EFFECTS OF GIBBERELLIC ACID AND BENZYL ADENINE ON GROWTH AND YIELD OF BROCCOLI (*Brassica oleracea* var. italica)

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EFFECTS OF GIBBERELLIC ACID AND BENZYL ADENINE ON GROWTH AND YIELD OF BROCCOLI (*Brassica oleracea* var. italica)

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A Thesis Submitted to the Post-Graduate Committee of the Yezin Agricultural University in Partial Fulfillment of the Requirements for the Degree of Master of Agricultural Science

Department of Horticulture and Agricultural Biotechnology
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The thesis attached hereto, entitled "**Effects of Gibberellic Acid and Benzyl Adenine on Growth and Yield of Broccoli (*Brassica oleracea* var. italica)**" was prepared under the direction of the chairperson of the candidate's Supervisory Committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **MASTER OF AGRICULTURAL SCIENCE (HORTICULTURE).**

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DECLARATION OF ORIGINALITY

This thesis represents the original works of the author, except where otherwise stated. It has not been submitted previously for a degree at any University.

Tuan Cung

Date __________________

DEDICATED TO MY BELOVED PARENTS,

U AL CI AND DAW DAWT HNEM

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ABSTRACT

Plant growth regulators (PGRs) have a great influence on plant growth, development and yield. To determine the effects of sole gibberellic acid (GA_3), and the combination effects of gibberellic acid and benzyl adenine (BA) on plant growth and yield of broccoli, two experiments were conducted from October 2012 to February 2014. First experiment was carried out in two locations: Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University (YAU), Zayyarthiri township and Nwe Yit village (NY), Tatkone township, Nay Pyi Taw. In experiment I (IA and IB), six concentrations of GA_3: 0, 10, 20, 30, 40, 50 mg. L^{-1} were used and they were arranged in a Randomized Complete Block (RCB) design with four replications. In experiment II, eight concentrations of GA_3 and BA (30+10, 30+20, 30+30, 30+40, 40+10, 40+20, 40+30, 40+40 mg. L^{-1}) were applied and they were arranged in RCB design with three replications. In both experiments, twenty eight days old seedlings were used and their roots were soaked in specific concentrations of selected PGRs for 24 hrs. The growth data were collected weekly in both experiments.

It was observed that GA_3 shortened the number of days required to initiate curd formation, but increased plant height, leaf length, leaf width, number of leaves, curd weight and curd yield. GA_3 30, 40 and 50 mg. L^{-1} gave better curd weight, curd yield and produced earlier curd formation in both locations. Curd weight and curd yield were higher in NY (416 g and 50.33 t ha^{-1}) than that of YAU (409.42 g and 49.5 t ha^{-1}). Curd formation was also earlier in NY (39.33 days) than in YAU (40.19 days).

Combined application of GA_3 and BA did not show remarkable difference on both growth parameters and yield parameters. However, combined application of GA_3 and BA (40 + 10 mg. L^{-1}) resulted in better curd weight and curd yield (443.67 g and 53.64 t ha^{-1}). The results revealed that the application of GA_3 alone or in combination with BA increases crop yield of broccoli.

Key words: *Brassica oleracea*, gibberellic acid, benzyl adenine, main curd, secondary curd, earliness

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1. INTRODUCTION

Broccoli (*Brassica oleracea* var. italica) belongs to the family Brassicaceae. It is an important winter season vegetable crop, which resembles cauliflower. Broccoli is an Italian word from the Latin *brachium*, meaning an arm or branch. Broccoli is an Italian vegetable, native to the Mediterranean region, cultivated in Italy in ancient in Roman times and about 1750 in England. World production of broccoli is 19,107,751 tones (FAO 2008).

The plants form a kind of head consisting of green buds and thick fleshy flower stalk. The terminal head is rather loose, green in color and the flower stalks are longer than cauliflower (Bose et al. 2002). Curd initiation requires the development of 14 leaves, seven of which are visible to the naked eye. Broccoli grows best in the cooler season and prefers temperature between 65 and 75 °F. Period of warm weather delays flower initiation and leads to greater number of leaves. Broccoli requires vernalization for flower initiation. Lower or higher temperatures result in the need for a longer vernalization period. Nowadays, broccoli attracted more attention due to its multifarious use and great nutritional value (Salunkhe and Kadam 1998, Talalay and Fahey 2001, Rangkadilok et al. 2002, 2004).

Broccoli is an important vegetable crop and has high nutritional and good commercial value (Yoldas et al. 2008). It is low in sodium food, fat free and calories, high in vitamin C and good source of vitamin A, vitamin B2 and calcium (Decoteau 2000). Broccoli has about 130 times more vitamin A contents than cauliflower and 22 times more than cabbage (Singh 2007). Also, broccoli has been shown to be effective in protecting against some cancers (Yoldas 2003, Yoldas and Esiyok 2004). Because of their sulphorathane content which is associated with the reduction of active oxygen in tissues, broccoli provide the protection from cancer and coronary diseases.

In recent years, a great deal of research work has been reported on the use of plant growth regulators in vegetable crops. Plant growth regulators modify the physiological processes within the plant, which ultimately affect the yield and quality of the crop. Among plant growth regulators, GA_3 and Kinetin (cytokinins) exhibited beneficial effect in several cole crops (Chhonkar and Singh 1963, Badawi and Sahhar 1978).

Gibberellins (GAs) play an essential role in many aspects of plant growth and development, such as seed germination (Haba et al. 1985, Khafagi et al. 1986, Kumar and Neelakandan 1992 and Maske et al. 1997), stem elongation and flower development (Yamaguchi and Kamiya 2000). Wang and Yang (2008) reported that the inflorescence differentiation and curd yield of broccoli were increased. Chauhan and Tandel (2009) reported that application of GA_3 increased the ascorbic content of cabbage.

Cytokinins occur as free molecules in plants, but are also found in the t-RNAs of the cytoplasm and chloroplast. Cytokinins produce various effects when applied to intact plants. They particularly stimulate protein synthesis and participate in cell cycle control. Cytokinins was mainly applied for the incitation of cell division, delay of senesce and cell enlargement. In whole plants, roots appear to be major sites of natural cytokinin biosynthesis, but some production does take place in other actively growing tissues (Van Staden and Davey 1979, Chen et al. 1985). The root apex, and particularly the cells of its ‘quiescent centre’, could be important sites of synthesis (Short and Torrey 1972, Torrey 1972). Cytokinins produced in roots of plants are normally transported in the xylem to other regions. Synthetic cytokinins most commonly used are the compounds kinetin and benzylaminopurine (BA). Wang et al. (2009) also studied the effect of different concentrations of cytokinin on broccoli and found that cytokinin increases flower yield, but weakens the flower quality.

From a practical standpoint, the application of GA_3 and BA for broccoli production should be economic. Besides, to determine the initiation of curd formation is also an important trait for the commercial production of broccoli. Earlier production in the market is an important point for commercial production of broccoli to obtain more benefit. Literatures have been already indicated that plant growth regulators play a significant role for earlier initiation of curd and the production of good quality curd. However, there is still limited information for efficient utilization of PGRs on growth and other physiological parameters of commercial broccoli production in Myanmar.

Therefore, this study was undertaken to investigate the effects of gibberellic acid, benzyl adenine and their combination effect on plant growth, curd yield and crop earliness of broccoli.

2. LITERATURE REVIEW

2.1 Morphological Characters of Broccoli

Broccoli (*Brassica oleracea* var italica) is fast becoming an important fresh market and processing vegetable crop in many parts of the world (Morelock et al. 1982, Magnifico et al. 1979). The crop is grown for its edible curd which has become a popular item in the kitchen because of its good organoleptic properties and high nutritive value (Feher 1986). Compared with other *Brassica* vegetables it has been found to have the highest protein, dietary fiber and vitamin C content (Wills et al. 1984).

The curd is morphologically similar to that of cauliflower (*Brassica loeracea* var. botrytis) although certain characteristics such as branching and time of floral initiation are different (Wiebe 1975). Broccoli produces a green curd with long and slender floret-stalks bearing fertile flower buds while cauliflower produces a single compact white curd which forms fertile flower buds only after the normal harvest stage. The maturity of the broccoli curd is primarily determined by the developmental stage of its florets. It is harvested shortly before it loses its compactness or just before buds start to open (Marshall and Thompson 1987).

Magnifico et al. (1979) have described typical growth curves in broccoli. They found that the growth rate was very slow at the start, and then increased dramatically as the vegetative buds underwent transition to the reproductive state as the main stem elongated. It then declined as the main head developed and increased again as the main head is at the marketable maturity. They found that leaves constituted 52.4%, stems 20.8%, heads 19%, and roots 13% of the total dry matter.

In broccoli, curd initiation represents the first step towards the transition from the vegetative to the reproductive state of the plant. Flowering in plants is a unitary and integrated process but can generally be divided into the two major phases of flower initiation and development (Bernier 1988). The events occurring in the apex that commit it to flower formation were called floral evocation by Evans (1969). Bernier (1988) cited two views concerning the nature of evocation. One holds that the switch to flowering primarily requires a change in gene expression in the meristem, specifically the “turning on” of the genetic program concerned with the control of sexual reproduction (Zeevart et al. 1977). Flower evocation is essentially an unspecific activation necessary to eliminate the vegetative pattern of morphogenesis. The morphological age of the plant at curd initiation time as measured by the final number of leaves can vary among the varieties depending upon the period of maturity. Salter (1969) showed that plants with earlier times to curd initiation had progressively smaller final leaf numbers than those initiating curds later.

2.2 Effects of Temperature on Morphological Developments and Curd Initiation of Broccoli

Difference in morphological age in cauliflower differed not only with varieties but with sowing dates as well (Wurr and Kay 1981). This suggests that there is no specific morphological age at the time of curd initiation for particular varieties since the final number of leaves can be influenced by climatic variables during a particular growth season. Gauss and Taylor (1969) found that in sprouting broccoli (cv. Coastal) the average number of macroscopically visible leaves formed prior to curd initiation increased as the temperature was increased from 13 °C to 29 °C. Moreover, Wiebe (1975) observed that time of curd initiation in cauliflower, sprouting broccoli and tropical cauliflower are different and this was correlated positively with the final leaf number. He found that temperate cauliflower cultivars had more leaf number than tropical cauliflower and the broccoli cultivars. At higher temperature the leaf number in tropical cauliflower was found to approach that of the temperate cauliflower but in broccoli cultivars the leaf number was less influenced by temperature.

Some studies showed that under some conditions the concentration of carbohydrates found in the shoot tips of broccoli and cauliflower is correlated with floral induction (Sadik and Ozbun 1968, Fontes and Ozbun 1972, Sadik and Ozbun 1967). Fontes and Ozbun (1972) found that if plants are grown continuously at a warm temperature then a high concentration of carbohydrates was not correlated with flowering which suggests that the association between carbohydrate concentration and floral induction under certain conditions is only coincidental and carbohydrate accumulation is not directly responsible for floral induction.

Broccoli grows best under moderately cool conditions (60–70 °F), especially toward the harvesting stage. The compactness of the head (flower bud formation), which is the important characteristic in broccoli, develops best under cool temperatures, although the early development of the plants can occur during fairly warm weather.

The periods from sowing to curd initiation and from curd initiation to maturity are two important developmental stages in broccoli which are temperature dependent. The duration of these stages progressively becomes shorter with increasing temperature regime, but up to a maximum as demonstrated in the controlled climate experiment (Misael 1989).

Along with yield, curd quality is a very important attribute in broccoli as it determines the value of the crop in the market. Misael (1989) showed that at least one week exposure of the plants to high temperature during the curd developmental period can reduce the quality of the curds. Before initiation, exposure to high temperature had no effect. Early spring or late summer sowings may be advantageous.

Misael (1989) described that the different growth and development processes in broccoli require different base temperatures. The base temperature for total dry weight production and rate of curd growth appeared to be higher (3 °C) than for curd initiation and for the rate of leaf production (0 °C and -2 °C, respectively). The former are growth processes and the latter are developmental events and may thus proceed at different base temperatures.

2.3 Nutritional Value of Broccoli

Broccoli is an important vegetable crop and has high nutritional and good commercial value (Yoldas et al. 2008). It is low in sodium, fat free and calories, high in vitamin C and good source of vitamin A, vitamin B2 and calcium (Decoteau 2000). According to Brown and Hutchison (1949), it contains 137 mg vitamin C and 9000 IU vitamin A. Nowadays, broccoli attracted more attention due to its multifarious use and great nutritional value (Salunkhe and Kadam 1998, Talalay and Fahey 2001, Rangkadilok et al. 2002, 2004).

Broccoli is high in compounds called glucosinolates-chemicals that help with the metabolism and processing of other molecules in cells. As a result, women who consume large amounts of glucosinolates from broccoli may experience a change in estrogen levels and estrogen signaling in their bodies. To receive the nutritional benefits of broccoli without over consuming estrogen-affecting chemicals, the Linus

Pauling Institute recommends around five servings of broccoli or related vegetables such as cabbage or cauliflower per week (Talalay and Fahey 2001).

