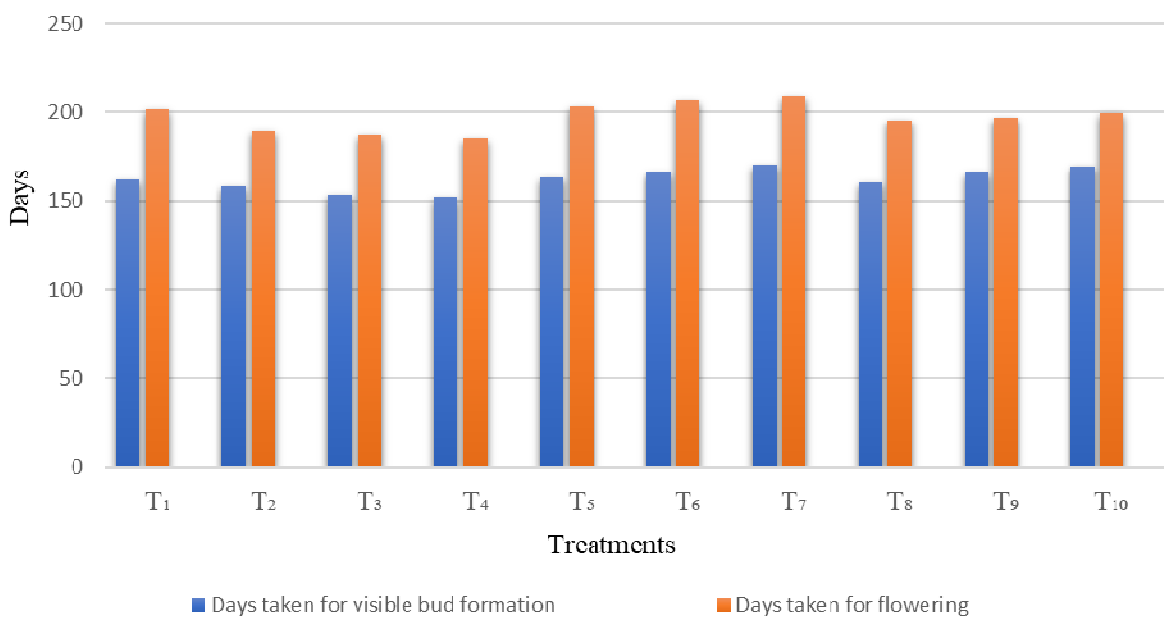

Fig.5: Effect of plant growth regulators on number of days taken for visible buds formation and for flowering of *Hydrangea macrophylla*

(1) Pea sized

(2) U.S. Nickel sized

(3) U.S. Silver dollar sized

(4) First pigment evidence

(5) Flower at peak pigment

Plate 3. Various developmental stages of inflorescence of *Hydrangea macrophylla*

4.8 Maximum number of inflorescences open at a time per plant

The data presented in Table 4.8 and Fig. 6 revealed that maximum number of inflorescences open at a time per plant were recorded in plants treated with GA_3 @ 100 ppm (4.13- T_4) which was statistically at par with T_7 (4.07) and T_8 (3.93).

The minimum number of inflorescences (3.06) open at a time per plant were recorded in plants treated with 250 ppm GA_{4+7} + 250 ppm BA (T_{10}) which was statistically at par with T_1 (3.20) being Control, T_2 (3.47) being GA_3 @ 25 ppm, T (3.07) being BA @ 50 ppm and T_6 (3.33) being BA @ 100 ppm.

Table 4.8. Effect of plant growth regulators on maximum number of inflorescences open at a time per plant of *Hydrangea macrophylla*

Treatment	Treatments Details	Maximum number of inflorescences open at a time per plant
T_1	Control	3.20
T_2	GA_3 @ 25 ppm	3.47
T_3	GA_3 @ 50 ppm	3.60
T_4	GA_3 @ 100 ppm	4.13
T_5	BA @ 50 ppm	3.07
T_6	BA @ 100 ppm	3.33
T_7	BA @ 150 ppm	4.07
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	3.93
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	3.67
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	3.06
	$C.D_{0.05}$	0.41

From the data presented in the Table 4.8, the maximum number of inflorescences open at a time per plant were recorded in plants treated where application of GA_3 @ 100 ppm was done. This is due to application of exogenous gibberellins which attributes to the direct activation of the genes that are necessary for flower formation. This is the first step of vegetative to reproductive phase transition and thus leading to the production of inflorescence meristems

(Blazquez *et al*., 1997). Thus, leading to opening of maximum inflorescences. Another reason can be increased amylase activity with application of gibberellic acid which leads to luxurious growth of plant and affecting the opening of florets at a time which overall affects opening of inflorescence at a time. The findings of present study are in agreement with those of Alshakhaly and Qrunfleh (2019) in *Cyclamen persicum*, Sumalatha (2017) in *Lilium longifolium*, Palie *et al*. (2016) in African marigold, Sudhakar and Kumar (2012) in gladiolus cv. 'White Friendship'.

BA treated plants also showed increase in number of inflorescences open at a time this might be due to greater number of shoots produced with application of BA. As it enhances lateral growth of plants so it is possible that due to high number of branches more inflorescences are produced. These results are in conformity with Fujii and Sasaki (2000) and Blanchard and Runkle (2008).

4.9 Inflorescence diameter (cm)

The results obtained on the effect of different plant growth regulators on diameter of inflorescences have been presented in Table 4.9 and graphically depicted in Fig.6.

The significantly maximum inflorescence diameter was recorded in T_4 (GA_3 @ 100 ppm) with 12.26 cm which was statistically at par with T_2, T_3, T_6 and T_7 i.e., 11.55 cm, 11.90 cm, 11.70 cm and 12.07 cm respectively. The minimum inflorescence diameter was recorded in T_1 (Control) with 9.73 cm.

Data presented in Table 4.9 shows that maximum inflorescence diameter (12.26) cm was recorded in T_4 (GA_3 @ 100 ppm) whereas the minimum (9.73 cm) inflorescence diameter was recorded in control. The increase in inflorescence diameter might be on account to the fact that GA_3 enhances translocation of metabolites at the site of flower bud development. This might have led to increase in floret size which eventually increased the diameter of inflorescences. Also, GA_3 causes more production of food material in leaves due to enhanced physiological activities in turn led to production of bigger sized flowers

Similar results were recorded by Srestha *et al*. (2020) where maximum bloom diameter was observed in plants treated with application of gibberellic acid in calendula. Sharifuzzaman *et al*. (2011) in chrysanthemum, Kanwar *et al*. (2013) in African marigold, Muhammad *et al*. (2016) in chrysanthemum also observed the same increase in size of flowers in their studies.

Table 4.9. Effect of plant growth regulators on inflorescence diameter (cm) of *Hydrangea macrophylla*

Treatment	Treatments Details	Inflorescence diameter (cm)
T_1	Control	9.73
T_2	GA_3 @ 25 ppm	11.55
T_3	GA_3 @ 50 ppm	11.90
T_4	GA_3 @ 100 ppm	12.26
T_5	BA @ 50 ppm	11.04
T_6	BA @ 100 ppm	11.70
T_7	BA @ 150 ppm	12.07
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	11.06
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	10.63
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	10.05
	$C.D_{0.05}$	1.15

4.10 Number of inflorescences per plant

The data regarding the effect of plant growth regulators on total number of inflorescences per plant is illustrated in Table 4.10 and graphically in Fig.6. The data shows that number of inflorescences per plant were found to be maximum (7.20) in T_7 (BA @ 150 ppm). Whereas, the minimum number of inflorescences (4.40**)** were recorded in T_1 (control).

The number of inflorescences per plant was significantly affected by the application of plant growth regulators. The maximum inflorescences per plant were recorded in plants where application of BA @ 150 ppm was done. The increase in number of inflorescences per plant is due to the production of more shoots per plant. These results were in accordance with work reported by Blanchard and Runkle (2008) in Orchids, Nambier *et al.* (2012) in Dendrobium hybrids cv. 'Angel White', Carey *et al* (2013) in *Salvia nemorosa*, Vasudevan and Kannan (2015) in rose, Ashwani and Chandrashekar (2017) in carnation.