Broccoli also contains multiple nutrients with potent anti-cancer properties, such as diindolylmethane and small amounts of selenium. A single serving provides more than 30 mg of Vitamin C and a half-cup provides 52 mg of Vitamin C. The 3´-Diindolylmethane found in broccoli is a potent modulator of the innate immune response system with anti-viral, anti-bacterial and anti-cancer activity. Broccoli also contains the compound glucoraphanin, which can be processed into an anti-cancer compound sulforaphane, though the benefits of broccoli are greatly reduced if the vegetable is boiled. Broccoli is also an excellent source of indole-3-carbinol, a chemical which boosts DNA repair in cells and appears to block the growth of cancer cells.

Brassica vegetables have been identified as important components of a healthy diet because of their high levels of constituents that may have a beneficial health-promoting role (Van Poppel et al. 1999, Lampe and Peterson 2002, Finley 2003b, Jeffery and Araya 2009). These vegetables are also known to be beneficial in the prevention of other major illnesses such as Alzheimer's disease, cataracts and some of the functional declines associated with ageing (Verhoeven et al. 1997). The main health-providing properties identified in *Brassica* are dietary flavonoids, essential vitamins and minerals and glucosinolates (and their breakdown products) (Heber 2004a, b, Moreno et al. 2006).

Brassica vegetables are an excellent source of a variety of vitamins, minerals and dietary fibre. Vitamin and provitamin antioxidants such as ascorbic acid (vitamin C), tocopherols (vitamin E) and carotenoids are compounds present at high levels in the vegetable *Brassica* and are likely to contribute to the beneficial effects of these vegetables in the diet (Kurilich et al. 1999, Jeffery and Araya 2009). In addition, *Brassica* vegetables provide significant levels of vitamin A, B2 (riboflavin), B6 (pyridoxine), K and folic acid (McKillop et al. 2002). Folic acid is particularly important during pregnancy. Foliate supplementation prior to conception can reduce the incidence of neural tube defects significantly (Bailey and Gregory 1999). Foliate deficiencies have also been implicated in the aetiology of megaloblastic anaemia, spina bifida, neuropsychiatric disorders and various forms of cancer.

Important minerals supplied by *Brassica* vegetables include calcium, potassium, iron, zinc, magnesium and selenium (Farnham et al. 2000, De Pascale et al. 2005, Moreno et al. 2006, Broadley et al. 2008). The calcium content of certain *Brassica* vegetables, including broccoli, has good bioavailability, making it a good source of calcium for lactose-intolerant people (Heaney et al. 1993). Supplementation studies with high-selenium broccoli have demonstrated the efficacy of selenium for prevention of colon cancer (Finley et al. 2000). The metabolism of selenium depends on its chemical form, and that which occurs in broccoli appears to be particularly effective at protecting laboratory animals against cancer (Finley 2003a, 2003b).

2.4 Soil Type and Mineral Requirements of Broccoli

Broccoli grows best on well drained soils; however, it will tolerate a wide range of soil textures. Excellent broccoli crops have been produced on soils ranging from sand to silty clay. Broccoli has greater salt tolerance than lettuce, carrots or onions. Broccoli will grow well in any soil that has a fair degree of fertility, a high water-holding capacity, and good drainage with a pH range of 6–7.

Boron is essential for plant growth and development. Its application to the soil increased head yield of broccoli (Yang et al. 2000). Broccoli has a great demand to nitrogenous fertilizer. The early and rapid vegetative growth of the plant is necessary for soft and succulent head and stem for a quality crop that is influenced by the nitrogenous fertilizer. Haque et al. (1996) found the highest curd yield at 180 kg ha^{-1} (Urea). The application of molybdenum increased the yield of broccoli by reducing whiptail incidence from 30 to 40 percent in control to 0-8 percent in treated plot (Mitra et al. 1990).

2.5 Role of Gibberellic Acid (GA_3) in Vegetable Production

2.5.1 Function of gibberellic acid on plant growth and yield

Gibberellins (GAs) are a family of plant hormones that mediate many responses in plants, from seed germination to senescence. The most widely available compound is GA_3 or gibberellic acid, which induces stem and internodes elongation, seed germination, enzyme production during germination and fruit setting and growth

(Davies 1995). According to Jordi et al. (1995), GA_3 has been reported to delay the loss of chlorophyll. GA_3 stimulated transplant recovery of cabbage seedlings (McKee 1981) but had no effect on growth or establishment of tomato transplants (Arteca 1982). This increase in seedling growth parameters of with GA might be related to the fact that GA promote stem and shoot elongation through the increase of both cell division and from internodes elongation in higher plant (Hartmann et al. 2002, Hopkins and Hüner 2004, Harris et al. 2004).

Wareing and Phillips (1976) recorded enhanced vegetative growth in plants sprayed with GA_3. Once the gibberellins have reached the vascular tissue they can rapidly move up to the active region of the stem (Hilton 1983). Cauliflower plants treated with 30 mg. L^{-1} GA_3 displayed the highest plant height (70.13 cm) (Caser 2009). He also reported that treated with 40 and 30 mg.L^{-1} GA_3 rates displayed the highest number of leaves plant^{-1} (35 and 32, respectively) of cauliflower.

Ouzounidou et al. (2010) described that there was improvement in pepper growth and yield under GA_3 application. They indicated that crop yield improvement was due to more efficient utilization of food for reproductive growth (flowering and fruit set), higher photosynthetic efficiency and enhanced source to sink relationship of the plant, reduced respiration, enhanced translocation and accumulation of sugars and other metabolites. Tomato plants treated with gibberellic acid 50 ppm showed an increased plant height, number of leaves, number of fruits and fruit weight of tomato (Kumar et al. 2014).

2.5.2 Role of GA_3 on seed germination

Seedling establishment is a critical stage in the life history of any plant species that relies on sexual reproduction for the persistence of its populations (Grubb 1977, Harper 1979 and Bu et al. 2008).

Gibberellins (GAs) play an essential role in many aspects of plant growth and development, such as seed germination (Haba et al. 1985, Khafagi et al. 1986, Kumar and Neelakandan 1992 and Maske et al. 1997), stem elongation and flower development (Yamaguchi and Kamiya 2000). GAs plays a key role in dormancy release and in the promotion of germination. GA biosynthesis in developing seeds of many species leads to the accumulation and storage of either bioinactive GA precursors or bioactive GA (Groot and Karssen 1987, Toyomasu et al. 1998, Kamiya and Garcia-Martinez 1999 and Yamaguchi et al. 2001). GA biosynthesis in developing seeds appears not to be involved in the establishment of primary dormancy per seed (Karssen and Lac 1986, Koornneef and Karssen 1994 and Bewley 1997), but in other aspects of seed development, including fertilization, embryo growth, assimilate uptake, fruit growth and the prevention of seed abortion, in tomato, pea and several species of the Brassicaceae (Groot and Karssen 1987, Swain et al. 1997, Batge et al. 1999, Hays et al. 2002, Koornneef et al. 2002 and Singh et al. 2002). GA is required for embryo cell elongation, for overcoming coat restrictions to germination of non-dormant and dormant seeds, and for inducing endosperm weakening.

Non-photodormant tobacco seeds have lost the GA requirement for dark germination, which could be due to increased GA sensitivity and/or increased endogenous GA (Leubner-Metzger 2001, 2002, and 2005). GA treatment of dark-imbibed non-photodormant tobacco seeds increases the rate of germination in the dark, demonstrating that GA is also a positive regulator of germination speed.

2.6 Role of Cytokinin in Vegetable Production

2.6.1 Function of cytokinin on plant growth and development

Cytokinins (CK) are a class of plant growth substances (phytohormones) that promote cell division, or cytokinesis, in plant roots and shoots. They are involved primarily in cell growth and differentiation, but also affect apical dominance, axillary bud growth, and leaf senescence (Hwang and Sakakibara 2006). There are two types of cytokinins: adenine-type cytokinins represented by kinetin, zeatin, and 6-benzylaminopurine, and phenylurea-type cytokinins like diphenylurea and thidiazuron (TDZ). Most adenine-type cytokinins are synthesized in roots. Typically, cytokinins are transported in the xylem (Kieber 2002). Cytokinins are important plant hormones that regulate various processes of plant growth and development. Cytokinins play an important role in the regulation of cell division, differentiation and organogenesis in developing plants, enhancement of leaf expansion, nutrient mobilization and delayed senescence (Skoog and Armstrong 1970, Hall 1973). The root apex, and particularly the cells of its ‘quiescent centre’, was important sites of synthesis. It has been suggested that the slow rate of cell division in the root quiescent centre could be the result of a supra-optimal cytokinin concentration (Short and Torrey 1972, Torrey 1972). Some experimental evidence that the root tip is a primary site of cytokinin synthesis was obtained by Ochatt and Power (1988) in the roots which developed from the callus of *Prunus cerasus*.

2.6.2 Role of cytokinin on postharvest life of vegetables

Cytokinins is an inhibitor of respiratory kinase in plants, and increases post-harvest life of green vegetables. Influence of cytokinin as 6-benzylaminopurine (BAP) in combination with other methods on postharvest green color retention on broccoli heads and asparagus spears, showed positive results for quality retention. Ohkawa (1979) found that 6-benzyladenine (BA, a synthetic compound with cytokinin activity) treatment had a significant influence on increasing flower numbers of *Lilium speciosum*, particularly when combined with gibberellins A_4 and A_7 (GA_{4+7}). Cytokinin can promote the maturation of chloroplasts and delay the senescence of detached leaves. Cytokinin application to a single site in the plant (e.g. to one leaf) causes the treated organ to become an active sink for amino acids, which then migrate to the organ from surrounding sites.

3. MATERIALS AND METHODS

3.1 Experimental Sites

Two experiments were conducted from 2012-2014. The first experiment was conducted at two locations (Nwe Yit village, Tatkone Township, Nay Pyi Taw and Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University (YAU), Zayyarthiri Township) in winter season (October 2012 – January 2013) and the second experiment was carried out at the Department of Horticulture and Agricultural Biotechnology, YAU during the winter season (November 2013 – February 2014). Nwe Yit is situated on 20˚ 7' N and 96˚ 13' E, and Yezin on 19˚ 15' N and 96˚ 0' 7" E.

3.2 Materials Used in the Experiment

Broccoli (*Brassica oleracea* var. italica) variety Green Magic (F_1) was used in all experiments. Two types of plant growth regulator: (1) GA_3 and (2) BA were used in the experiment.

3.3 Experimental Design and Layout

3.3.1 Experiment I

The experiment was conducted in two locations: Nwe Yit village, Tatkone Township, Nay Pyi Taw and Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University, Yezin, Nay Pyi Taw from October 2012 to January 2013. Randomized Complete Block Design (RCBD) with four replications was used in both experiments. Six different concentrations of gibberellic acid 0, 10, 20, 30, 40 and 50 mg. L^{-1} were used. The plot size was 1.7 m x 3.3 m and the whole experimental area was 13.0 m x 15.7 m (0.01 ha). There were 21 plants for each plot and 504 plants for the whole experiment. The row and plant spacing was 0.6 m x 0.45 m.

Experiment I A – Department of Horticulture and Agricultural Biotechnology Yezin Agricultural University, Zayyarthiri Towndship, Nay Pyi Taw

Experiment I B – Nwe Yit village, Tatkone Township, Nay Pyi Taw

3.3.2 Experiment II

The experiment was conducted at the Department of Horticulture and Agricultural Biotechnology, YAU from November 2013 to February 2014. The experiment was laid out in a Randomized Complete Block (RCB) Design with three replications. The treatments for the experiment II were based on the results of experiment I. Thus, the second experiment was carried out by the combination of four levels of benzyl adenine (10, 20, 30, 40 mg. L^{-1}) and two level of gibberellic acid (30, 40 mg.L^{-1}). The plot size was 2.3 m x 3.32 m and total experimental area was about 19 m x 17 m (0.02 ha). The row and plant spacing was 0.6 m x 0.45 m**.** There were 28 plants $plot^{-1}$ and 672 plants for the whole experiment.

3.4 Experimental Procedure

3.4.1 Experiment I

3.4.1.1 Nursery bed preparation

A nursery bed with the length of 17 m, 1 m width, and 0.15 m height was prepared and cow dung manure at the rate of 10 tons ha^{-1} was incorporated into the soil and they were thoroughly mixed.

3.4.1.2 Raising of seedlings

The broccoli seeds were sown thinly in the nursery bed and covered with rice straw to conserve the soil moisture. When the seeds started to germinate, the rice straw was removed. Watering was done daily depending on moisture content of the soil.

3.4.1.3 Treatment application

When the seedlings were twenty eight days old, the plants were up-rooted. The healthy plant seedlings were selected and the roots were washed with water to remove adhered soil. After washing the roots, the seedlings were soaked in six specific concentrations of GA_3 for 24 hrs according to the treatments. The seedlings were transplanted after soaking (Figure 1).

3.4.1.4 Land preparation, manure and fertilizer application

The plots with the length of 3.3 m and width 1.7 m were well prepared and cow dung manure at the rate of 10 tons ha^{-1} was well-incorporated into the soil. Compound fertilizer (16:16:8) was applied three times: at 7 days after transplanting (DAT), 30 DAT and 45 DAT at the rate of 150 kg ha^{-1}. Urea, 224 kg ha^{-1} was applied at 15 DAT.

3.4.1.5 Transplanting and care and management

Twenty-eight-day old seedlings were transplanted in the field at the spacing of 0.6 cm x 0.45 cm after dipping their roots in different concentration of GA_3 for 24 hrs. The plants were watered daily up to 2 weeks after transplanting. After 2 weeks, the plot was furrow irrigated every 6 days. Weeding was done every two weeks. Pesticide (Doza) was sprayed two times (29 ml. L^{-1}) at two weeks after transplanting and five weeks after transplanting to prevent the incidence of pests and insects.

3.4.2 Experiment II

The nursery bed preparation, care and management for the seedlings were the same as experiment I. The difference to that, the 28 days old seedlings were treated with different combinations of benzyl adenine and gibberellic acid according to the treatments. The soaking duration was 24 hrs (one day). Then, the same procedures were followed as in experiment I.

Treatment procedures

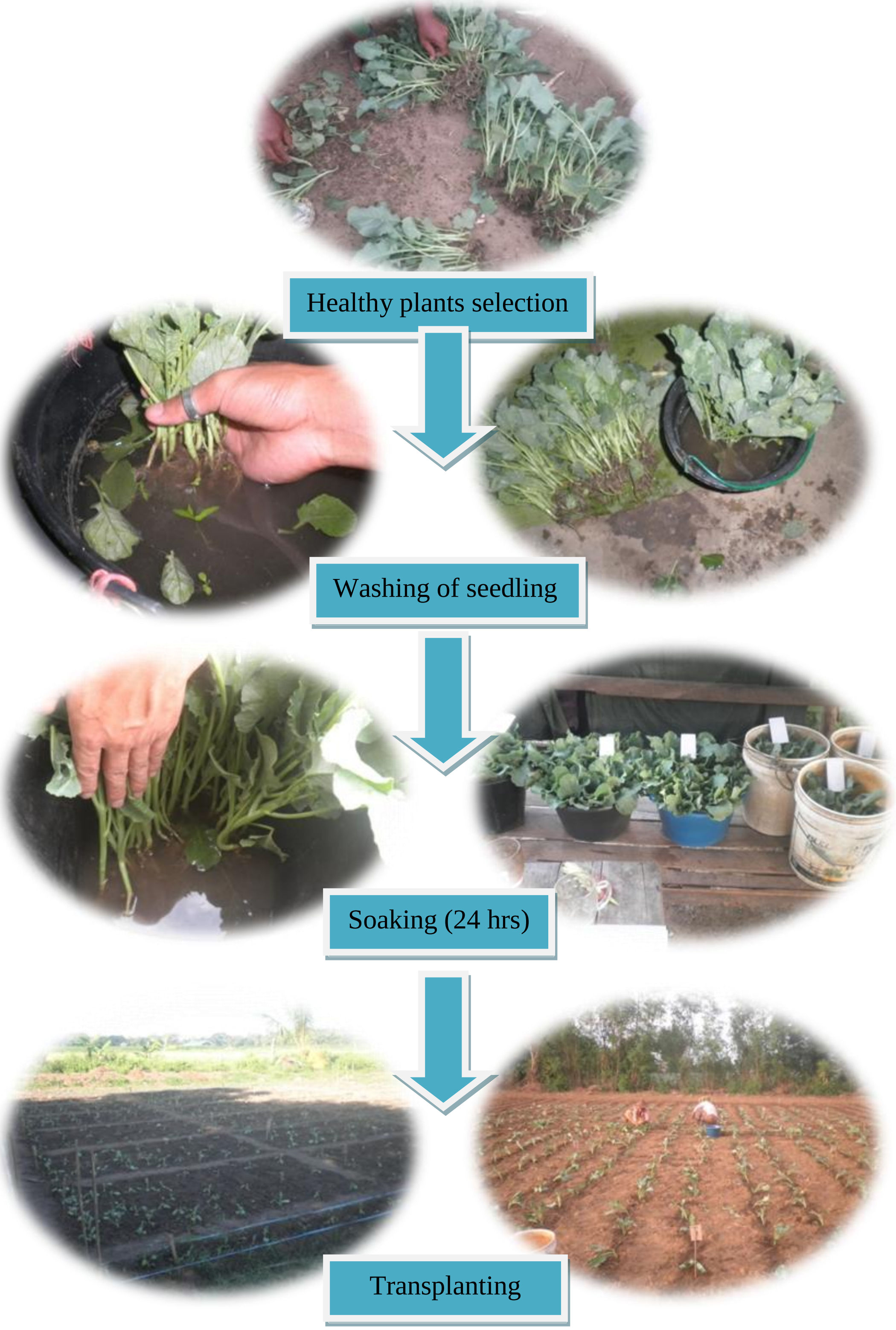

Figure 1. Procedures of the treatment application and transplanting

3.5 Data Collection

3.5.1 Growth parameters

Growth parameters were measured weekly up to 7 weeks after transplanting (WAT). Five plants per plot in experiment I, and ten plants per plot in experiment II for each treatment were randomly selected for data collection. The growth parameters included plant height, number of leaves, leaf length, leaf width, number of secondary curd and days to curd formation.

Plant height: It was measured in centimeter from the base of the stem (just above the ground level) to the tip of the plant.

Number of leaves: It was the total number of leaves collected by counting all leaves on a single plant.

Leaf length: It was the length of the biggest leaf in the plant. It was measured in centimeter (cm).

Leaf width: It was the widest portion of the leaf. It was measured in centimeter (cm).

Number of secondary curd: It was the total number of secondary curds in a single plant.

Days to curd formation: It was the number of days from the date of transplanting to initiation of curd formation.

3.5.2 Yield parameters

Yield parameters were collected at the time of curd harvest. Five curd samples were randomly selected in each plot to measure harvest data. Curd was harvested when the compaction of curd looks like loose before the curd color changes from green to yellow. Harvest data included curd diameter, curd weight, primary curd yield and secondary curd yield.

Curd diameter: It was the biggest portion of the curd and measured in centimeter (cm).

Curd weight: Curd with stem was cut to 15 cm long. It was weighed and expressed in gram.

Primary curd yield per hectare: It was calculated from the weight of primary curd.

Secondary curd yield per hectare: The secondary curds were harvested one week after harvesting of the primary curd and the yield was calculated from the weight of secondary curd.

Both yields were calculated and expressed in per hectare basis.

3.6 Statistical Analysis

The data were statistically analyzed by one way analysis of variance (ANOVA) using SAS 9.0. Means of those variables, that showed significantly different at ANOVA, were compared at 5 % level LSD, while mean comparisons were not conducted for those variables that were not significant at ANOVA. For Experiment I, combined analysis was used for the two locations (McIntosh, 1983) in order to know the location effect.

4. RESULTS AND DISCUSSION

4.1 Experiment I

4.1.1 Growth parameters

Growth parameters were referred to as plant height, leaf length, leaf width, number of leaves, days to central curd formation. The growth parameters were significantly affected by soaking the roots of seedlings in GA_3 solution before transplanting.

4.1.1.1 Plant height

Results indicated that GA_3 has a strong influence on plant height of broccoli. GA_3 responses to plant height were highly significant starting from 1 WAT. Similarly, location effect was also observed. However, location effect started from 2 WAT (Table 1). Comparing two locations, plant height of broccoli in NY was significantly higher than those of YAU from 2 to 7 WAT (10.62, 12.99, 16.03, 19.80, 23.26 and 27. 83 cm in NY, and 10.15, 12.47, 15.40, 18.88, 22.25 and 26.74 cm in YAU) (Table 2). This would be due to the effect of temperature since temperature in NY was lower (nearly 2^{o}C) than that of YAU (Appendix Table 1). Hatfield (2011) described that the rate of plant growth and development is dependent upon the temperature surrounding the plant. Location × GA_3 interaction effects on plant height were also observed at 2, 3, 4 and 7 WAT (Table 1). These data suggested that the impacts of GA_3 on plant height of broccoli could vary depending on the location.

Among the GA_3 concentrations, significant differences of plant height were observed. The response patterns of plant height of broccoli to different GA_3 were similar in both locations (Table 3). Plant height of broccoli steadily increased with duration (week by week) in all treatments and reached their maximum at 7 WAT in both locations. GA_3 treated plants were significantly taller than non treated plants (Control) in each evaluation period. At 7 WAT, 10, 20, 30 and 40 mg. L^{-1} GA_3 was significantly higher than 50 mg. L^{-1} GA_3 (Table 3). These results indicated that GA_3 promoted the plant height of broccoli significantly though there was a significant difference in plant height response depending on the concentration of GA_3. This would be due to the effect of GA_3 for the elongation of cell. Ouzounidou et al. (2010) described that GA_3 promoted the total stem length as well as the elongation of the first internode in cauliflower. Wareing and Philips (1976) recorded enhanced vegetative growth in plants of cauliflower sprayed with GA_3. Caser (2009) also found the highest plant height with 30 mg. L^{-1} GA_3 in cauliflower. Plant height of okra was predominantly increased by the application of GA_3.

4.1.1.2 Leaf length

Leaf length of broccoli varied depending on the concentration of the GA_3. The response patterns on leaf length of broccoli to different GA_3 were similar in the two locations. Location effect on leaf length of broccoli was observed from 3 WAT to 7 WAT (Table 4). Comparing two locations, broccoli leaves were significantly longer in NY (11.76, 15.87, 19.28, 24.26 and 29.32 cm, respectively) than those of YAU (11.35, 15.33, 18.65, 23.53 and 28.29 cm, respectively) from 3 to 7 WAT (Table 5). It may be due to the difference of temperature between the two locations since temperature can affect higher carbohydrate production for leaf length elongation.

No interaction effect (location × GA_3) on leaf length was also observed except 3 WAT (Table 4). It suggested that in most situations, leaf length responses to GA_3 do not vary between locations. In both locations, leaf length of non GA_3 treated plants was not different from those of GA_3 treated plants at an early stage of the growth, however, it became even longer than most of GA_3 treated plants at the later part of development (Table 6). It seemed that leaf length responses to GA_3 concentrations were not uniform in this experiment.

4.1.1.3 Leaf width

Leaf width of broccoli varied depending on the concentration of the GA_3. The response patterns of leaf width of broccoli to different GA_3 were similar in both locations. The effects of GA_3 on leaf width were highly significant among the GA_3 concentrations throughout the study period (Table 7, 9). The presence of location effect was also observed in this experiment starting from 3 WAT (Table 7). Between the two locations (NY and YAU), leaf width from NY was significantly higher than those of YAU from 5 to 7 WAT (16.18, 20.62 and 25.87 cm in NY, and 15.66, 19.92 and 24.92 cm in YAU, respectively) (Table 8). These data suggested that leaf width of broccoli in NY showed a better performance than that of YAU. However, there was no location × GA_3 interaction effect on leaf width of broccoli. Therefore, leaf width responses to GA_3 were not location specific and its effect was consistent (Table 7).

However leaf width was not significantly different between GA_3 treated and non treated plants (Control) in most situations. At 6 WAT, maximum leaf widths were observed in control and 10 mg. L^{-1} GA_3 treatments, and at 7 WAT, the broadest leaf width was found in 10 mg. L^{-1} GA_3 treatments (Table 9). It appeared that, like leaf length, GA_3 responses to leaf width were not uniform.

4.1.1.4 Number of leaves

Results indicated that GA_3 has a strong influence on the number of leaves of broccoli. Leaf number of broccoli varied depending on the concentration of the GA_3. The response patterns of leaf number of broccoli to different GA_3 were similar in both locations. Leaf numbers were highly significant starting from 2 WAT (Table 10). The presence of location effect was also observed in this experiment from 2 WAT to 7 WAT. So, broccoli grown in NY showed more broccoli leaves than those of YAU from 2 to 7 WAT (7.32, 11.34, 14.38, 18.09, 21.51 and 24.08 in NY, and 7.14, 10.72, 13.62, 17.48, 20.82 and 23.29 in YAU) (Table 11). However, the existence of location × GA_3 interaction effect on the number of leaves at 3 to7 WAT suggested that, leaf numbers could vary depending on GA_3 concentrations and location.

In both experiments, leaf number of broccoli increases constantly (week by week) in all treatments reaching their maximum at 7 WAT (Table 12). More leaf numbers were observed in GA_3 treated plants than in non treated plants (Control) throughout the study period (1 to 7 WAT). Among the concentrations, significant difference of leaf number was observed in both locations (Table 12). In YAU, the highest leaf number was observed in 30 mg. L^{-1} and it was significantly higher than 0, 10, 40 and 50 mg. L^{-1} at 7 WAT. In NY, the highest leaf number was observed in 20 mg. L^{-1} and it was significantly higher than 0, 30, 40 and 50 mg. L^{-1} at 7 WAT (Table 12). These results indicated that GA_3 influence the number of leaves formed however, depending on the concentration of GA_3, its effectiveness varied. It would be due to the positive effect of GA_3 on plant height because leaf numbers could vary with the plant height of broccoli. Roy and Nasiruddin (2011) also noted that significant differences in number of leaves plant^{-1} of cabbage at different days after transplanting due to the application of GA_3.