Table 4.10. Effect of plant growth regulators on number of inflorescences per plant of *Hydrangea macrophylla*

Treatment	Treatments Details	Number of inflorescences per plant
T_1	Control	4.40
T_2	GA_3 @ 25 ppm	5.26
T_3	GA_3 @ 50 ppm	5.67
T_4	GA_3 @ 100 ppm	6.13
T_5	BA @ 50 ppm	6.40
T_6	BA @ 100 ppm	6.53
T_7	BA @ 150 ppm	7.20
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	5.46
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	5.67
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	6.07
	$C.D_{0.05}$	0.45

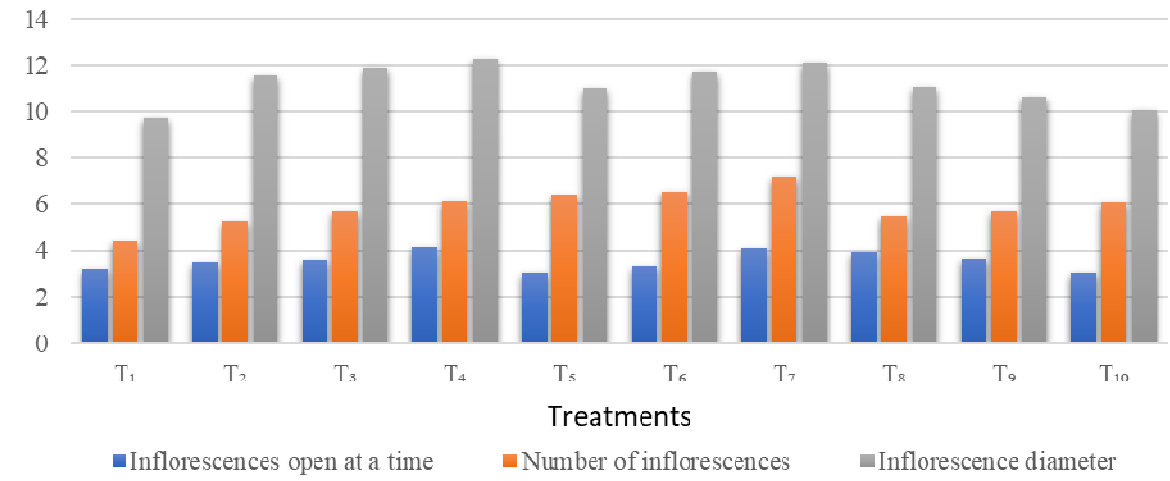

Fig.6: Effect of plant growth regulators on number of inflorescences per plant open at a time , total number of inflorescences and inflorescence diameter (cm) of *Hydrangea macrophylla*

GA_3 treated plants also showed increase in number of inflorescences this can be due to enhanced production and accumulation of more photosynthates that were diverted to the sink and

produced high number of inflorescences (Sharifuzzaman *et al.,* 2011). Another reason can be the indirect effect of gibberellins which causes increase in number of leaves and leaf area, this might have boosted the formation and accumulation of assimilates that were translocated from source to sink for flowers production. These results were in similar trend with findings of Sumalatha (2017) in Asiatic lilium, Alshakhaly and Qrunfleh (2019) in Cyclamen where high number of flowers were recorded in treatment with gibberellic acid.

4.11 Length of flower stalk (cm)

The data pertaining the effect of plant growth regulators on length of flower stalk has been shown in Table 4.10 and graphically in fig.-7. From the table it is clear that shortest flower stalks were recorded in plants treated with BA @ 150 ppm (T_7) with 2.74 cm. The longest flower stalks were recorded in T_4 (GA_3 @ 100 ppm) being 3.77 cm which was followed by T_3 (GA_3 @ 50 ppm) being 3.41 cm and T_8 (GA_{4+7} @ 50 ppm + BA @ 50 ppm) being 3.27 cm.

Table 4.11. Effect of plant growth regulators on length of flower stalk (cm) of *Hydrangea macrophylla*

Treatment	Treatments Details	Length of flower stalk (cm)
T_1	Control	3.01
T_2	GA_3 @ 25 ppm	3.11
T_3	GA_3 @ 50 ppm	3.41
T_4	GA_3 @ 100 ppm	3.77
T_5	BA @ 50 ppm	3.02
T_6	BA @ 100 ppm	2.85
T_7	BA @ 150 ppm	2.74
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	3.27
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	3.11
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	3.03
	$C.D_{0.05}$	0.17

The flower stalk length was significantly affected by application of different plant growth regulators at varying concentrations. It was found that with application of BA there was significant decrease in flower stalk length. The minimum was recorded in plants treated with BA @ 150 ppm this can be due to inhibition of cell elongation and cell division at higher concentration of benzyl adenine. The significance of short flower stalk length is that it will give compact inflorescences. Similar results were found by Mishra *et al*. (2019) in Amaryllis belladonna cv. 'Zephyranthes' and Maheshwari and Sivasanjeevi (2019) in Tuberose cv. "Single".

Likewise, maximum flower stalk length (3.77 cm) was found in treatment where foliar application of GA_3 @ 100 ppm was done. This increase in length is due to elongation of cells Farag *et al*. (2018). Also, this can be due to high photosynthetic and metabolic activity caused by gibberellins which results in increased translocation and use of photosynthetic products.

These results were in conformity with findings of Dhaduk *et al*. (2007) in anthurium, Asil *et al*. (2011), Sharifuzzaman *et al*. (2011) in chrysanthemum, Dogra *et al*. (2012) in gerbera where similar increase in length of stalk was recorded with application of gibberellic acid.

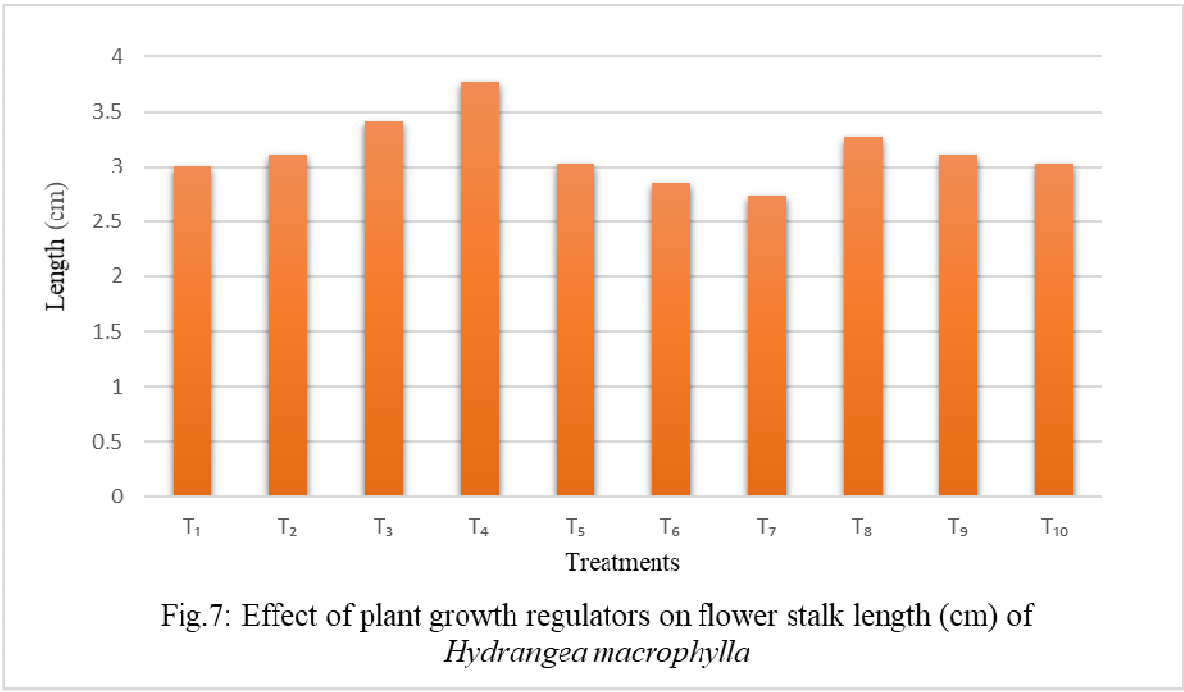

Fig.7: Effect of plant growth regulators on flower stalk length (cm) of *Hydrangea macrophylla*

4.12 Duration of flowering (days)

The results mentioned in Table 4.12 and graphically in Fig.8 on duration of flowering by the use of different plant growth regulators on hydrangea.

The maximum duration of flowering was recorded in plants treated with foliar application of BA @ 150 ppm (T_7) with 86.82 days whereas minimum duration of flowering was recorded in T_1 (Control) with 65.19 days. From data recorded it is clear that among the concentration of gibberellic acid used GA_3 @ 100 ppm (T_4) had the maximum duration of flowering (76.12), whereas in case of benzyl adenine (T_7) with 150 ppm and in combination GA_{4+7} + BA (T_8) with 50 ppm each were reported with maximum duration of flowering.

Table 4.12. Effect of plant growth regulators on duration of flowering (days) of *Hydrangea macrophylla*

Treatment	Treatments Details	Duration of flowering (days)
T_1	Control	65.19
T_2	GA_3 @ 25 ppm	70.82
T_3	GA_3 @ 50 ppm	73.01
T_4	GA_3 @ 100 ppm	76.12
T_5	BA @ 50 ppm	79.56
T_6	BA @ 100 ppm	83.96
T_7	BA @ 150 ppm	86.82
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	73.11
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	69.57
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	66.83
	$C.D_{0.05}$	1.95

From the Table 4.12 it is clear that different concentration of plant growth regulators had significantly affected the duration of flowering. The maximum duration of flowering was recorded in plants where foliar application of BA @ 150 ppm was done. There was an increase

in duration of flowering with increase in concentration of BA. This increase might be due to the effect to increased endogenous BA concentration on various physiological activities like maintaining membrane permeability, water balance and protein and nucleic acid metabolism of the plant tissue. Optimal concentration of BA might have decreased the level of ethylene production in flowers and thus extended the duration of flowering.