Table 1. Analysis of variance of plant height of broccoli grown at two locations (Yezin Agricultural University and Nwe Yit)

Source of Variation	df	Mean square of plant height						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
Location	1	1.98 ns	27.12**	31.52**	48.13**	101.75**	124.03**	143.01**
GA_3	5	26.01**	64.32**	54.68**	167.18**	145.80**	136.42**	326.81**
Location x GA_3	5	0.20ns	3.38*	3.51*	2.80*	0.74 ns	0.72 ns	9.55*
Total	47							
CV%		16.34	9.92	7.79	6.08	6.29	5.78	5.60
Pr> F (location)		0.2343	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Pr> F(GA_3)		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Pr> F (location x GA_3)		0.9820	0.0078	0.0035	0.0099	0.7754	0.8363	0.0012

ns Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 2. Comparison of plant height of broccoli affected by GA_3 at two locations (Yezin Agricultural University and Nwe Yit)

Location	Weeks after transplanting							Average
	1	2	3	4	5	6	7	
YAU	7.16	10.15b	12.47b	15.40b	18.88b	22.25b	26.74b	16.15
NY	7.29	10.62a	12.99a	16.03a	19.80a	23.26a	27.83a	16.83
T test	Ns	**	**	**	**	**	**	**
Average	7.22	10.38	12.73	15.72	19.34	22.75	27.29	

[ns] Non-significant at Pr < 0.05, [*] Significant at Pr < 0.05, [**] Significant at Pr < 0.01

Table 3. Comparison of plant height of broccoli at two different locations in response to different GA_3 concentrations

	GA_3 ($mg.L^{-1}$)	Plant height (cm)						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
YAU	0	6.55 bc	8.32 c	10.85 d	13.23 d	16.48 c	19.63 c	22.10 c
	10	7.44 ab	10.17 b	12.75 bc	15.28 bc	18.68 b	22.43 b	27.70 a
	20	7.28 abc	10.55 ab	12.73 bc	14.90 c	18.98 b	22.90 ab	27.75 a
	30	7.75 a	11.03 a	13.33 a	15.55 b	18.83 b	22.23 b	27.73 a
	40	6.41 c	10.68 ab	12.93 ab	17.03 a	20.50 a	23.58 a	28.45 a
	50	7.53 a	10.18 b	12.30 c	16.45 a	19.85 a	22.75 ab	26.75 b
YAU mean		7.16	10.15	12.48	15.40	18.88	22.25	26.75
$LSD_{0.05}$		0.93	0.55	0.56	0.60	0.87	0.91	0.92
NY	0	6.68 bc	8.86 b	11.38 c	13.48 d	17.58 d	20.95 c	24.43 b
	10	7.70 ab	11.05 a	13.80 a	16.23 b	19.65 c	23.15 b	28.70 a
	20	7.43 abc	10.90 a	13.05 b	15.50 c	20.00 bc	23.90 ab	28.78 a
	30	7.78 a	11.10 a	13.43 ab	15.68 c	19.40 c	23.25 b	28.73 a
	40	6.41 c	10.68 a	13.03 b	17.90 a	21.53 a	24.60 a	28.63 a
	50	7.74 a	11.18 a	13.28 ab	17.45 a	20.68 ab	23.75 ab	27.78 a
NY mean		7.29	10.63	12.99	16.04	19.80	23.27	27.84
$LSD_{0.05}$		1.02	0.51	0.55	0.52	0.90	0.93	1.70

Means in the same column within each location followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

Table 4. Comparison of leaf length of broccoli at two different locations in response to different GA_3 concentrations

Source of Variation	Df	Mean square of leaf length						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
Location	1	0.37 ^{ns}	4.09 ^{ns}	19.72**	34.88 **	47.08 **	63.80 **	125.87 **
GA_3	5	3.09 *	4.52 **	7.51**	24.14 **	7.89 **	238.00 **	93.47 **
Location x GA_3	5	0.21 ^{ns}	0.89 ^{ns}	5.69 **	3.32 ^{ns}	3.36 ^{ns}	3.03 ^{ns}	3.49 ^{ns}
Total	47							
CV%		15.31	10.80	7.55	7.65	5.92	7.12	6.11
Pr > F (location)		0.4896	0.0236	<.0001	<.0001	<.0001	<.0001	<.0001
Pr > F (GA_3)		0.0014	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Pr > F (location x GA_3)		0.9246	0.3459	<.0001	0.0419	0.0217	0.3895	0.3443

^{ns} Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 5. Comparison of leaf length of broccoli affected by GA_3 at two different locations (Yezin Agricultural University and Nwe Yit)

Location	Weeks after transplanting							Average
	1	2	3	4	5	6	7	
YAU	5.71	8.15	11.35b	15.33b	18.65b	23.53b	28.29b	15.86
NY	5.76	8.33	11.76a	15.87a	19.28a	24.26a	29.32a	16.37
T test	Ns	ns	**	**	**	**	**	**
Average	5.74	8.24	11.56	15.60	18.97	23.89	28.81	

^{ns} Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 6. Analysis of variance of leaf length of broccoli grown at two locations (Yezin Agricultural University and Nwe Yit)

	GA$_3$ (mg.L^{-1})	Leaf length (cm)						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
YAU	0	5.90	7.78 b	10.80 cd	14.27 d	18.35 bc	25.31 a	28.86 b
	10	5.61	8.11 ab	11.28 bc	15.81 ab	19.36 a	26.08 a	29.94 a
	20	5.67	8.67 a	11.84 a	15.22 bc	18.59 abc	22.64 b	27.69 cd
	30	5.43	8.08 a	11.93 a	15.84 ab	18.77 abc	22.64 b	28.14 bc
	40	5.67	8.24 ab	11.66 ab	16.17 a	18.86 ab	22.72 b	28.31 bc
	50	5.97	8.00 ab	10.62 d	14.69 cd	17.99 c	21.80 b	26.82 d
YAU mean		5.71	8.15	11.35	15.33	18.65	23.53	28.29
LSD$_{0.05}$		0.55	0.69	0.53	0.74	0.78	0.95	0.99
NY	0	5.96	8.31	11.90	15.24 b	19.52 ab	26.56 a	30.30 a
	10	5.88	8.31	11.51	16.09 a	19.64 a	26.43 a	31.03 a
	20	5.68	8.73	11.87	15.72 ab	19.21 ab	23.29 b	28.95 bc
	30	5.43	8.08	11.93	16.11 a	19.21 ab	23.43 b	29.13 b
	40	5.67	8.24	11.66	16.27 a	19.04 b	22.98 b	28.55 bc
	50	5.97	8.33	11.69	15.78 ab	19.06 b	22.86 b	27.95 c
NY mean		5.76	8.33	11.76	15.87	19.28	24.26	29.32
LSD$_{0.05}$		0.61	0.88	0.53	0.63	0.59	0.90	1.02

Means in the same column within each location followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

Table 7. Comparison of leaf width of broccoli at two different locations in response to different GA_3 concentrations

Source of Variation	df	Mean square of leaf width						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
Location	1	0.07 ns	0.16 ns	6.89 ns	17.52 ns	32.60 **	58.87 **	108.40 **
GA_3	5	2.05 **	8.16 **	13.86 **	8.21 **	6.02 *	281.73 **	85.35 **
Location x GA_3	5	0.03 ns	0.05 ns	3.37 ns	1.91 ns	2.14 ns	2.69 ns	0.62 ns
Total	47							
CV%		15.42	13.66	11.22	10.96	7.70	8.61	7.32
Pr> F (location)		0.6759	0.6080	0.0068	0.0021	<.0001	<.0001	<.0001
Pr> F (GA_3)		<.0001	<.0001	<.0001	0.0005	0.0014	<.0001	<.0001
Pr> F (location x GA_3)		0.9965	0.9949	0.0032	0.3888	0.2143	0.4915	0.9701

ns Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 8. Comparison of leaf width of broccoli affected by GA_3 at two different locations (Yezin Agricultural University and Nwe Yit)

Location	Week after transplanting							Average
	1	2	3	4	5	6	7	
YAU	4.02	5.64	8.48	12.13	15.66b	19.92b	24.92b	12.97
NY	4.04	5.68	8.72	12.51	16.18a	20.62a	25.87a	13.37
T test	ns	ns	ns	ns	**	**	**	**
Average	4.03	5.66	8.60	12.32	15.92	20.27	25.39	

[ns] Non-significant at Pr < 0.05, [*] Significant at Pr < 0.05, [**] Significant at Pr < 0.01

Table 9. Analysis of variance of leaf width of broccoli grown at two locations

	GA_3 ($mg.L^{-1}$)	Leaf width (cm)						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
	0	4.27 a	6.08 a	8.84	11.62 c	15.62	22.01 a	25.29 b
	10	4.02 ab	5.75 ab	8.20	12.34 ab	15.96	22.42 a	26.49 a
YAU	20	4.00 ab	5.88 ab	8.73	11.98 abc	15.48	18.81 b	24.63 bc
	30	3.77 b	5.29 b	8.64	12.49 a	16.03	19.10 b	25.43 b
	40	4.04 ab	5.38 b	8.20	12.63 a	15.47	18.74 b	24.06 c
	50	4.02 ab	5.50 ab	8.28	11.73 bc	15.40	18.42 b	23.60 c
YAU mean		4.02	5.64	8.48	12.13	15.66	19.92	24.92
$LSD_{0.05}$		0.43	0.60	0.72	0.68	0.71	0.78	1.04
	0	4.27 a	6.15 a	9.86 a	12.58	16.71 a	23.28 a	26.30 b
	10	4.10 ab	5.87 ab	8.59 b	12.76	16.53 ab	23.00 a	27.54 a
NY	20	4.00 ab	5.88 ab	8.73 b	12.18	16.01 bc	19.78 b	25.69 c
	30	3.77 b	5.29 b	8.64 b	12.64	16.15 abc	19.38 b	26.03 b
	40	4.11 ab	5.41 b	8.24 b	12.78	15.77 c	19.16 b	25.04 cd
	50	4.02 ab	5.50 b	8.28 b	12.15	15.92 bc	19.12	24.61 d
NY mean		4.04	5.68	8.72	12.51	16.18	20.62	25.87
$LSD_{0.05}$		0.46	0.64	0.74	0.70	0.61	0.80	0.80

Means in the same column within each location followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

Table 10. Comparison of number of leaves of broccoli at two different locations in response to different GA_3 concentrations

Source of variation		Mean square of number of leaf						
	df	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
Location	1	0.92 ^{ns}	3.85*	46.25**	68.25**	44.41**	58.10**	75.21**
GA_3	5	0.72 ^{ns}	1.58*	3.37**	47.18**	29.29**	19.93**	4.15**
Location x GA_3	5	0.32 ^{ns}	0.55 ^{ns}	5.16**	8.14**	11.57**	13.05**	5.75**
Total	47							
CV%		16.06	9.02	6.31	5.55	5.03	4.62	3.38
Pr> F (location)		0.2320	0.0028	<.0001	<.0001	<.0001	<.0001	<.0001
Pr> F (GA_3)		0.3459	0.0027	<.0001	<.0001	<.0001	<.0001	<.0001
Pr> F (location x GA_3)		0.7786	0.2680	<.0001	<.0001	<.0001	<.0001	<.0001

^{ns} Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 11. Comparison of leaf number of broccoli affected by GA_3 at two different locations (Yezin Agricultural University and Nwe Yit)

Location	Weeks after transplanting							Average
	1	2	3	4	5	6	7	
YAU	4.94	7.14b	10.72b	13.62b	17.48b	20.82b	23.29b	14.00
NY	5.03	7.32a	11.34a	14.38a	18.09a	21.51a	24.08a	14.54
T test	ns	*	**	**	**	**	**	**
Average	4.99	7.23	11.03	14.00	17.79	21.17	23.69	

[ns] Non-significant at Pr < 0.05, [*] Significant at Pr < 0.05, [**] Significant at Pr < 0.01

Table 12. Analysis of variance of number of leaves of broccoli grown at two locations (Yezin Agricultural University and Nwe Yit)

	GA_3 ($mg.L^{-1}$)	Number of leaves						
		1 WAT	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT	7 WAT
	0	5.05 a	6.93 b	10.65 b	13.20 c	17.10 cd	20.48 b	22.93 d
	10	4.73 b	7.20 ab	10.68 b	14.35 ab	17.80 ab	21.23 a	23.30 bc
YAU	20	4.83 ab	7.03 ab	10.78 ab	14.43 a	18.30 a	21.05 a	23.60 ab
	30	5.08 a	7.40 a	10.68 b	13.25 c	17.83 ab	20.80 ab	23.83 a
	40	5.08 a	7.13 ab	11.15 a	14.00 b	17.38 bc	20.85 ab	23.00 cd
	50	4.90 ab	7.15 ab	10.38 b	12.50 d	16.48 d	20.50 b	23.10 cd
YAU mean		4.94	7.14	10.72	13.62	17.48	20.82	23.29
$LSD_{0.05}$		0.30	0.41	0.42	0.40	0.65	0.51	0.30
	0	5.05	7.15 c	11.75 a	14.88 a	18.25 bc	21.58 b	24.00 c
	10	4.98	7.55 a	11.65 a	15.35 a	18.80 ab	22.18 a	24.33 ab
NY	20	5.08	7.40 ab	11.40 ab	15.23 a	18.98 a	22.10 a	24.55 a
	30	5.08	7.40 ab	10.68 c	13.28 c	16.93 d	19.85 c	23.53 d
	40	5.08	7.13 c	11.15 b	14.03 b	18.10 c	21.88 ab	24.00 c
	50	4.93	7.28 bc	11.40 ab	13.50 bc	17.48 d	21.50 b	24.10 bc
NY mean		5.03	7.32	11.34	14.38	18.09	21.51	24.08
$LSD_{0.05}$		0.25	0.22	0.41	0.73	0.58	0.42	0.32

Means in the same column within each location followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

4.1.2 Yield parameters

4.1.2.1 Curd weight

Results indicated that GA_3 has a strong influence on curd weight of broccoli. Curd weight of broccoli varied depending on the concentration of the GA_3.The curd weights of GA_3 treated plants were highly significant and they differed depending on the concentration of GA_3 applied.