These results were in accordance with Baghele *et al*. (2014) in rose where plants treated with BA had maximum flower duration. Mondal and Sarkar (2017) in hybrid tea rose cv. 'Bugatti' with BA @ 200 ppm also reported same results. Likewise, Bala and Singh (2018) in chrysanthemum also recorded the increase in flower life with application of BA @ 200 ppm.

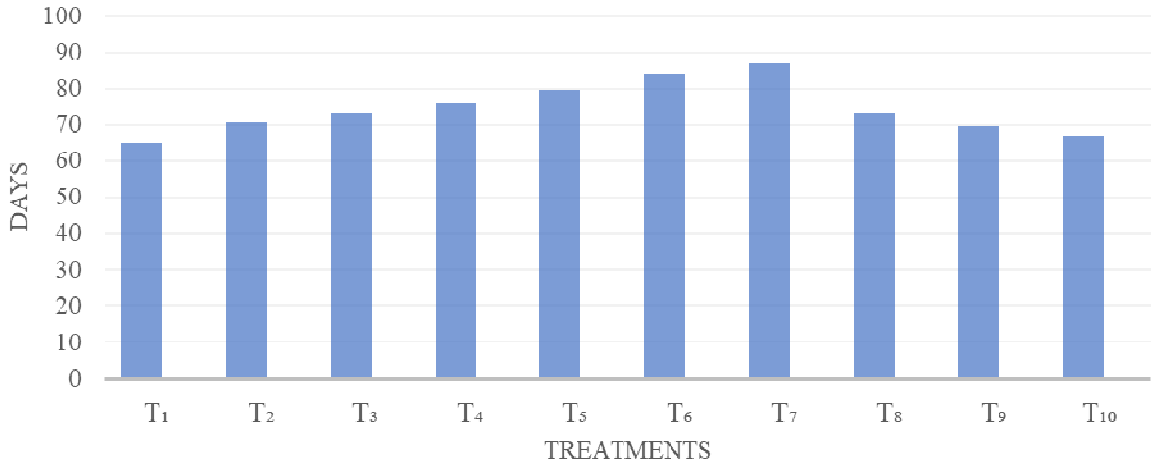

Fig.-8: Effect of plant growth regulators on duration of flowering (days) on *Hydrangea macrophylla*

4.13 Pot presentability

Table 4.13 and Fig. 9 depicts the data pertaining pot presentability. The analysis of data exhibited the significant effect of plant growth regulators on pot presentability scores.

The maximum pot presentability score was recorded in T_8 (88.17) when the plants were treated with GA_{4+7} @ 50 ppm + BA @ 50 ppm, which was found at par with T_7 (86.20). Whereas, minimum pot presentability was recorded in T_1 (Control) with a score of 73.92.

The data presented in the table had significantly varied with the use of plant growth regulators. The maximum pot presentability (88.17) was recorded in T_8 where application of

GA_{4+7} @ 50 ppm + BA @ 50 ppm was done. This might be due to the combined effect of both GA_{4+7} + BA. As their effect resulted in overall growth of plant that includes plant height, plant spread in balance with pot, number of inflorescences, duration of flowering. As gibberellins might have contributed in the various physiological activities like cell elongation, induction of hydrolytic enzymes which regulates mobilization of proteins and metabolites. Whereas, BA might have increased the lateral growth of the plant, increasing the number of inflorescence shoots, delayed senescence and increased duration of flowering.

Thus, the combined effect of gibberellins and cytokinins enhanced overall growth and flowering of hydrangea i.e., pot presentability. The results were in accordance with Henschke *et al.* (2015) in their study on *Helloborus orientalis* 'Red Hyrids' and Markovic and Klett (2021) in *Salvia pachyphylla* and *Osteospermum* hybrid. The minimum pot presentability score (73.92) was recorded in control where no application of plant growth regulators was done.

Table 4.13. Effect of plant growth regulators on pot presentability of *Hydrangea macrophylla*

Treatment	**Treatments Details**	**Pot presentability (Score out of 100)**
T_1	Control	73.92
T_2	GA_3 @ 25 ppm	79.50
T_3	GA_3 @ 50 ppm	81.34
T_4	GA_3 @ 100 ppm	83.63
T_5	BA @ 50 ppm	80.83
T_6	BA @ 100 ppm	82.76
T_7	BA @ 150 ppm	86.20
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	88.17
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	84.64
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	81.13
	$C.D_{0.05}$	3.52

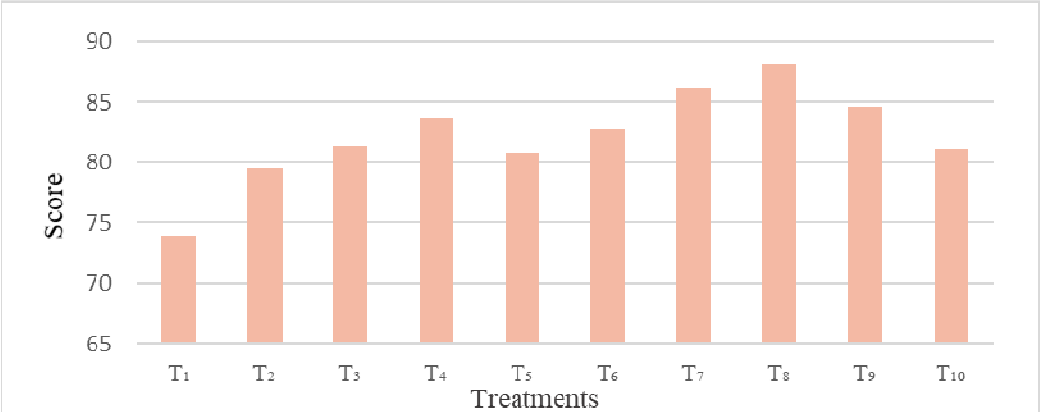

Fig.9: Effect of plant growth regulators on pot presentability of *Hydrangea macrophylla*

4.14 Vase life (days)

The data illustrated in Table 4.14 and graphically in Fig.10 indicates that the vase life of plants where application of plant growth regulators was done showed significant difference between the treatments.

Table 4.14. Effect of plant growth regulators on vase life (days) of *Hydrangea macrophylla*

Treatment	Treatments Details	Vase life (days)
T_1	Control	8.93
T_2	GA_3 @ 25 ppm	10.86
T_3	GA_3 @ 50 ppm	11.53
T_4	GA_3 @ 100 ppm	12.60
T_5	BA @ 50 ppm	12.86
T_6	BA @ 100 ppm	13.33
T_7	BA @ 150 ppm	13.67
T_8	GA_{4+7} @ 50 ppm + BA @ 50 ppm	11.93
T_9	GA_{4+7} @ 150 ppm + BA 150 ppm	11.07
T_{10}	GA_{4+7} @ 250 ppm + BA @ 250 ppm	10.13
	$C.D_{0.05}$	0.64

T_1
(control)

T_2
(GA_3-25 ppm)

T_3
(GA_3-50 ppm)

T_4
(GA_3-100 ppm)

T_5
(BA-50 ppm)

T_6
(BA-100 ppm)

T_7
(BA-150 ppm)

T_8
(GA_{4+7} - 50 ppm
+ BA-50 ppm)

T_9
(GA_{4+7}-150 ppm
+ BA -50 ppm)

T_{10}
(GA_{4+7}-250 ppm
+ BA-250 ppm)

Plate 4. Effect of plant growth regulators on growth and flowering of *Hydrangea macrophylla*

From the data presented in Table 4.14 it was understandable that the maximum vase life (13.67) was recorded in T_7 where plants were treated with BA @ 150 ppm. This treatment was at par with T_6 (13.33) with application of BA @ 100 ppm. The minimum vase life (8.93) was observed in T_1 (Control).

The result of the present investigation indicated that maximum vase life (13.67) was observed in plants treated with BA @ 150 ppm as compared to control where minimum vase life was recorded. The increase in vase life may be due to the anti-senescence property of benzyl adenine. As senescence is a genetically regulated and mediated through interaction between hormonal and developmental signaling pathways (Chang *et al.*,2003). BA delays the senescence by inhibiting the ethylene synthesis by decreasing the formation of ethylene synthesizing enzymes thus increases the longevity of flowers. Another reason can be decreasing the cellular respiration rate caused by decreased ethylene activity in cells. The results are in accordance with findings of Asil *et al.* (2011) in *Polianthes tuberose* where a significant increase in vase life was recorded in plants treated with BA @ 100 ppm as compared to GA_3 treated plants and Kapri *et al.* (2018) in lily where maximum vase life was recorded with application of BA @ 100 ppm.