The presence of location effect was also observed (Table 13). So, in average, curd weights of broccoli in NY were significantly higher than those of YAU (416.17 g in NY, and 409.42 g in YAU) (Table 14). However, no interaction effect (location × GA_3) on curd weight of broccoli was observed (Table 13). Therefore, curd weight responses to GA_3 were consistent (with concentration) in both locations.

In both locations, GA_3 treated plants were higher than non treated plants (Control). In YAU, maximum curd weights were observed in 30 and 40 mg. L^{-1}, however they were not significantly different from 50 mg.L^{-1} treatment. In NY, maximum curd weight was observed in 30 mg. L^{-1} GA_3, however it was not significantly different from that of 50 mg. L^{-1} GA_3. So, in the given treatments, the higher the concentration of GA_3 (30, 40 and 50 mg. L^{-1}), the heavier was the curd weight (Table 15). This could be due to the effect of gibberellic acid in activation of photosynthesis process and increase of absorption to water and nutrition, then lead to the increase of metabolism of this nutrition by plant and movement to the curds and increase its growth.

4.1.2.2 Curd diameter

Results indicated that curd diameter of broccoli was strongly impacted by GA_3. Curd diameter of broccoli varied significantly depending on the concentration of the GA_3 (Table 15). Location effect on curd diameter was also observed in this experiment suggesting that curd diameters of broccoli varied when they were grown either at NY or at YAU (Table 13). According to the results, curd diameter from NY was bigger than that of YAU (Table 14).

There was also no location x GA_3 interaction effect on curd diameter of broccoli (Table 13). Therefore, curd diameter responses to GA_3 did not change with location. Comparing GA_3 concentrations, GA_3 treated plants were higher than non treated plants (Control). Among the GA_3 concentrations, 40 mg. L^{-1} showed the maximum curd diameter, however it was not significantly different from 10, 20, 30 and 50 mg. L^{-1} in YAU. In NY, maximum curd diameter was observed in 30 mg. L^{-1} and it was not significantly different from 20, 40 and 50 mg. L^{-1}. Minimum curd diameter was observed in control in both locations (Table 15).

4.1.2.3 Days to curd formation

Results indicated that number of days required for curd formation of broccoli was influenced by GA_3. The presence of location effect was also observed in this experiment (Table 13). So, on average, days to curd formation of broccoli at NY were significantly lower than those at YAU (39.33 in NY, and 40.19 in YAU) (Table 14). There was no interaction between location and GA_3 on days to curd formation of broccoli. It suggests that the effects of GA_3 on days to curd formation can be consistent depending on the production site either NY or YAU (Table 13).

According to the findings, it was resulted that GA_3 treated plants produced curds earlier than non treated plants. Among the GA_3 concentrations, differences were also observed (Table 15). In both locations (YAU and NY), as the GA_3 concentration was increased from 10 to 50 mg. L^{-1}, the curd formation was earlier. The earliest curd formation was observed in 50 mg. L^{-1} and followed by 40, 30, 20 and 10 mg. L^{-1}. Therefore, if the concentration of GA_3 was increased up to 50 mg. L^{-1}, earlier curd can be produced. These data indicated that GA_3 induced earlier curd formation (Table 15). This could be due to the effects of GA_3 that induces curd initiation. Roy and Nasiruddin (2011) also showed that days to curd formation of cabbage were also shortened by the application of GA_3.

4.1.2.4 Curd Yield

Results indicated that GA_3 has a strong influence on curd yield of broccoli. Curd yield of broccoli varied depending on the concentration of the GA_3. The curd yields of GA_3 treated plants were highly significant and they differed depending on the concentration of GA_3 applied. The presence of location effect was also observed (Table 13). So, on average, curd yields of broccoli at NY were significantly higher than those at YAU (50.33 t ha^{-1} in NY, and 49.52 t ha^{-1} in YAU) (Table 14). There was no location and GA_3 interaction effect on curd yield of broccoli (Table 13).

Therefore, curd yield responses to GA_3 were consistent (with concentration) in both locations. In both locations, GA_3 treated plants were higher than non treated plants (Control). In YAU, maximum curd yield were observed in 30 mg. L^{-1}, however it was not significantly different from 40 and 50 mg.L^{-1} treatment. In Nwe Yit, maximum curd yield was observed in GA_3 concentrations 30 mg. L^{-1} and it was not significantly different from 40 and50 mg.L^{-1} GA_3 treatment. In the given treatments, the higher the concentration of GA_3 (30, 40 and 50 mg.L^{-1}), the higher is the curd yield (Table 15). These data suggested that GA_3 promoted the curd yield of broccoli. Wang and Yang (2008) reported that inflorescence differentiation and curd yield was increased by GA_3 application.

Table 13. Curd weight, curd diameter, days to curd formation and yield of broccoli in response to different GA_3 concentrations at two locations

Source of variation	df	Mean square of yield parameters: Curd weight (g)	Curd diameter (cm)	Days to curd formation (days)	Yield (t ha^{-1})
Location	1	2733.75 *	378.76**	45.93**	0.40*
GA_3	5	2964.42 **	18.43**	160.38**	0.43 **
Location x GA_3	5	297.75 ^{ns}	1.78 ^{ns}	0.15^{ns}	0.04 ^{ns}
Total	47				
CV%		4.32	10.35	4.03	4.32
Pr> F (location)		0.0038	<.0001	<.0001	0.0038
Pr> F (GA_3)		<.0001	<.0001	<.0001	<.0001
Pr> F (location x GA_3)		0.4588	0.4303	0.9975	0.4588

Table 14. Comparison of yield parameters of broccoli affected by GA_3 at two locations (Yezin Agricultural University and Nwe Yit)

Location	Yield parameters: Curd weight (g)	Curd diameter (cm)	Days to curd formation (days)	Yield (t ha^{-1})
YAU	409.42b	11.76b	40.19a	49.52b
NY	416.17a	14.27a	39.33b	50.33a
T test	*	**	**	*
Average	412.79	13.02	39.76	49.93

^{ns} Non-significant at Pr < 0.05, * Significant at Pr < 0.05, ** Significant at Pr < 0.01

Table 15. Analysis of variance of yield parameters of broccoli grown at two locations (Yezin Agricultural University and Nwe Yit)

	GA_3 (mg. L^{-1})	Curd Weight (g)	Curd Diameter (cm)	Days to curd Formation (days)	Yield (t ha^{-1})
	0	395.00 d	10.80 b	43.13 a	47.78 d
	10	399.00 cd	11.68 ab	41.45 b	48.26 cd
YAU	20	407.00 bc	11.50 ab	40.65 bc	49.23 bc
	30	420.50 a	12.03 a	39.53 cd	50.86 a
	40	419.00 a	12.35 a	38.63 de	50.68 a
	50	416.00 ab	12.20 a	37.75 e	50.32 ab
YAU mean		409.42	11.76	40.19	49.52
$LSD_{0.05}$		10.05	0.88	1.20	1.22
	0	411.50 bc	13.08 d	42.20 a	49.78 bc
	10	409.00 c	13.55 cd	40.45 b	49.47 c
NY	20	410.00 c	14.30 bc	39.65 bc	49.59 c
	30	424.50 a	14.80 ab	38.73 cd	51.35 a
	40	423.00 ab	14.75 ab	37.90 de	51.17 ab
	50	419.00 abc	15.20 a	37.08 e	50.68 abc
Nwe Yit mean		416.17	14.27	39.33	50.33
$LSD_{0.05}$		12.20	0.88	1.13	1.48

Means in the same column within each location followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

4.2 Experiment II

4.2.1 Growth parameters

4.2.1.1 Plant height

Results indicated that combination of GA_3 + BA does not show a strong impact on plant height of broccoli. The response patterns of plant height of broccoli to different combination of GA_3 + BA were similar. Significant differences between treatments were observed at 4 WAT and 7 WAT. At 4 WAT, the maximum plant height was observed in combination of GA_3 and BA 30+30 mg. L^{-1} and the lowest was observed in 40+20 mg.L^{-1}. Similar result was also observed at 7 WAT. These results indicated that the combination of GA_3 and BA ratio used in this experiment does not give a significant difference in plant height of broccoli among the combination ratio (Figure 2). The probable reason could be that these combinations of GA_3 and BA used in this experiment are equally effective. Both plant growth regulators play an important role in plant growth and development. For example gibberellic acid helps in cell elongation, tissue growth and development while benzyl adenine mainly promotes cell division and cell enlargement. Singh et al. (2011) reported that combination of 30+30 mg. L^{-1} gibberellic acid and benzyl adenine had maximum influence on plant height. Abbas (2011) also indicated that GA_3 stimulated the growth and expansion of cells through increasing the wall plasticity of cells.

4.2.1.2 Number of leaves

It was resulted that the application of GA_3 + BA combinations significantly affected the number of leaves of broccoli. Leaf number of broccoli varies depending on the concentration of the GA_3 + BA combination. Significant differences were observed in all weeks (2, 3, 4, 5 and 6 WAT) except 7 WAT. Among the treatments, maximum leaf number was observed in 30+30 mg. L^{-1} GA_3 and BA from 2 to 6 WAT. This might be due to the effects of gibberellic acid on cell division, leaf expansion, cell enlargement and thus the number of leaves (Figure 3).

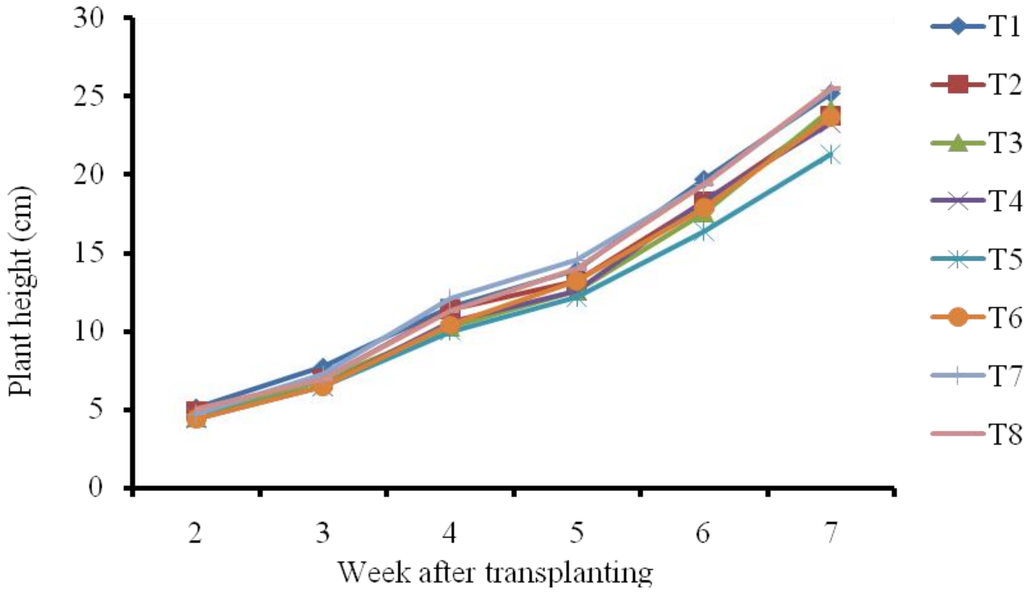

Figure 2. Plant height of broccoli in response to different concentrations of GA_3 and BA combination

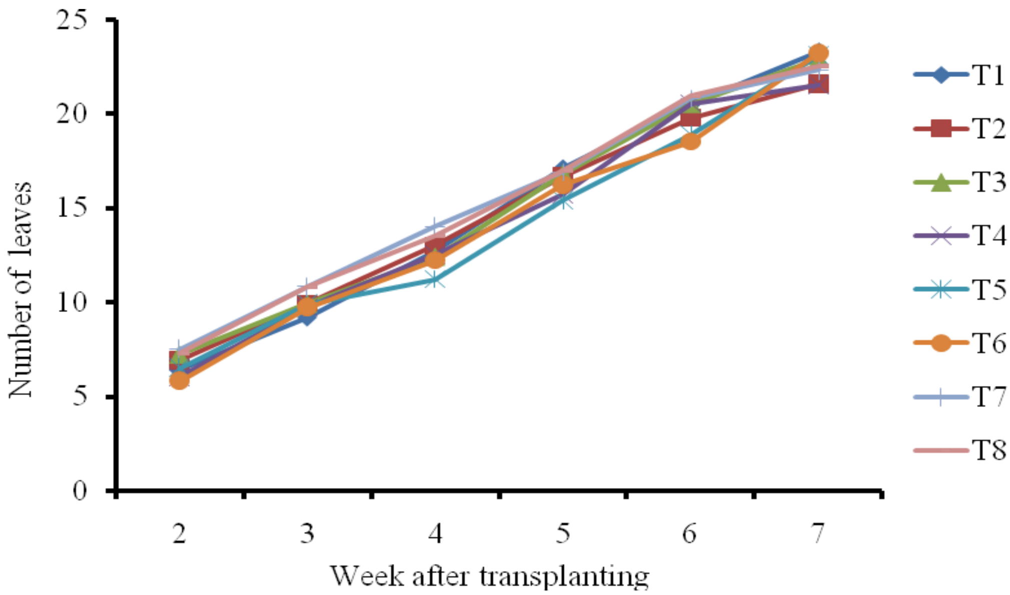

Figure 3. Number of leaves of broccoli in response to different concentrations of GA_3 and BA combination

T_1 = GA_3 30 $mg.L^{-1}$ + BA 10 $mg.L^{-1}$

T_2 = GA_3 30 $mg.L^{-1}$ + BA 20 $mg.L^{-1}$

T_3 = GA_3 30 $mg.L^{-1}$ + BA 30 $mg.L^{-1}$

T_4 = GA_3 30 $mg.L^{-1}$ + BA 40 $mg.L^{-1}$

T_5 = GA_3 40 $mg.L^{-1}$ + BA 10 $mg.L^{-1}$

T_6 = GA_3 40 $mg.L^{-1}$ + BA 20 $mg.L^{-1}$

T_7 = GA_3 40 $mg.L^{-1}$ + BA 30 $mg.L^{-1}$

T_8 = GA_3 40 $mg.L^{-1}$ + BA 40 $mg.L^{-1}$

4.2.1.3 Leaf length

The application of gibberellic acid and benzyl adenine combinations significantly affected leaf length of broccoli. Leaf length of broccoli varies depending on the concentration of the GA_3 + BA combination. The response patterns of leaf length of broccoli to different combination of GA_3 + BA were similar (Figure 4). Significant differences were observed in all weeks (2, 3, 4 and 5 WAT) except 6 WAT. Among the treatments, maximum leaf length was observed in combination of GA_3 and BA (30+30 $mg.L^{-1}$) at all weeks (2, 3, 4, 5 and 6 WAT) (Figure 4).

4.2.1.4 Leaf width

The application of gibberellic acid and benzyl adenine combinations significantly affected leaf width of broccoli. Leaf width of broccoli varies depending on the concentration of the GA_3 + BA combination. The response patterns of leaf width of broccoli to different combination of GA_3 + BA were similar (Figure 5). Significant differences were observed in all weeks (2, 3and 4 WAT). Among the treatments, maximum leaf width was observed in combination of GA_3 and BA (30+30 $mg.L^{-1}$) at all weeks (2, 3 and 4 WAT) (Figure 5).

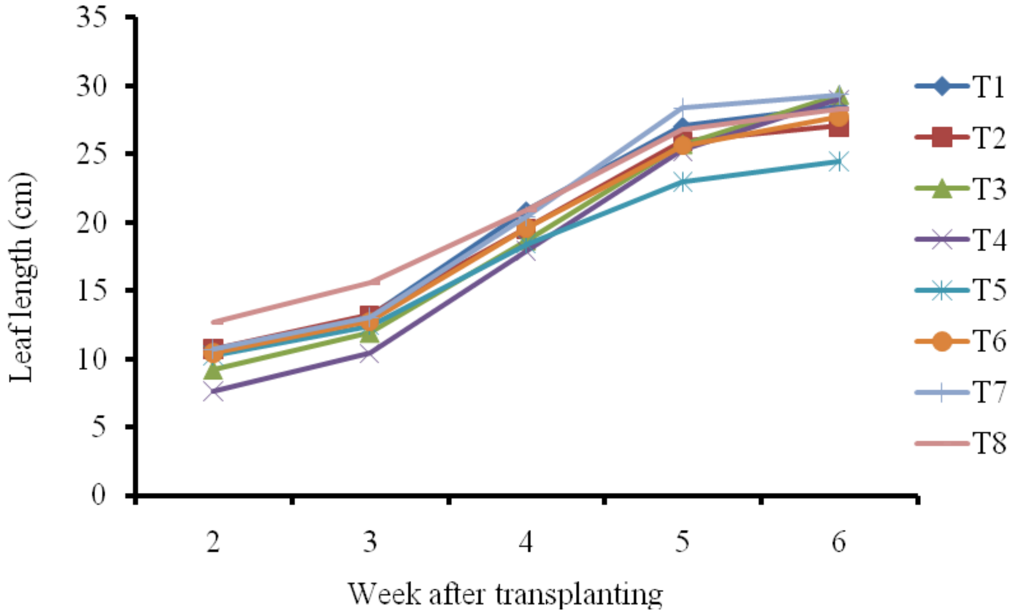

Figure 4. Leaf length of broccoli in response to different concentrations of GA_3 and BA combination

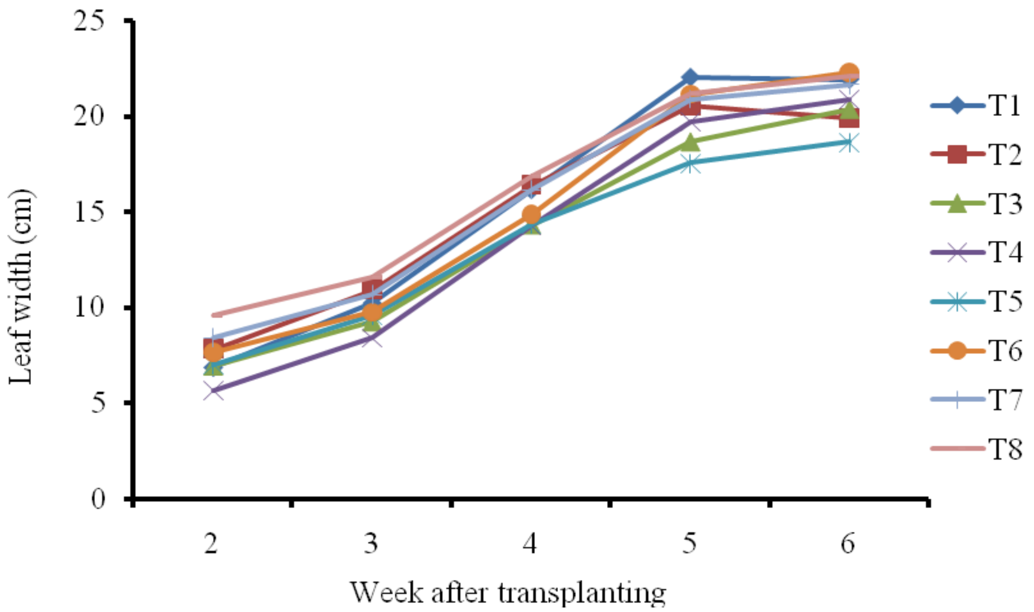

Figure 5. Leaf width of broccoli in response to different concentrations of GA_3 and BA combination

T_1 = GA_3 30 mg.L^{-1} + BA 10 mg.L^{-1}	T_5 = GA_3 40 mg.L^{-1} + BA 10 mg.L^{-1}
T_2 = GA_3 30 mg.L^{-1} + BA 20 mg.L^{-1}	T_6 = GA_3 40 mg.L^{-1} + BA 20 mg.L^{-1}
T_3 = GA_3 30 mg.L^{-1} + BA 30 mg.L^{-1}	T_7 = GA_3 40 mg.L^{-1} + BA 30 mg.L^{-1}
T_4 = GA_3 30 mg.L^{-1} + BA 40 mg.L^{-1}	T_8 = GA_3 40 mg.L^{-1} + BA 40 mg.L^{-1}

4.2.2 Yield parameters

4.2.2.1 Main curd and secondary curd weight

Results indicated that the combination of GA_3 and BA does not show a significant effect on main curd weight and secondary curd weight of broccoli though there are some differences in curd weight of broccoli. Among the treatments, the application of 40 + 10 mg. L^{-1} GA_3 and BA combination showed the highest main curd weight (443.67 g) and followed by 40 + 40 mg. L^{-1} (443.00 g), 30 + 10 mg. L^{-1} (430.86 g), 30 + 30 mg. L^{-1} (421.47 g) and 40 + 20 mg. L^{-1} (421.33 g) respectively. Among the combinations, 30 + 40 mg. L^{-1} GA_3 and BA gave the lowest main curd weight (368.00 g). Similar results were observed in secondary curd weight. The highest secondary curd weight was observed in 30 + 10 mg. L^{-1} (155.33 g) and the lowest was observed in 40 + 20 mg. L^{-1} (116.83 g) (Table 16).

4.2.2.2 Curd diameter

Curd diameter ranges from 15.30 cm to 16.24 cm but they were not significantly different. So, different concentrations of the GA_3 and BA combinations did not affect curd diameter of broccoli in this experiment (Table 16).

4.2.2.3 Days to curd formation

Results indicated that days to curd formation of broccoli vary significantly depending on the ratio of GA_3 + BA combination. Combination of 30 + 30 mg. L^{-1} GA_3 and BA showed the earliest curd formation with 46.07 days and it was 2 days earlier than 30 + 10 mg. L^{-1} and 40 + 20 mg. L^{-1}. Combination of 30 + 40 mg. L^{-1} GA_3 + BA took 50.40 days to produce the broccoli curd and it was the latest among the other treatments (Table 17).

4.2.2.4 Main curd yield and secondary curd yield

Results showed that main curd yield vary depending on different concentrations of GA_3 and BA combination. The main curd yield was maximum in 40 + 10 mg. L^{-1} GA_3 + BA combination (53.64 t ha^{-1}), followed by 40 + 40 mg. L^{-1} (53.56 t ha^{-1}), 30 + 10 mg. L^{-1} (52.09 t ha^{-1}), 30 + 30 mg. L^{-1} (50.96 t ha^{-1}), 40 + 20 mg. L^{-1} (50.94 t ha^{-1}), 49.87 t ha^{-1} in (30 + 20 mg. L^{-1}), and 47.67 t ha^{-1} in (40 + 30 mg. L^{-1}) respectively. The minimum curd yield (44.9 t ha^{-1}) was observed in 30 + 40 mg. L^{-1} (Table 17).

Secondary curd yield also vary depending on the concentration of GA_3 and BA. The highest secondary curd yield (18.78 t ha^{-1}) was observed in 30 + 10 mg. L^{-1} GA_3 and BA and the lowest (14.13 t ha^{-1}) was observed in 30 + 10 mg. L^{-1} (Table 17). Literatures indicated that the use of plant growth regulators like auxins, gibberellins and cytokinins enhanced plant growth and crop yield (Briant 1974, Srivastava and Sachan 1971). Singh et al. (2011) have been reported that maximum curd yield of broccoli can be obtained by using the combination of GA_3 and BA.

4.2.2.5 Number of secondary curd

Significant difference of secondary curd number was observed only at 4 WAT. Maximum number of secondary curd was observed in 30 + 30 mg. L^{-1} and the lowest was observed in 30 + 40 mg. L^{-1} (Table 18). However, no significant difference was observed at 5 and 6 WAT. These data revealed that the combination of GA_3 and BA promoted the secondary curd number per plant at an early growth stage though there was no profound impact at the later growth stage. This could be due to the impacts of both BA and GA_3, since BA plays an important role in cell division and GA_3 promotes vegetative growth by way of cell elongation and cell division.

Table 16. Main curd diameter, main curd weight and secondary curd weight of broccoli in response to different concentrations of GA_3 and BA combination

Treatment (GA_3 + BA)	Main curd diameter (cm)	Main curd weight (g)	Secondary curd weight (g)
30 + 10 $mg.L^{-1}$	16.03	430.86	155.33
30 + 20 $mg.L^{-1}$	15.88	412.50	127.17
30 + 30 $mg.L^{-1}$	16.24	421.47	128.83
30 + 40 $mg.L^{-1}$	15.72	368.00	126.83
40 + 10 $mg.L^{-1}$	15.30	443.67	143.50
40 + 20 $mg.L^{-1}$	15.55	421.33	116.83
40 + 30 $mg.L^{-1}$	15.80	394.33	137.17
40 + 40 $mg.L^{-1}$	15.60	443.00	130.83
CV%	12.90	21.15	35.43
Pr> F	0.83	0.52	0.35

Means in the same column followed by the same letters are not significantly different at 5% level.