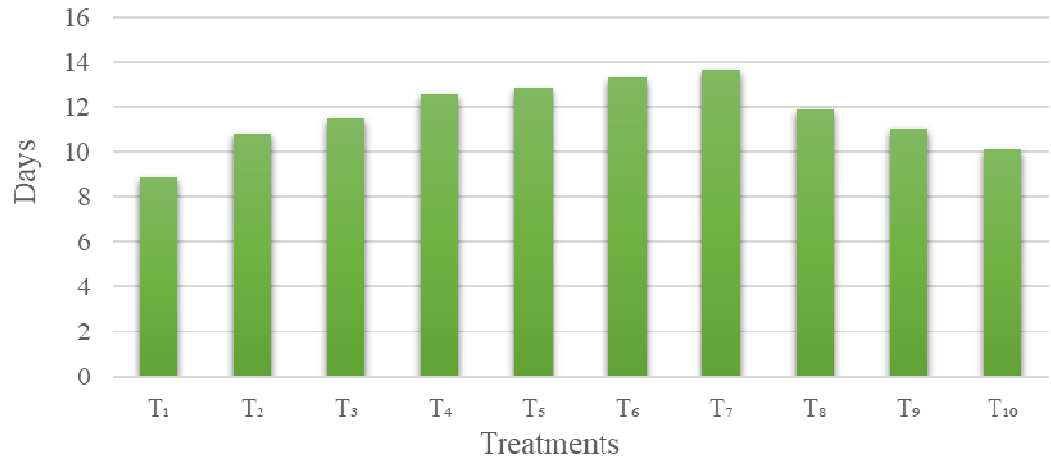

Fig.10: Effect of plant growth regulators on vase life (days) of *Hydrangea macrophylla*

4.15 Cost-Benefit ratio:

The total cost of cultivation of *Hydrangea macrophylla* by use of different plant growth regulators i.e., GA_3, BA and GA_{4+7} + BA was calculated per pot (APPENDIX IV).

The net profit and BC ratio was highly influenced by the use PGRs. The maximum cost benefit ratio (1.69:1) was obtained in T_8 (GA_{4+7} @ 50 ppm + BA @ 50 ppm) with net profit (Rs. 277.26 per pot) followed by T_7 (BA @ 150 ppm) with BC ratio 1.65:1. The minimum cost benefit ratio was obtained in T_{10} (1.25:1). Thus, from this it is evident that plants treated with GA_{4+7} @ 50 ppm + BA @ 50 ppm gained maximum productivity with increased net income. The variation in treatments might be due to production of more shoots, flowers, better growth index and maximum pot presentability score.

4.16 Susceptibility to pest and diseases and nutritional chlorosis:

The pest like aphids and whiteflies were observed during the vegetative phase of the trail. To control them application of Imidachlorprid @ 0.5 ml/L of water was done. Deficiency of iron was observed as interveinal chlorosis was seen on younger leaves of the plants. To control this foliar application of ferrous sulphate EDTA was done 2 g/ L at fortnightly interval.

There was no incidence of disease during the experimentation.

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled "**Growth regulator studies in mop-head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering**" was conducted at Horticultural Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni (Solan) during the year 2021-2022. The experiment was conducted under naturally ventilated polyhouse of 105x7x3.5 m^2 size. The experiment was laid in Complete Randomized Design (CRD) with three levels of GA_3 *viz.* 25 ppm, 50 ppm and 100 ppm; three levels of BA *viz.* 50 ppm, 100 ppm and 150 ppm, three levels of GA_{4+7} +BA that are 50 ppm, 150 ppm and 250 ppm each and one control that makes a total of ten treatments each having three replications. Uniformed developed one and half years old stock plants were planted in pots having growing media consisting of pine wood soil, FYM, sand, pine needle leaf mould and shredded pine tree bark (2:1:1:1:1v/v).

The parameters like plant height, plant spread, number of shoots, length of shoots, number of days taken for visible bud formation, growth index, days taken for flowering, inflorescence diameter, number of inflorescences, length of flower stalk, maximum number of inflorescences open at a time per plant, duration of flowering, pot presentability, vase life and benefit cost ratio were observed during the study.

The salient findings of the results obtained during the course of investigation are summarized below:

- Plants treated with GA_3 @ 100 ppm showed maximum plant height (39.60 cm) which was closely followed by T_8 (36.67 cm) @ 50 ppm GA_{4+7} + 50 ppm BA whereas the minimum (28.33 cm) plant height was obtained in plants treated with BA @ 150 ppm.
- Maximum plant spread (35.43 cm) was recorded in plants treated with BA @150 ppm (T_7). This data was at par with plants treated with 50 ppm GA_{4+7} + 50 ppm BA (T_8). The minimum plant spread (27.09) was recorded in plants where GA_3 @ 25 ppm (T_2) application was done.

- Among various treatments, the maximum number of shoots per plant (12.15) were obtained in plants treated with BA @ 150 ppm (T_7) and minimum (6.98) number of shoots were recorded in T_1 (Control).
- The maximum length of shoots was recorded in T_4 (27.51 cm) with application of GA_3 @ 100 ppm and minimum length of shoots was recorded in T_7 (14.59 cm) with application of BA @ 150 ppm.
- The maximum (35.81 cm) value of growth index was obtained in plants treated with 50 ppm GA_{4+7} + 50 ppm BA (T_8) and minimum (29.54 cm) growth index was recorded in control (T_1).
- Minimum days (151.47 days) were recorded for visible bud formation in plants treated with GA_3 @ 100 ppm (T_4) whereas maximum days were taken by (170.13 days) were observed in T_7 (BA @ 150 ppm).
- GA_3 @ 100 ppm (T_4) showed minimum (184.53) days taken for flowering whereas the maximum days (208.83) were recorded in T_7 (BA @ 150 ppm).
- Among all the treatments maximum number of inflorescences open at a time per plant were recorded in plants treated with GA_3 @ 100 ppm (4.13) which was at par with T_7 (4.07) and T_8 (3.93) whereas the minimum number of inflorescences (3.06) open at a time per plant were recorded in plants treated with 250 ppm GA_{4+7} + 250 ppm BA (T_{10}).
- Maximum inflorescence diameter (12.26 cm) was recorded in T_4 (GA_3 @ 100 ppm) and minimum inflorescence diameter (9.73 cm) was recorded in T_1 (Control).
- Shortest flower stalk (2.74 cm) was recorded in plants treated with BA @ 150 ppm (T_7) and longest flower stalk (3.77 cm) was recorded in T_4(GA_3 @ 100 ppm).
- The number of inflorescences per plant were maximum (7.20) in T_7 (BA @ 150 ppm. Whereas the minimum (4.40**)** number of inflorescences were recorded in T_1 (control).
- Duration of flowering were found maximum (86.82 days) in plants where application of BA @ 150 ppm was done (T_7) as compared to control (T_1) where minimum (65.19) duration of flowering was recorded.
- Among various treatments, the plants treated with 50 ppm GA_{4+7} + 50 ppm BA had the maximum (88.17) pot presentability score whereas minimum (73.92) pot presentability score was recorded in T_1 (Control).

- Longest vase life (13.67) was recorded with treatment BA @ 150 ppm whereas minimum vase life (8.93) was observed in T_1 (Control).
- The maximum cost benefit ratio (1.69:1) was observed in T_8 (GA_{4+7} @ 50 ppm + BA @ 50 ppm) with maximum net profit (Rs. 277.26 per pot).

CONCLUSION:

On the basis of these results revealed from the study it can be concluded that GA_{4+7} **@** 50 ppm + BA @ 50 ppm when applied three times at 15 days interval during the vegetative growth of plant had the maximum growth index and maximum pot presentability. Also, it significantly affected other parameters like plant height, plant spread, length of shoots, inflorescences per plant, flower stalk length and early flowering.

The plants treated with GA_3 @ 100 ppm had highest plant height, maximum length of shoots, minimum days taken for visible bud formation and flowering and maximum number of inflorescences open at a time per plant. However, the maximum plant spread, number of shoots, longest duration of flowering, maximum vase life was remarkably found best in plants treated with BA @ 150 ppm. Thus, from this it is concluded that hydrangea plants treated with GA_{4+7} @ 50 ppm + BA @ 50 ppm resulted in most desirable and presentable potted plants with maximum benefit cost ratio.

LITERATURE CITED

Aier S, Langthasa S, Hazarika D N, Gautam B P and Goswami R K. 2015. Influence of GA_3 and BA on morphological, phenological and yield attributes in gladiolus cv. Red Candyman. *Journal of Agriculture and Veterinary Sciences* **8**:37-42.

Alshakhaly Z M & Qrunfleh M M. 2019. Effect of plant growth regulators on flower development and quality of five *Cyclamen persicum* hybrids. *Acta Horticulturae* **1263**:215–22.

Albrecht M L and Tayama H K. 1992. *Tips on the use of chemical growth regulators on floriculture crops*. Columbus, Ohio: Ohio Florists' Association.

Andres F, Porri A, Torti S, Mateos J, Romera-Branchat M, Garcia-Martinez J L and Coupland G. 2014. Short vegetative phase reduces gibberellin biosynthesis at the Arabidopsis shoot apex to regulate the floral transition. *Proceedings of the National Academy of Science of the United States of America* **111**:2760-769.

Anuradha S, Gowda J V N and Sane A. 2010. Characterization of gerbera (*Gerbera jamesonii*) genotypes using morphological characters, *Plant Genetics Resources Newsletter* **128**:64-67.

Ashwani K and Chandra Sekhar R. 2017. Effect of Plant Growth Regulators on Vegetative Growth of Carnation (*Dianthus caryophyllus*) cv. 'Domingo' in second season crop. *Plant Archives* **2**:1113-116.

Asil M H, Roein Z and Abbasi J. 2011. Response of tuberose (*Polianthes tuberose* L.) to gibberellic acid and benzyladenine. *Horticulture, Environment and Biotechnology* 52:46.

Attiya H J, Naji D A and Askar H M. 2015. Effect of Plant growth regulators (IBA, BA and CCC) on some flowering characters of three hybrid lily cultivars (Lilium spp. L.). *Iraqi Journal of Science* **56**:3107-113.

Bailey D A 1992. Plant growth regulators labeled for floriculture use. North Carolina Flower Growers' Bulletin **37**:6-9.

Bailey D and Whipker B E. 1998. Best management practices for plant growth regulators used in floriculture. Horticulture Information Leaflet, North Carolina Cooperative Extension **529**:1-16.

Bailey L H and Bailey E Z. 1976. *Hydrangea. In: Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada*. MacMillan Publication, New York, pp.578–579.

Baker J A. 2001. *Plant Growth Regulators*. College of Agriculture and Life Sciences. N. C. State University. Raleigh, North Carolina **27**:695-60.

Bala M and Singh T. 2018. Effect of foliar spray of Benzyl adenine, Gibberellic acid and Putrescine on post-harvest keeping quality of chrysanthemum. *Agricultural Research Journal* **55**:386-88.

Baghele R D, Dhaduk B K, Chawla S L and Jadega R. 2014. Effect of growth regulators and cow urine on rose (*Rosa hybrida*) cv. Poison. *Bioinfolet* **11**:673-76.

Banker G J and Mukhopadhay. 1982. Gibberellic Acid Influences Growth and Flowering of Rose cv. "Queen Elizabeth". *Indian Journal of Horticulture* **39**:130-33.

Baskaran V, Abirami K and Roy S D. 2014. Effect of plant growth regulators on yield and quality in gladiolus under Bay Island conditions. *Journal of Horticulture Sciences* **9**:213-16.

Bhatt S T and Chauhan N M. 2012. Effect of GA_3 and BA on growth and flowering of Dendronium cv. "Sonia-17". *Asian Journal of Ornamental Horticulture* **7:**197-199.

Bhattarcharjee S K (2006). Flowering shrubs and seasonal ornamentals. In: *Advances in Ornamental Horticulture* (Volume 1). Pointer Publisher, Jaipur, India pp. 201-216.

Blanchard M G and Runkle E S. 2009. Benzyladenine Promotes Flowering in *Doritaenopsis* and *Phalaenopsis* Orchids. *Journal of Plant Growth Regulators* **27**:141.

Blazquez M A, Soowal L N, Lee I and Weigel D. 1997. LEAFY expression and flower initiation in *Arabidopsis*. *Development* **124**:3835-844.

Blom T J and Piott BD. 1992. Florists' hydrangea blueing with aluminum sulfate applications during forcing. *HortScience* **27**:1084–087.

Brian P V. 2008. Effects of Gibberellins on plant growth and development. *Biological Reviews* **34**:37-77.

Buban T. 2000. The use of benzyl adenine in orchard fruit growing: A mini review. *Plant Growth Regulation* **32**:381-90.

Cardoso J C, Ono E O and Rodrigues J D. 2012. Gibberellic acid in vegetative and reproductive development of Phalaenopsis orchid hybrid genus. *Horticultura Brasileira* **30**:71-74.

Carey D J, Fair B A, Buhler W, McCall I and Whipker B E. 2013. Growth control and flower promotion of Salvia (*Salvia nemorosa* L.) with benzyladenine foliar sprays. *Journal of Applied Horticulture* **15:**87-89.

Celikel F G, Dodge L L and Reid M S. 2002. Efficacy of 1-MCP and Promalin (GA_{4+7}+BA) for extending the post-harvest life of Oriental lilies (*Lilium* 'Mona Lisa' and 'Stargazer'). *Scientia Horticulturae* **93**:149- 55.

Chakradhar M. 2002. Effect of growth regulators on growth, flowering and vaselife of rose cv. 'Gladiator'. M.Sc. (Agriculture) Thesis. Dr. PDKV, Akola.57-59p.

Chandrappa. 2002. Evaluation and effect of media, biofertilizers and growth regulators on growth and flowering in anthuriums. PhD Thesis. University of Agricultural Sciences, Bangalore.175p.

Chang H, Jones M L, Banowezt M G and Clark D G. 2003. Over production of cytokinins in petunia flowers transformed with P_{SAG12} – IPT delays corolla senescence and decreases sensitivity to ethylene. Plant physiology **132**:2174-183.

Chaudhari S R. 2001. Influence of plant growth regulators on growth, flowering and quality of rose (*Rosa hybrida* L.) cv. 'Gladiator'. M.Sc. Thesis. Department of Floriculture, Gujrat Agriculture University, Navsari 49-55p.

Chen X H, Xia X J, Guo X, Zhou Y H, Shi K, Zhou J & Yu J Q. 2016. Apoplastic H_2O_2 plays a critical role in axillary bud outgrowth by altering auxin and cytokinin homeostasis in tomato plants. *New Phytologist* **211**:1266-278.

Cody C A, Larsen F E and Fritts R. 1985. Stimulation of lateral branch development in tree fruit nursery stock with promalin (GA_{4+7} + BA). *HortScience* **20**:758-59.

Conover C A. 1986. Quality. *Acta Horticulturae* **181**:201-05.

Dahab A M A, Eldabh R S and Salam M A. 1987. Effect of gibberellic acid on growth, flowering and constituents of *Chrysanthemum fructescense*. *Acta Horticulturae* ***2*05**:125-129.

Diana R and Fulcher A. 2013. Type and rate of plant growth regulator influence vegetative, floral growth and quality of Little Lime Hydrangea. *HortTechnology* **3**:306-311.

Dicks J W, Gilford J M and Rees A R. 2003. The influence of timing of application and gibberellic acid on the effects of ancymidol on growth and flowering of mid- century hybrid lily cv. 'Enchantment'. *Scientia Horticulturae* **2**:153-63.

Dirr M A. 2012. *Hydrangeas: Breeding, selection and marketing*. Plant Introductions, Athens, GA.

Dhaduk B K, Kumara S, Singh A and Desai J R. 2007. Response of gibberellic acid on growth and flowering attributes in anthurium (*Anthurium andreanum* Lind.). *Journal of Ornamental Horticulture* **10**:187-89.

Dogra S, Pandey R K and Bhatt D J. 2012. Influence of gibberellic acid and plant geometry on growth flowering production in gerbera under Jammu agroclimate. *International Journal of Pharma and Bio Sciences* **3**:1083-090.

Dun E A, Germain A S, Rameau C and Beveridge C A. 2012. Antagonistic action of strigo lactone and cytokinin in bud outgrowth control. *Plant Physiology* **158**:487–98.

Dutta J P and Ramadas S. 1998. Growth and flowering of chrysanthemum (*Dendranthema grandiflora*) to growth regulators treatments. *Orissa Journal of Horticulture* **26**:70-75.

Duran E C. 1999. Hydrangeaceae Flora de Veracruz. *Japanese Journal of Soil Plant Nutrient* **24**:22-33.

Eid R A, Khalifa R K M and Shaaban S H A. 2010. Effect of foliar application of zinc and benzyl adenine on growth, yield and chemical constituent of tuberose plants. *Research Journal of Agriculture and Biological Sciences* **6**:732-43.

Emongor F, Meulenberg P and Pholes O. 2004. Effect of promalin on growth and development of kale (*Brassica oleracea* L. var. Acephala DC). *Journal of Agronomy* **3**:208-14.

Eshed Y and Lippman Z B. 2019. Revolutions in agriculture chart a course for targeted breeding of old and new crops. *Science* **10**:1-14.

Farag G, Mahmoud K and Naggar A E. 2018. Effect of Benzyl adenine and Gibberellic acid on the vegetative growth and flowering of chrysanthemum plant. *Alexandria Journal of Agricultural Sciences* **63**:29-40.

Foley J T and Keever G J. 1992. Chemical promotion of axillary shoot development of geranium stock plants. *Journal of Environment Horticulture* **10**:90-94.

Foley J T and Keever G J. 1993. Chemically Induced Branching of Vinca minor. *Journal of Environment Horticulture* **11**:149-52.

Fujii Y and Sasaki S. 2000. *Effect of plant growth regulators on sprouting of non- branching type chrysanthemum (Dendranthema grandii)*. Bulletin of the Nara Agriculture Experiment Station **31**:42-43.

Gianfagna T J and Merritt R H. 1998. $GA_{4/7}$ promotes stem growth and flowering in genetic line of *Aquilegia x hybrida* Sims. *Plant Growth Regulation* **24**:1-5.

Gilman E F. 1999. *Hydrangea macrophylla*. University of Florida, Cooperation Extension Service, Fact Sheet, 258p.