Table 17. Days to curd formation, main curd and secondary curd yield of broccoli in response to different concentrations of GA_3 and BA combination

Treatment (GA_3 + BA)	Days to curd formation (days)	Main curd yield (t ha^{-1})	Secondary curd yield (t ha^{-1})
30 + 10 $mg.L^{-1}$	48.83 ab	52.09	18.78
30 + 20 $mg.L^{-1}$	47.87 bcd	49.87	15.37
30 + 30 $mg.L^{-1}$	46.07 d	50.96	15.58
30 + 40 $mg.L^{-1}$	50.40 a	44.49	15.33
40 + 10 $mg.L^{-1}$	47.23 bcd	53.64	17.35
40 + 20 $mg.L^{-1}$	48.77 abc	50.94	14.13
40 + 30 $mg.L^{-1}$	47.40 bcd	47.67	16.58
40 + 40 $mg.L^{-1}$	46.83 cd	53.56	15.82
LSD	2.59	-	-
CV%	8.16	21.15	35.43
Pr> F	0.04	0.52	0.23

Means in the same column followed by the same letters are not significantly different at 5% level.

Figure 6. Secondary curd of broccoli

Figure 7. Main curd of broccoli

Table 18. Number of secondary curd of broccoli in response to different concentrations of GA_3 and BA combination

Treatments (GA_3 + BA)	Number of secondary curd		
	4 WAT	5 WAT	6 WAT
30 + 10 $mg.L^{-1}$	4.93 abc	6.73	7.23
30 + 20 $mg.L^{-1}$	5.77 ab	7.67	8.23
30 + 30 $mg.L^{-1}$	6.53 a	7.37	7.33
30 + 40 $mg.L^{-1}$	3.73 c	6.27	7.27
40 + 10 $mg.L^{-1}$	4.83 abc	6.07	7.53
40 + 20 $mg.L^{-1}$	4.33 bc	6.53	7.43
40 + 30 $mg.L^{-1}$	4.37 bc	6.57	7.70
40 + 40 $mg.L^{-1}$	4.83 abc	6.13	7.40
$LSD_{0.05}$	1.75	-	-
CV%	21.10	12.80	14.50
Pr> F	0.003	0.379	0.404

Means in the same column followed by the same letters are not significantly different at 5% level.

WAT = Weeks After Transplanting

5. CONCLUSION

The present study clearly revealed that the effects of gibberellic acid or combination of gibberellic acid and benzyl adenine applications showed a positive trend in plant growth parameters and curd yield. GA_3 treated plants are higher and have more number of leaves than non-treated plants. In experiment I, 30, 40 and 50 $mg.L^{-1}$ GA_3 gave better curd weight, yield and produced earlier curd formation in both locations. Among them, 30 mg. L^{-1} GA_3 resulted in maximum curd weight, curd yield and curd diameter. The earliest curd formation was observed in 50 mg. L^{-1} GA_3. Location effect was also observed in broccoli production suggesting that the impacts of GA_3 could vary depending on the location. Comparing two locations, plants grown in Nwe Yit were higher and have more number of leaves than those of YAU. Curd weight and curd yield were higher in Nwe Yit (416 g and 50.33 t ha^{-1}, respectively) than in YAU (409.42 g and 49.5 t ha^{-1}, respectively) highlighting that Nwe Yit is more suitable for broccoli production than YAU.

In experiment II, the number of secondary curd, curd weight, curd diameter and curd yield were also affected by the application of gibberellic acid and benzyl adenine at different concentrations. The combination of 40 + 10 mg. L^{-1} GA_3 and BA gave the highest main curd yield (53. 64 t ha^{-1}) and 30 + 10 mg. L^{-1} GA_3 and BA gave the highest secondary curd yield (18.78 t ha^{-1}). Our findings highlighted that plant growth and yield performance of broccoli can be improved by using either gibberellic acid alone or combination of gibberellic and benzyl adenine. Moreover, the results of this study will also help in justification of using GA_3 and BA in broccoli production.

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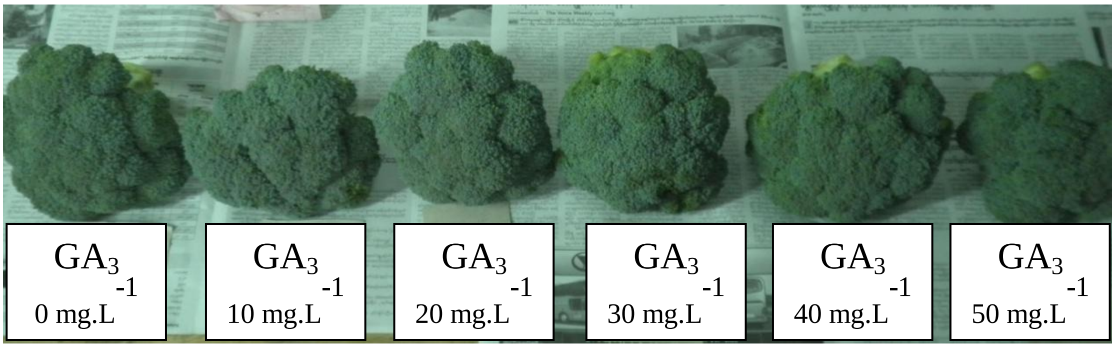

Plate 1. Effects of six different concentration of GA_3 on curd diameter

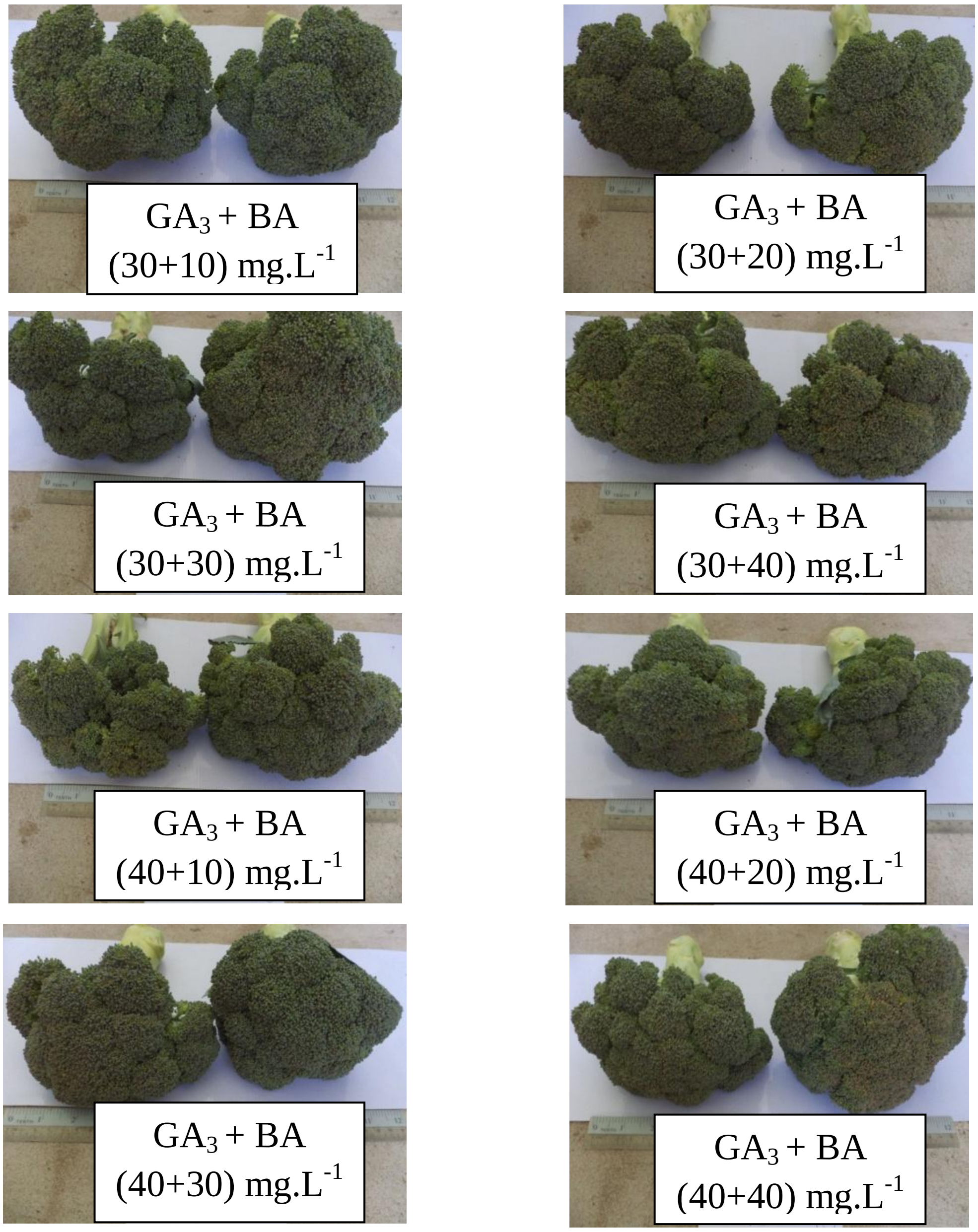

Plate 2. Effects of different concentrations of GA_3 and BA combination on curd diameter

Appendix 1. Daily minimum, maximum and average temperature at YAU and NY during October 2012 and January 2013

Date	YAU			NY		
	Min (˚C)	Max (˚C)	Average	Min (˚C)	Max (˚C)	Average
1-Oct-2012	20.00	37.50	28.75	18.50	35.50	27.00
2-Oct-2012	21.00	37.10	29.05	18.50	35.50	27.00
3-Oct-2012	19.50	37.20	28.35	18.50	35.40	26.95
4-Oct-2012	20.40	37.50	28.95	18.50	35.50	27.00
5-Oct-2012	21.30	37.40	29.35	18.40	35.40	26.90
6-Oct-2012	19.00	37.60	28.30	18.20	35.30	26.75
7-Oct-2012	19.20	37.00	28.10	18.30	35.50	26.90
8-Oct-2012	20.50	36.80	28.65	18.50	35.40	26.95
9-Oct-2012	21.50	36.70	29.10	18.20	35.20	26.70
10-Oct-2012	20.50	36.20	28.35	18.50	35.10	26.80
11-Oct-2012	21.50	36.10	28.80	18.20	35.00	26.60
12-Oct-2012	20.00	36.50	28.25	18.20	35.20	26.70
13-Oct-2012	21.00	36.40	28.70	18.20	35.10	26.65
14-Oct-2012	21.50	36.50	29.00	18.00	35.00	26.50
15-Oct-2012	20.40	36.70	28.55	18.00	35.60	26.80
16-Oct-2012	19.50	36.00	27.75	18.30	35.50	26.90
17-Oct-2012	19.00	36.00	27.50	17.80	35.00	26.40
18-Oct-2012	19.20	36.30	27.77	17.50	35.00	26.25
19-Oct-2012	20.20	36.40	28.30	17.50	34.70	26.10
20-Oct-2012	19.00	36.50	27.75	17.50	34.80	26.15
21-Oct-2012	19.60	35.50	27.55	17.60	34.80	26.20
22-Oct-2012	19.20	35.60	27.40	17.50	34.20	25.85
23-Oct-2012	19.40	35.00	27.20	17.80	34.10	25.95
24-Oct-2012	19.10	35.40	27.25	17.40	34.00	25.70
25-Oct-2012	19.00	35.50	27.25	17.50	34.00	25.75
26-Oct-2012	19.00	35.30	27.15	17.60	34.20	25.90
27-Oct-2012	18.70	35.40	27.05	17.50	34.30	25.90
28-Oct-2012	18.40	35.60	27.00	17.50	34.20	25.85
29-Oct-2012	18.00	35.00	26.50	17.50	34.00	25.75
30-Oct-2012	18.00	35.20	26.60	17.00	34.00	25.50
31-Oct-2012	18.00	35.00	26.50	17.00	34.00	25.50
October Average	19.69	36.22		17.90	34.85	

Appendix 1 (Cont'd)

Date	YAU			NY		
	Min (˚C)	Max (˚C)	Average	Min (˚C)	Max (˚C)	Average
1-Nov-2012	18.50	36.50	27.50	15.50	34.50	25.00
2-Nov-2012	18.50	36.50	27.50	15.50	34.70	25.10
3-Nov-2012	18.50	36.50	27.50	15.50	34.50	25.00
4-Nov-2012	18.20	36.50	27.35	15.40	34.60	25.00
5-Nov-2012	18.30	36.40	27.35	15.30	34.50	24.90
6-Nov-2012	18.50	36.20	27.35	15.20	34.50	24.85
7-Nov-2012	18.40	36.00	27.20	15.40	34.20	24.80
8-Nov-2012	18.00	36.40	27.20	15.50	34.30	24.90
9-Nov-2012	18.30	36.50	27.40	15.20	34.20	24.70
10-Nov-2012	18.20	36.80	27.50	15.30	34.20	24.75
11-Nov-2012	18.40	36.20	27.30	15.40	34.10	24.75
12-Nov-2012	18.20	36.20	27.20	15.20	34.00	24.60
13-Nov-2012	18.20	36.50	27.35	15.50	34.20	24.85
14-Nov-2012	18.00	36.50	27.25	15.50	34.50	25.00
15-Nov-2012	18.50	36.20	27.35	15.20	34.20	24.70
16-Nov-2012	18.60	36.10	27.35	15.40	34.10	24.75
17-Nov-2012	18.50	36.20	27.35	15.20	34.20	24.70
18-Nov-2012	18.20	36.00	27.10	15.20	34.00	24.60
19-Nov-2012	18.40	36.70	27.55	15.00	34.00	24.50
20-Nov-2012	18.30	36.50	27.40	15.00	34.30	24.65
21-Nov-2012	18.20	36.40	27.30	14.80	33.70	24.25
22-Nov-2012	18.20	35.20	26.70	14.70	33.50	24.10
23-Nov-2012	18.20	35.50	26.85	14.50	33.40	23.95
24-Nov-2012	18.00	35.20	26.60	14.50	33.50	24.00
25-Nov-2012	18.20	35.20	26.70	14.50	33.50	24.00
26-Nov-2012	18.00	35.60	26.80	14.60	33.40	24.00
27-Nov-2012	17.20	35.80	26.50	14.20	33.20	23.70
28-Nov-2012	17.20	35.20	26.20	14.30	33.00	23.65
29-Nov-2012	17.00	35.00	26.00	14.50	33.00	23.75
30-Nov-2012	17.10	35.20	26.15	14.30	33.00	23.65
November Average	18.13	36.05		15.04	33.96	