Gomez K A and Gomez A A. 1984. *Statistical procedure for Agricultural Research*. 2nd ed. Jhon Wiley and Sons Inc, New York.680p.

Gupta V N and Datta S K. 2001. Influence of gibberellic acid (GA_3) on growth and flowering in chrysanthemum (*Chrysanthemum morifolium*, Ramat) cv. 'Jayanti'. *Indian Journal of plant Physiology* **6**:420-22.

Grzesik M and Rudnicki R M. 1985. The use of growth regulators in nursery production of woody ornamental plants-II. The effect of growth regulators on branching of some woody ornamental plants. *Acta Horticulturae* **167:**417-22.

Grossman M, Freeborn J, Scoggins H and Latimer. 2014. Effect of application of benzyl adenine on the branching and growth of herbaceous perennial liners. *Acta Horticulture* **1049**:237-42.

Hartmann H T, Kester D E, Davies F T and Geneve R L. 2002. *Plant propagation: Principles and practices*. 7th Ed. Pearson Education, Upper Saddle River, NJ.

Henschke M, Czuchaj P K and Szczepaniak S J. 2015. The effect of benzyladenine and gibberellic acid on growth and flowering of *Helloborus orientalis* Lam. *Bulgarian Journal of Agricultural Sciences* **21**:1198-203.

Hernandez P. 1997. Morphogenesis in sunflower as affected by exogenous application of plant growth regulators. *AgriScientia* **13**:3–11.

Holkar P S, Chandrashekar S Y, Kumar P H, Basavalingaiah and Ganapathi M. 2018. Effect of Benzyl Adenine and Gibberellic Acid on flowering and flower quality attributes of gladiolus. *International Journal of Current Microbiology and Applied Sciences* **7**:944-50.

Ibrahim S M M, Taha L S and Farahat M M. 2010. Vegetative growth and chemical constituents of croton plants as affected by foliar application of benzyl adenine and gibberellic acid. *Journal of USA Sciences* **6**:126-30.

Jana B K and Biswas S C. 1979. Effect of growth substances on growth and flowering of tuberose *Polianthus tuberosa* L. *Haryana Journal of Horticulture Science* **8**:216-19.

Jessica A. 2008. Why my Hydrangeas not flowering? Bay landscaping news. Perennials plant care, Published on 15 September.

Jayshree N, Chandrashekar S Y, Hemla Naik B, Hanumantharaya L and Ganapathi M. 2020. Influence of benzyl adenine and gibberellic acid on morphological behavior of Asiatic lily. *International Journal of Chemical Studies* **8**:2028-031.

Jasinski S, Piazza P, Craft J, Hay A, Woolley L, Rieu I and Tsiantis M. 2005. KNOX action in Arabidopsis is mediated by coordinate regulation of cytokine and gibberellin activities. *Current Biology* **15:**1560-565.

Joustra M K. 1989. Application of growth regulators to ornamental shrubs for use as interior decoration. *Acta Horticulturae* **251**:359–70.

Kapri M, Singh A K, Sisodia A and Padhi M. 2018. Influence of GA_3 and BA (Benzyladenine) on flowering and post-harvest parameters in lily. *Journal of Pharmacognosy and Phytochemistry* **7**:1916-918.

Kanwar J and Khandelwal S K. 2013. Effect of plant growth regulators of growth and yield African marigold (*Tagetes erecta* L.). *Madras Agriculture Journal* **100**:45-47.

Kalaimani M, Sathappan C T, Kaandasamy R and Singaravel R. 2017. Article investigation of different levels plant growth regulators and pinching treatments on flowering and yield parameters of African marigold (*Tagetes erecta* L.). *Chemical Science Review and Letters* **6**:741-45.

Kim H J and Miller W B. 2008. Effects of GA_{4+7} and benzyladenine application on postproduction quality of 'Seadov' pot tulip flowers. *Postharvest Biology and Technology* **47:**416–21.

Kim J H, Lee A K and Suh J K. 2005. Effect of certain pre-treatment substances on vase life and physiological character in *Lilium* spp. *Acta Horticulturae* **673**:307–14.

Koen T B, Jones K M and Oakford M J. 1989. Promoting branching in young trees of apple cv. Red Delicious using growth regulators. *Journal of Horticultural Science* **64**:521-25.

Kohl H C and Kofranek A M. 1957. Gibberellin on flower crops: Studies made of response of some commercially grown flowers to applications of plant growth regulating chemical compound. California Agriculture, May.

Kumar V, Kumar V, Umrao V and Singh M. 2012. Effect of GA_3 and IAA on growth and flowering of carnation. *HortFlora Research Spectrum* **1**:69-72.

Kumari S, Kumar S and Singh C P. 2018. Effect of pre harvest sprays of hormones on spike quality and vase life of Asiatic lilium cv. 'Tresor'. *The Pharma Innovation Journal* **7**:470-73.

Litlere B, Stromme E. 1975. The influence of temperature, daylength and light intensity of flowering in *Hydrangea macrophylla* (Thunb.). *Symposium on Protected Cultivation of Flowers and Vegetables* **51**:285-98.

Maheshwari T U and Sivasanjeevi K. 2019. Response of tubersose (*Polianthes tuberosa* L.) cv. Single to plant growth regulators. *Annals of Plant and Soil Research* **21**:48-50.

Markovic S J and James E K. 2021. Influencing stock production of Mojave sage and Cape daisy with the application of plant growth regulators. *HortScience* **31**:192-96.

McClintock E. 1957. A monograph of the genus hydrangea. *Proceedings of the California Academy of Sciences* **14**:147-255.

Mishra S K, Mishra A and Bahadur V. 2019. Effect of growth regulators on growth, yield and shelf life in amaryllis lily (*Amaryllis belladona*) cv. Zephyranthes. *Journal of Pharmacognosy and Phytochemistry* **8**:1217-219.

Moe R, Funnell K A, Whitman C M and Heins R D. 2001. GA $_{4+7}$ +BA reduce foliar chlorosis of *Lilium longiflorum. Scientia Horticulturae* **89**:143-54.

Mondal S and Sarkar M M. 2017. Influence of plant growth regulators on growth, flowering and yield characteristics of hybrid Tea Roses cv. "Bugatti" during spring-summer months. *Advances in Research* **12**:1-7.

Moore G M. 1984. Mechanisms of hormone action in plants. *Proceedings of International Plant Propagators Society* **34**:79-90.

Muhammad S, Noorul A, Habib A and Khalid K. 2016. Effect of gibberellic acid on enhancing flowering time in *Chrysanthemum morifolium*. *Pakistan Journal of Botany* **48**:477-83.

Munk W J and Gijzenberg. 1977. Flower bud blasting in tulip plants mediated by the hormonal status of the plant. *Scientia Horticulturae* **7:**255-68.

Nambiar A, Siang T C and Mahmood M. 2012. Effect of BAP on flowering of Dendrobium orchid. *Australian journal of crop sciences* **6**:225-31.

Nagarjuna B, Reddy V P, Rao M R and Reddy E N. 1988. Effect of growth regulators and potassium nitrate on growth, flowering and yield of chrysanthemum *(Chrysanthemum indicum* L.*). South Indian Horticulture* **36**:136-40.

Newton L A and Runkle E S. 2015. Effect of benzyl adenine on vegetative growth and flowering of potted Miltoniopsis orchids. *Acta Horticulture* **1078**:121-28.

Nishijima T M, Hideari M, Sasaki K and Okazawa T. 2006. Cultivar and anatomical analysis of corolla enlargement of petunia (*Petunia hybrida* Vilm.) by cytokinin application. *Scientia Horticulturae* **111:**49-55.

Ohkawa K. 1979. Effect of gibberellins and benzyl adenine on dormancy and flowering of *Lilium speciosum*. *Scientia Horticulturae* **10**:255-60.

Olwell A and Andrew P K. 1992. Improving the lateral branching of Fuji/ M9 nursery trees. In: *Proceedings of Washington Horticultural Society* **88**:278-80.

Padhye S, Runkle E, Olrich M and Reinbold L. 2008. Crop cultivation: Improving Branching and Postharvest Quality. Greenhouse Production News

Patil S J. 2001. Effect of plant growth regulators on growth, flowering and quality of gerbera (*Gerbera jamesonii* Hook.) cv. 'Sangria' under South Gujrat conditions. M.Sc. Thesis. Department of Floriculture and Landscaping, Gujrat Agriculture University, Navsari. 36-38p.

Patel H, Singh A, Patel N B, Bhandari A J and Shah H P. 2020. Effect of foliar spray of plant growth regulators on growth of potted hibiscus. *International Journal of Chemical Studies*. **8**:119-22.

Parmar A B, Patel H C, Chavd J C and Parma J R. 2009. Effect of plant growth regulators on growth and flowering of spider lily (*Hymenocallis speciosa* L.). *The Asian Journal of Horticulturae* **4**:170-72.

Patra S K, Beura S and Shasani T. 2015. Efficacy of GA_3 on growth and flowering regulation of in vitro raised hybrid gerbera under shade net. *Agricultural Science Digest* **35**:173-77.