Appendix 1 (Cont'd)

Date	YAU			NY		
	Min (˚C)	Max (˚C)	Average	Min (˚C)	Max (˚C)	Average
1-Dec-2012	12.50	38.50	25.50	11.50	33.50	22.50
2-Dec-2012	12.50	38.70	25.60	11.50	33.40	22.45
3-Dec-2012	12.50	38.60	25.55	11.50	33.00	22.25
4-Dec-2012	12.30	38.40	25.35	11.50	32.70	22.10
5-Dec-2012	12.50	38.00	25.25	11.40	32.50	21.95
6-Dec-2012	12.00	38.20	25.10	11.20	32.20	21.70
7-Dec-2012	12.50	38.10	25.30	11.30	32.50	21.90
8-Dec-2012	12.40	38.90	25.65	11.40	32.10	21.75
9-Dec-2012	12.50	38.20	25.35	11.50	32.50	22.00
10-Dec-2012	12.60	38.40	25.50	11.00	32.00	21.50
11-Dec-2012	12.30	38.20	25.25	11.80	32.00	21.90
12-Dec-2012	12.00	38.50	25.25	11.50	32.00	21.75
13-Dec-2012	12.50	38.10	25.30	11.70	31.50	21.60
14-Dec-2012	12.00	38.00	25.00	11.20	31.20	21.20
15-Dec-2012	12.50	38.40	25.45	11.40	31.50	21.45
16-Dec-2012	12.00	38.20	25.10	11.60	31.50	21.55
17-Dec-2012	12.00	38.50	25.25	11.50	31.60	21.55
18-Dec-2012	12.00	38.20	25.10	10.70	31.50	21.10
19-Dec-2012	12.30	38.00	25.15	10.50	31.00	20.75
20-Dec-2012	12.30	38.50	25.40	10.30	31.40	20.85
21-Dec-2012	12.50	37.50	25.00	10.40	31.50	20.95
22-Dec-2012	12.40	37.50	24.95	10.50	31.50	21.00
23-Dec-2012	12.50	37.60	25.05	10.50	31.30	20.90
24-Dec-2012	12.50	37.60	25.05	10.50	31.50	21.00
25-Dec-2012	12.00	37.50	24.75	10.50	31.30	20.90
26-Dec-2012	12.40	37.50	24.95	10.30	31.20	20.75
27-Dec-2012	11.50	37.50	24.50	10.00	31.00	20.50
28-Dec-2012	11.50	37.20	24.35	10.40	31.00	20.70
29-Dec-2012	11.60	37.10	24.35	10.20	31.20	20.70
30-Dec-2012	11.50	37.20	24.35	10.20	31.00	20.60
31-Dec-2012	11.50	37.00	24.25	10.00	31.00	20.50
December Average	12.19	37.99		10.95	31.77	

Appendix 1 (Cont'd)

Date	YAU			NY		
	Min (˚C)	Max (˚C)	Average	Min (˚C)	Max (˚C)	Average
1-Jan-2013	13.50	39.50	26.50	13.50	34.50	24.00
2-Jan-2013	13.50	39.00	26.25	13.40	34.20	23.80
3-Jan-2013	13.50	39.50	26.50	13.40	34.30	23.85
4-Jan-2013	13.50	39.00	26.25	13.50	34.20	23.85
5-Jan-2013	13.50	38.80	26.15	13.50	34.00	23.75
6-Jan-2013	13.40	38.50	25.95	13.20	34.30	23.75
7-Jan-2013	13.60	38.60	26.10	13.00	33.50	23.25
8-Jan-2013	13.50	38.50	26.00	13.00	33.50	23.25
9-Jan-2013	13.20	38.30	25.75	13.00	33.40	23.20
10-Jan-2013	13.40	38.20	25.80	12.70	33.50	23.10
11-Jan-2013	13.20	38.40	25.80	12.50	33.30	22.90
12-Jan-2013	13.50	38.20	25.85	12.50	33.40	22.95
13-Jan-2013	13.20	38.00	25.60	12.50	33.20	22.85
14-Jan-2013	13.20	38.50	25.85	12.40	33.20	22.80
15-Jan-2013	13.40	38.60	26.00	12.40	33.40	22.90
16-Jan-2013	13.20	38.20	25.70	12.50	33.00	22.75
17-Jan-2013	13.00	38.50	25.75	12.40	33.20	22.80
18-Jan-2013	13.00	38.40	25.70	12.30	33.00	22.65
19-Jan-2013	13.00	38.50	25.75	12.20	33.50	22.85
20-Jan-2013	12.80	38.00	25.40	12.30	32.50	22.40
21-Jan-2013	12.90	38.00	25.45	12.00	32.50	22.25
22-Jan-2013	12.80	38.50	25.65	12.00	32.50	22.25
23-Jan-2013	12.80	38.50	25.65	12.10	32.30	22.20
24-Jan-2013	12.50	38.00	25.25	12.00	32.50	22.25
25-Jan-2013	12.50	38.00	25.25	12.30	32.40	22.35
26-Jan-2013	12.60	37.50	25.05	12.00	32.30	22.15
27-Jan-2013	12.50	37.60	25.05	12.00	32.00	22.00
28-Jan-2013	12.50	37.20	24.85	12.30	32.00	22.15
29-Jan-2013	12.80	37.50	25.15	12.00	32.10	22.05
30-Jan-2013	12.40	37.00	24.70	12.10	32.20	22.15
31-Jan-2013	12.80	37.00	24.90	12.00	32.00	22.00
January Average	13.07	38.25		12.54	33.09	

Appendix 2. Daily minimum, maximum and average temperature at YAU during November 2013 and February 2014

Date	November, 2013 (YAU)			Date	December, 2013 (YAU)		
	Min (˚C)	Max (˚C)	Average		Min (˚C)	Max (˚C)	Average
1-Nov-2013	21.50	33.50	27.50	1-Dec-2013	13.50	38.50	26.00
2-Nov-2013	21.50	33.50	27.50	2-Dec-2013	13.50	38.50	26.00
3-Nov-2013	21.50	33.40	27.45	3-Dec-2013	13.40	38.50	25.95
4-Nov-2013	21.30	33.20	27.25	4-Dec-2013	13.20	38.40	25.80
5-Nov-2013	21.50	33.30	27.40	5-Dec-2013	13.10	38.30	25.70
6-Nov-2013	21.30	33.20	27.25	6-Dec-2013	13.10	38.20	25.65
7-Nov-2013	21.20	33.20	27.20	7-Dec-2013	13.00	38.00	25.50
8-Nov-2013	21.00	33.10	27.05	8-Dec-2013	13.00	38.00	25.50
9-Nov-2013	21.00	33.00	27.00	9-Dec-2013	12.50	38.00	25.25
10-Nov-2013	21.00	33.00	27.00	10-Dec-2013	12.50	37.80	25.15
11-Nov-2013	20.70	33.00	26.85	11-Dec-2013	12.50	37.80	25.15
12-Nov-2013	20.50	32.50	26.50	12-Dec-2013	12.40	37.70	25.05
13-Nov-2013	20.50	32.50	26.50	13-Dec-2013	12.30	37.50	24.90
14-Nov-2013	20.50	32.50	26.50	14-Dec-2013	12.00	37.50	24.75
15-Nov-2013	20.30	32.30	26.30	15-Dec-2013	12.00	37.50	24.75
16-Nov-2013	20.20	32.40	26.30	16-Dec-2013	12.00	37.40	24.70
17-Nov-2013	20.30	32.30	26.30	17-Dec-2013	12.00	37.30	24.65
18-Nov-2013	20.20	32.20	26.20	18-Dec-2013	11.80	37.20	24.50
19-Nov-2013	20.10	32.00	26.05	19-Dec-2013	11.70	37.30	24.50
20-Nov-2013	20.10	32.00	26.05	20-Dec-2013	11.80	37.00	24.40
21-Nov-2013	20.00	32.00	26.00	21-Dec-2013	11.50	37.00	24.25
22-Nov-2013	19.70	31.70	25.70	22-Dec-2013	11.50	37.00	24.25
23-Nov-2013	19.20	31.50	25.35	23-Dec-2013	11.50	36.70	24.10
24-Nov-2013	19.50	31.50	25.50	24-Dec-2013	11.30	36.50	23.90
25-Nov-2013	19.20	31.40	25.30	25-Dec-2013	11.20	36.70	23.95
26-Nov-2013	19.30	31.40	25.35	26-Dec-2013	11.20	36.50	23.85
27-Nov-2013	19.20	31.50	25.35	27-Dec-2013	11.20	36.20	23.70
28-Nov-2013	19.50	31.20	25.35	28-Dec-2013	11.00	36.10	23.55
29-Nov-2013	19.20	31.30	25.25	29-Dec-2013	11.00	36.20	23.60
30-Nov-2013	19.00	31.00	25.00	30-Dec-2013	11.00	36.00	23.50
				31-Dec-2013	11.00	36.00	23.50
November Average	20.33	32.35		**December Average**	12.08	37.33	

Appendix 2. (Cont'd)

Date	January, 2014		
	Min (˚C)	Max (˚C)	Average
1-Jan-2014	15.50	39.80	27.65
2-Jan-2014	15.50	39.80	27.65
3-Jan-2014	15.50	39.50	27.50
4-Jan-2014	15.20	39.50	27.35
5-Jan-2014	15.10	39.50	27.30
6-Jan-2014	15.00	39.20	27.10
7-Jan-2014	15.00	39.10	27.05
8-Jan-2014	15.00	39.10	27.05
9-Jan-2014	14.50	39.00	26.75
10-Jan-2014	14.50	39.00	26.75
11-Jan-2014	14.50	38.80	26.65
12-Jan-2014	14.20	38.70	26.45
13-Jan-2014	14.30	38.60	26.45
14-Jan-2014	14.50	38.60	26.55
15-Jan-2014	14.20	38.70	26.45
16-Jan-2014	14.20	37.50	25.85
17-Jan-2014	14.10	38.50	26.30
18-Jan-2014	14.10	38.50	26.30
19-Jan-2014	14.00	38.50	26.25
20-Jan-2014	14.00	38.50	26.25
21-Jan-2014	14.00	38.20	26.10
22-Jan-2014	13.80	38.30	26.05
23-Jan-2014	13.80	38.10	25.95
24-Jan-2014	13.80	38.00	25.90
25-Jan-2014	13.70	38.00	25.85
26-Jan-2014	13.50	38.00	25.75
27-Jan-2014	13.50	37.50	25.50
28-Jan-2014	13.50	37.80	25.65
29-Jan-2014	13.50	37.50	25.50
30-Jan-2014	13.50	37.50	25.50
31-Jan-2014	13.50	37.50	25.50
January Average	14.29	38.54	

Date	February, 2014		
	Min (˚C)	Max (˚C)	Average
1-Feb-2014	16.50	39.50	28.00
2-Feb-2014	16.50	39.50	28.00
3-Feb-2014	16.20	39.50	27.85
4-Feb-2014	16.20	39.40	27.80
5-Feb-2014	16.40	39.40	27.90
6-Feb-2014	16.20	39.40	27.80
7-Feb-2014	16.00	39.10	27.55
8-Feb-2014	16.00	39.10	27.55
9-Feb-2014	16.10	39.10	27.60
10-Feb-2014	16.20	39.00	27.60
11-Feb-2014	16.00	39.10	27.55
12-Feb-2014	16.00	39.00	27.50
13-Feb-2014	15.80	39.00	27.40
14-Feb-2014	15.80	38.50	27.15
15-Feb-2014	15.80	38.50	27.15
16-Feb-2014	15.80	38.70	27.25
17-Feb-2014	15.60	38.60	27.10
18-Feb-2014	15.60	38.30	26.95
19-Feb-2014	15.50	38.50	27.00
20-Feb-2014	15.50	38.30	26.90
21-Feb-2014	15.50	38.20	26.85
22-Feb-2014	15.20	38.20	26.70
23-Feb-2014	15.40	38.00	26.70
24-Feb-2014	15.30	38.00	26.65
25-Feb-2014	15.50	38.00	26.75
26-Feb-2014	15.20	37.80	26.50
27-Feb-2014	15.30	37.80	26.55
28-Feb-2014	15.20	37.50	26.35
February Average	15.79	38.67	