Palei S, Das A K and Dash D K. 2016. Effect of plant growth regulators on growth, flowering and yield attributes of African marigold (*Tagetes erecta* L.). *International Education and Research Journal* **6**:44-52.

Poneidzialek W and Porebski S. 1992. Effect of feathering of apple trees in the nursery on their growth and cropping in the orchard. Scientific papers of the Agricultural University in Krakow Rolnictwo, Poland. 59p.

Prakash V and Jha K K. 1998. Effect of GA_3 on the floral parameters of gladiolus cultivars. *Journal of Applied Biology* **8**:24-28.

Preece J E and Read P E. 1993. *The Biology of Horticulture: An Introductory Textbook.* Wiley, New York.

Rakesh R S and Beniwal B S. 2003. Effect of GA_3 and pinching on the growth and yield of chrysanthemum. *Haryana Journal of Horticultural Sciences*. **32**:61-63.

Rana P, Kumar J and Kumar M. 2005. Response of GA_3, plant spacing and planting depth on growth, flowering and corm production in gladiolus. *Journal of Ornamental Horticulture* **8**:41-44.

Ranwala A P and Miller W B. 1998. Gibberellin$_{4+7}$, benzyladenine and supplemental light improve postharvest leaf and flower quality of cold stored 'Stargazer' hybrid lilies. *Journal of American Society of Horticultural Science* **123**:563-68.

Ranwala A P and Miller W B. 1999. Timing of Gibberellin$_{4+7}$ +Benzyladenine sprays influences efficacy against foliar chlorosis and plant height in Easter Lily. *HortScience* **34**:902-03.

Richardson D and Wilkinson R I. 1984. Effect of manual pinching, potting- on and cytokinins on branching and flowering of Camellia, Rhododendron and Rosa. *Scientia Horticulturae* **23**:75-83.

Rufato L, Marchioretto L R, Orlandi J C, Michelon M F, Rossi A, Sander G F and Macedo T A. 2019. Lateral branch induction at nursery with growth regulators in 'Maxi Gala' apple trees grafted on four rootstocks. *Scientia Horticulturae* **253**:349-57.

Salisbury F B and Ross C W. 1992. *Plant Physiology*. 4th ed. Belmont, Company. pp. 682.

Sebanek J. 1976. On the Role of Exogenous Gibberellin and Cytokinin in the Correlation Between the Leaf and its Axillary Bud in Hortensia (*Hydrangea opuloides* C. KOCH). *Biologia Plantarum* **18**:307-10.

Sharifuzzaman S M, Ara K A, Rahman M H, Kabir K and Talukdar M B. 2011. Effect of GA_3, CCC and MH on vegetative growth, flower yield and quality of chrysanthemum. *International Journal of Experimental Agriculture* **2**:17-20.

Shinde K H, Parekh N S, Upadhyay N V and Patel H C. 2010. Investigation of different levels of gibberellic acid (GA_3) and pinching treatments on growth, flowering and yield of chrysanthemum (*Chrysanthemum morifolium* R.) cv. 'IIHR-6' under middle Gujrat conditions. *Asian Journal of Horticulture* **5**:416-19.

Shrestha B, Karki A and Shrestha J. 2020. Effect of foliar application of gibberellic acid (GA_3) on quality attributes of Calendula flowers (*Callendula officinalis* L.) cv. 'Gitana Fiesta' in Chitwan, Nepal. *Journal of Agricultural Sciences and Practice* **5**:168-73.

Sijo J, Sankar M, Sreelatha U, Kumar K A and Deepthy K B. 2020. Morphological and floral characters of rose as influenced by growing media and growth regulators. *Journal of Tropical Agriculture* **1**:58.

Soad M M I, Lobna S, Taha and Farahat M M. 2010. Vegetative growth and chemical constituents of croton plants as affected by foliar application of benzyl adenine and gibberellic acid. *Journal of American Sciences* **6**:126-30.

Sudhakar M and Kumar S R. 2012. Effect of growth regulators on growth, flowering and corms production pf gladiolus cv. White Friendship. *Indian Journal of Plant Sciences* **1:**133-36.

Sujatha A N, Singh V and Sharma T V R S. 2002. Effect of plant growth regulators and quality of gerbera under by island conditions. *Indian Journal of Horticulture* **59**:100-05.

Sumalatha A. 2017. Assessment of gibberellic acid treatment on vegetative, floral and bulb characteristics of Asiatic Lilium (*Lilium longifolium* L.) cv. Menorca. M.Sc. Thesis. Department of Horticulture (Floriculture and Landscaping), GB Pant University of Agriculture & Technology.101-103p.

Shudo K. 1994. *Chemistry of Phenylurea cytokinins*. In Mokk DV and Mok MC (Ed) Cytokinins: Chemistry, activity and function, CRC Press, Boca Raton pp.35-42.

Suresh K S. 2008. Effect of plant growth regulators on growth, flowering, yield and vase life of rose cv. Gladiator. M.Sc. Thesis. Department of Horticulture, Marathwada Agriculture University, Parbhani.54- 55p.

Talukdar M and Paswan L. 1996. Growth and flowering of chrysanthemum (*Dendranthema grandiflora*) cv. 'Prot Harris' as influenced by growth regulators. *Horticultural Journal* **9**:155-58.

Takeda K, Kariuda M and Itoi H. 1985. Blueing of sepal color of *Hydrangea macrophylla*. *Phytochemistry* **24**:2251-254.

Treder J, Grzeskiewicz HW, Podwyszynska M and Hempel M. 1989. Effect of cytokinin (BAP) and pinching on growth and flowering of pot roses. http://www.cbr.edu.pl/eng/index.php

Vasudevan V and Kannan M. 2015. Effect of bending and plant growth regulators on maximizing the yield and quality of rose (*Rosa hybrida* var. Tajmahal) under greenhouse conditions. *Progressive Horticulture* **47**:275-79.

Verma V K and Parmar Y S. 2003. Response of foliar application of nitrogen and gibberellic acid on growth and flowering of carnation (*Dianthus caryophyllus* L.) *Himachal Journal of Agriculture Research* **29**:59-64.

Van Gelderen C J and Van Gelderen D M. 2004. *Encyclopedia of Hydrangeas*. Timber Press, Portland, Orgeon.

Whitman C M, Heins R D, Moe R and Funnell K A. 2001. GA_{4+7} +BA reduce chlorosis of *Lilium longiflorum. Scientia Horticulturae* **89**:143-54.

Weiler T C. 1980. Hydrangeas In: Larson R A (ed.) Introduction to Floriculture, Academic Press, New York pp 345-75.

Yawale A K, Belorkar P V, Bhattacharya J, Chanekar M A and Chimurkar B S. 1998. Effect of paclobutrazol on thickness of stem, flower diameter, fresh weight and dry weight of aerial portion of chrysanthemum. *Journal of Soils Crops* **8**:73-75.

Yogendra R. 2021. Responses of different plant growth regulators on growth and flowering of calendula (*Calendula officinalis* L.) cv. 'Bon Bon Yellow' under Raipur condition. M.Sc. Thesis. Department of Floriculture and Landscape Architecture. Indira Gandhi Krishi Vishwavidyalaya Raipur, Chhattisgarh.64p.

Yasuda T, Khanthavong P, Soisouvanh P and Phongchanmixay S. 2020. Field phenotyping of plant height in an upland rice field in Loas using low-cost small unmannered aerial vehicles (UAVs). *Agronomy & Crop Ecology* **4**:452-65.

Zhang L, Shen C, Wei J and Han W. 2018. Effects of exogenous 6-Benzyladenine on dwarfing, shoot branching and yield of tea plant *(Camellia sinensis). HortScience* **53**:651-55.

APPENDIX I

Monthly Average Meteorological data of the experimental area during the research period August 2021- June 2022

Month	Temperature (°C)		Rainfall (mm)	Relative humidity (%)
	Minimum	Maximum		
August, 2021	17	26	180.8	78
September, 2021	16	27	49.5	83
October, 2021	13	27	9.5	59
November, 2021	8	20	0	42
December, 2021	6	18	3.4	39
January, 2022	5	18	51.2	62
February, 2022	7	21	18.7	58
March, 2022	10	25	0.3	32
April, 2022	11	27	1.2	21
May, 2022	14	27	11	30
June, 2022	18	29	15	35

Source: National Centres for Environmental Predictions (NCEP) and World Meteorological Organization.

APPENDIX II

Physico-Chemical properties and available nutrient in growing media at the time of planting

Parameter	Quantity
pH	6.13
EC dS m^{-1}	0.14
Organic Carbon (%)	0.21
N (kg ha^{-1})	508
P (kg ha^{-1})	30.2
K (kg ha^{-1})	214

APPENDIX III

Analysis of variance for characters under study as influenced by growth regulator on *Hydrangea macrophylla*

Source of variation	Characters Mean sum of squares (MSS)					
	df	Plant height (cm)	Plant spread (cm)	Number of shoots	Length of shoots (cm)	Growth Index (cm)
Treatment	9	37.05	24.85	9.17	52.72	12.71
Error	20	0.45	1.11	0.11	0.53	0.52
Total	29					

Source of variation	Characters Mean sum of squares (MSS)				
	df	Number of days taken for visible bud formation	Number of days taken for flowering	Maximum number of inflorescences open at a time per plant	Inflorescence diameter (cm)
Treatment	9	112.45	186.10	0.47	1.52
Error	20	1.69	0.816	0.06	0.58
Total	29				

Source of variation	Characters Mean sum of squares (MSS)					
	df	Length of flower stalk (cm)	Number of inflorescences per plant	Duration of flowering (days)	Pot presentability	Vase life (days)
Treatment	9	0.26	1.85	68.97	74.48	6.66
Error	20	0.01	0.06	2.97	0.16	0.14
Total	29					

APPENDIX IV

A. Cost of production of potted *Hydrangea macrophylla*

S.No.	**Particulars**	**Price (Rs)**
1	Pine wood soil	15.00 per kg
2	FYM	2.00 per kg
3	Sand	2.00 per kg
4	Pine needle leaf Mould	15.00 per kg
5	Shredded pine tree bark	15.00 per kg
6	Rooted cuttings of hydrangea	10.00 per cutting
7	Cost of black plastic pots (8 inches)	80.00 per pot
8	Labour charges (Rs 350/ day)	20.00 per pot
9	Gibberellic acid (GA_3)	160.00 per 1g
10	Benzyl adenine (BA)	128.00 per 1g
11	GA_{4+7}+BA	1100.00 per 1g

B. Details of the cost of production of *Hydrangea macrophylla* per flowering *pot*

	Particulars	**T_1 (control)**	**T_2**	**T_3**	**T_4**	**T_5**
1	Cost of growing media	24.5	24.5	24.5	24.5	24.5
2	Cost of rooted cuttings of hydrangea	10.00	10.00	10.00	10.00	10.00
3	Cost of pots	80.00	80.00	80.00	80.00	80.00
4	Cost of nutrients and plant protection	5.00	5.00	5.00	5.00	5.00
5	Cost of labour/ maintenance	20.00	20.00	20.00	20.00	20.00
6	Cost of plant growth regulators per pot	0.00	0.53	1.06	2.13	0.85
7	Miscellaneous charges	20.00	20.00	20.00	20.00	20.00
	Total expenditure per pot	159.50	160.03	160.56	160.63	160.35
*	**Market price of potted hydrangea**	369.60	397.50	408.15	418.15	404.15
	Net profit per pot	210.10	237.47	247.59	257.52	243.80
	Benefit-Cost ratio	1.31:1	1.47: 1	1.54:1	1.60:1	1.52:1

	Particulars	T_6	T_7	T_8	T_9	T_{10}
1	Cost of growing media	24.5	24.5	24.5	24.5	24.5
2	Cost of rooted cuttings of hydrangea	10.00	10.00	10.00	10.00	10.00
3	Cost of pots	80.00	80.00	80.00	80.00	80.00
4	Cost of nutrients and plant protection	5.00	5.00	5.00	5.00	5.00
5	Cost of labour/ maintenance	20.00	20.00	20.00	20.00	20.00
6	Cost of plant growth regulators per pot	1.70	2.56	4.09	12.28	20.4
7	Miscellaneous charges	20.00	20.00	20.00	20.00	20.00
	Total expenditure per pot	161.20	162.06	163.59	171.78	179.9
*	**Market price of potted hydrangea**	413.80	431.00	440.85	423.20	405.65
	Net profit per pot	252.60	268.94	277.26	251.42	225.75
	Benefit-Cost ratio	1.55:1	1.65:1	1.69:1	1.46:1	1.25:1

D. Total expenditure, Net Profit and Benefit-Cost Ratio of *Hydrangea macrophylla* per pot

	Treatments	Total expenditure (Rs.)	Market Price (Rs.)	Net profit (Rs.)	B:C ratio
1	Control	159.50	369.60	210.10	1.31:1
2	GA_3-25ppm	160.03	397.50	237.47	1.47: 1
3	GA_3-50ppm	160.56	408.15	247.59	1.54:1
4	GA_3-100ppm	160.63	418.15	257.52	1.60:1
5	BA-50ppm	160.35	404.15	243.80	1.52:1
6	BA-100ppm	161.20	413.80	252.60	1.55:1
7	BA-150ppm	162.06	431.00	262.94	1.65:1
8	50ppm GA_{4+7} + 50ppm BA	163.59	440.85	277.26	1.69:1
9	150ppm GA_{4+7}+ 150ppm BA	171.78	423.20	251.42	1.46:1
10	250ppm GA_{4+7} + 250ppm BA	179.9	405.65	225.75	1.25:1

*****The market price of the individual flowering pot plant, was calculated treatment wise, according to the pot presentability score of pots under different treatments. The price of the pot was decided by the advisor's guidance and with comparing with the present market value of single pink hydrangea pots.

$$\textbf{Sale price per pot (Rs)} = \frac{\textbf{Presentability score x Rs 500.00}}{\textbf{100}}$$

Department of Floriculture and Landscape Architecture
Dr. Yashwant Singh Parmar University of Horticulture and Forestry
Nauni, Solan-173230 (HP), India

Title of thesis	:	**"Growth regulator studies in mop head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering"**
Name of Student	:	Rupali Thakur
Admission number	:	H-2020-23-M
Major Discipline	:	Floriculture and Landscape Architecture
Minor Discipline	:	i) Plant Physiology ii) Soil Science and Water Management
Date of Thesis Submission	:	
Total Pages of the Thesis	:	67 + vi
Major Advisor	:	Dr. Rajesh Thakur

ABSTRACT

The present investigation entitled "Growth regulator studies in mop head hydrangea (*Hydrangea macrophylla*) for improved vigour and flowering" was carried out at Horticultural Research & Training Station and Krishi Vigyan Kendra at Kandaghat, Solan. The experiment was conducted under naturally ventilated polyhouse of 105x7x3.5 m^2. The experiment was laid out in Completely Randomized Design (CRD) having 10 treatments replicated thrice. Uniformly developed one and half years old stock plants were planted in 8 inches pot having growing media consisting of pine wood soil, FYM, sand, pine needle leaf mould and shredded pine tree bark (2:1:1:1:1 v/v). The treatments comprised of different concentration of plant growth regulators i.e., GA_3 (25 ppm, 50 ppm and 100 ppm), BA (50 ppm, 100 ppm and 150 ppm) and GA_{4+7} + BA (50 ppm, 150 ppm and 250 ppm). The observations recorded during the investigation were plant height (cm), plant spread (cm), length of shoots (cm), number of shoots, number for days taken for visible bud formation, number of days taken for flowering, number of inflorescences, inflorescence diameter (cm), maximum number of inflorescences open at a time, flower stalk length (cm), growth index (cm), pot presentability, duration of flowering (days) and vase life (days). From the data recorded during the investigation it was revealed that among different treatments the plants treated with GA_3 @ 100 ppm had maximum plant height (39.60 cm), maximum length of shoots (27.51 cm), minimum days taken for visible bud formation (151.47 days), minimum days for flowering (184.53 days) and maximum number of inflorescences open at a time per plant (4.13). Whereas, maximum pot presentability (88.17), growth index (35.81 cm) and maximum benefit cost ratio was recorded in plant with application of GA_{4+7} @ 50 ppm +BA @ 50 ppm. However, the maximum plant spread (35.43 cm), number of shoots (12.15), maximum number of inflorescences (7.20), minimum length of flower stalk (2.74 cm), longest duration of flowering (86.82 days), maximum vase life (13.67) was found best in plants treated with BA @ 150 ppm. From this, it is concluded that hydrangea plants treated with GA_{4+7} @ 50 ppm +BA @ 50 ppm resulted in most desirable and presentable potted plants with greater benefit cost ratio.

Signature of student
(Rupali Thakur)

Signature of Major Advisor
(Dr. Rajesh Thakur)

Countersigned

Professor and Head
(Department of Floriculture and Landscape Architecture)

BRIEF BIO-DATA

Name	**:**	Rupali Thakur
Father's Name	**:**	Mr. Neelamjeet Thakur
Mother's Name	**:**	Mrs. Champa Thakur
Date of Birth	**:**	28.02.1997
Gender	**:**	Female
Marital status	**:**	Unmarried
Permanent Address	**:**	Village Seriberh PO Khokhan, Tehsil Bhunter, District Kullu, Himachal Pradesh (175125)

Educational Qualifications:

Examination Passed	Year of passing	School/University	Board/ University	Marks	Division
10th Class	2013	Holy Angels School, Shamshi, Distt. Kullu (HP)	CBSE	10/10 (CGPA)	First
12th Class	2015	Arunodaya Senior Secondary School, Mohal, Distt. Kullu (HP)	HPBSE	441/500	First
B. Sc. Horticulture (Hons.)	2020	Dr Y.S. Parmar UHF, Nauni, Solan (HP)	Dr Y.S. Parmar UHF, Nauni, Solan (HP)	8.13/10 (OGPA)	First

Whether sponsored by some state/ Central Govt./Univ./SAARC : NA

Scholarship/ Stipend/ Fellowship/Any other financial assistance received during the study period : University stipend

Rupali Thakur